"COMPOSITION, ABUNDANCE AND DISTRIBUTION PATTERNS OF ZOOPLANKTON IN A TROPICAL RESERVOIR, NAIROBI DAM, KENYA."

BY

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DECLARATION

I, Mary Lusweti, hereby declare that this is my own original work and has not been presented for a degree in any other university.

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This thesis has been submitted for the award of the degree of Master of Science of the University of Nairobi with my approval as the University supervisor.

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DEDICATION

This work is dedicated to my children Willy & Billy for their patience during the period of my research and write-up.

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ABSTRACT

The seasonal composition and abundance of zooplankton in Nairobi Reservoir, a small suburban water body, were investigated from October 1989 to September 1990 to establish taxonomic composition, abundance and seasonality of zooplankton in this Reservoir.

zooplankton were sampled from vertical hauls from different depths at three stations, a limnetic station (Station 1), a littoral station (Station 2), and an inlet station (Station 3), and concentrations of dissolved oxygen and chlorophyll *a*, water temperature, total alkalinity, conductivity, Secchi depth, and rainfall were simultaneously measured.

The findings show that there were trends in seasonal abundance of particular species with the composition varying both quantitatively and qualitatively. There was evidence of species succession among the three groups: Rotifera, Cladocera, and Copepoda with the abundance or dominance of different species at different times of the year. The seasonal variation in densities and species succession is discussed in relation to seasonal fluctuations of basic limnological parameters.

Rotifera had a high species diversity comprising of twelve genera including six species of *Brachionus*: *Brachionus angularis* Gosse, *Brachionus dimidiatus* Bryce, *Brachionus calyciflorus* Pallas, *Brachionus caudatus* Barrois & Daday, *Brachionus falcatus* Zacharias, and

Brachionus quadridentatus Hermann. The microcrustacean taxa included two cyclopoid copepods; *Thermocyclops oblongatus* Sars and *Mesocyclops equitorialis* Keifer plus four cladoceran species represented by *Ceriodaphnia rigaudi* Richard, *Daphnia pulex* Sars, *Diaphanosoma excisum* Sars, and *Moina micrura* Kurz.

Although the zooplankton community was relatively uniform in composition among stations, there were notable variations in abundance through both space and time. The average number of total zooplankton was higher during the cool and dry months of June to August (2594 individuals per litre) and relatively lower during the wet months of March to April (662 individuals per litre). The abundance of zooplankton for the entire water column at each station over time gave an annual average of 884 individuals per litre, 1601 individuals per litre, and 1397 individuals per litre for stations 1, 2, and 3 respectively. Although the horizontal spatial variation was not very pronounced for most environmental factors, vertical spatial variation for environmental factors such as dissolved oxygen, chlorophyll *a*, and temperature were evident.

Overall, the number of zooplankton species recorded from Nairobi Reservoir were, eighteen species of Rotifera, two species of Copepoda, four species of Cladocera plus the larvae of *Chaoborus* sp.

CHAPTER 1

INTRODUCTION

1.1 General introduction

Knowledge of zooplankton composition, abundance, distribution and seasonal succession in tropical African lakes is meagre. The only detailed studies come from Lake George, Uganda, (Burgis 1974); Lake Turkana, Kenya (Ferguson 1982): Lake Chad, Chad, (Robinson & Robinson 1971, Carmouze, et al. 1983); and Lake Naivasha, Kenya (Mavuti 1983, 1990). Much of the work carried out on the African lakes has been concerned with the ecology of zooplankton in old, natural lakes. Beadle (1974, 1981) provides an introduction to the limnology and biogeography of African inland waters. This work summarised the status of African limnology and has laid a foundation for many of the limnological studies subsequently carried out.

Data on African artificial lakes is given by Obeng (1966), Balon and Coche (1974), and Beadle (1974). An observation of these authors works indicates that apart from Lake Kariba where a comprehensive study on the limnology and ichthyobiology have been undertaken and reported, work on the other African lakes were short term and not detailed enough as a base for future reference. Since these studies were carried out soon after the dams were filled changes are likely to have occurred over the years.

For the most part, freshwater zooplankton are dominated by three phyla, namely the Protozoa, Rotifera, and Crustacea. Examples of planktonic organisms from other groups include medusae of coelenterata, flatworms, and larval insects such as <u>Chaoborus</u> sp. Many larval insects and cercaria of trematodes are usually found as meroplankters. The very restricted number of meroplanktonic larvae of soft-bodied invertebrates in fresh water contrasts conspicuously with the situation in the sea (Hutchinson 1967, Bougis 1976).

Given the current extensive human activities in and around Nairobi Reservoir, coupled with a desire to understand and describe the dynamics of zooplankton in a tropical urban reservoir, there was need for a qualitative and quantitative survey of zooplankton in this reservoir.

1.2 Role of zooplankton in freshwater

The exploitation of water resources for food, quality water for domestic, industrial or recreational purposes requires adequate knowledge of the organisms in the water. Monitoring conditions in reservoirs is important since biological problems such as pollution, disease spreading, and ecological problems, as well as prospective uses of reservoir water, can be determined from the biological and physico-chemical characteristics of the water body.

Mavuti (1990) stated that research on the ecology of zooplankton has important implications for the production of aquatic ecosystems due to the important role played by zooplankton in the lakes trophic networks as grazers of phytoplankton, and its significance in the diet of fish. Davies & Hart (1981) reported that most of the exploitation and development of fishery resources of Africa have been carried out in the absence of adequate knowledge of fish food organisms. Winberg (1971) stressed the need for detailed information on the ecology of fish food organisms, particularly if it is necessary to accurately predict the potential production of fish in a body of water. Therefore, to understand the trophic relationships in any body of water, it is necessary to evaluate the composition, abundance, and seasonality of zooplankton.

In Lake George, Uganda, Moriarty *et al.* (1973) found that the cichlid fishes *Haplochromis nigripinnis* Regan and *Tilapia* (=*Oreochromis*) *niloticus* L. were zooplanktivorous. In Lake Turkana, Kenya, Ferguson (1982) found that zooplankton are important food items for the following pelagic fishes, *Alestes minutus* (sp. nov.), *Alestes baremose* Joannis, and *Engraulycypris stellae* Worthington. While in Lake Albert, Uganda Green (1967a) noted that *Alestes baremose*, *Engraulicypris bredoi* Poll and *Alestes nurse* Ruppell feed on zooplankton. The same author reports that two clupeoids *Limnothrissa miodon* Boulenger and *Stolothrissa tanganicae* Boulenger are zooplanktivores and form a large proportion of the fisheries of Lake Tanganyika. The fishing of L. miodon which was introduced into Lake Kariba in 1967 has greatly expanded. The success of this fishery has been attributed to an adequate zooplankton production since Limnothrissa is a zooplankton feeder (Magadza 1979). Thus, an understanding of the ecology of zooplankton in any water body is essential for the proper management of zooplanktivorous fishes.

Recent data on the the feeding ecology of zooplanktivorous fish in East African waters were presented during the Hydrobiological Society of Eastern Africa (HYSEA) Annual Symposium in Nairobi in 1988. During this symposium, S. B. Wandera and W. Ligtovoet (pers. comm.) reported that the food of Rastrineobola argentea Pellegrin in Lake Kyoga and Lake Victoria, respectively, consisted mainly of zooplankton. More recent reports on the kenyan waters by Mavuti (1990) and by Mavuti & Litterick (1991) show that zooplankton are an important food source for juveniles and adults of some fish species resident in lakes Naivasha and Victoria respectively. The meroplanktonic larvae of Chaoborus spp. have been shown to be important food items for the tilapias in lakes Victoria and Naivasha.

Other reports show that zooplankton recycle nutrients through excretion, respiration, and defecation, by releasing substances into water which then become available for uptake by phytoplankton and bacteria (Moss 1980). Thus, in aquatic systems not dominated by algivorous or macrophyte-eating fish; zooplankton occupy a central position between primary producers and secondary consumers. Because zooplankton occupy a key position in aquatic foodwebs, studies of the composition, abundance, and seasonality of zooplankton assemblages offer a basis for establishing ecosystem productivity particularly by fishery biologists and limnologists.

An understanding of zooplankton community responses to environmental change is useful because it helps in assessing the effects of changing environmental conditions on freshwater systems. Several studies have shown that zooplankton are good indicators of anthropogenic disturbances such as pollution (Winner 1975, Nursall 1966). In addition, some planktonic organisms such as *miracidia* of trematodes and mosquito larvae, are vectors of the diseases schistosomiasis and malaria respectively. Thus, a careful study of zooplankton density and diversity could provide useful information that could lead to the formulation of policies effectively managing the aquatic environment.

Limnological studies of zooplankton in Kenyan waters is of great importance particularly because of their bearing on secondary production, where they provide a link in understanding the impact of fish on the ecosystem and in addition give information on the food quality through the seasons. Since fish are an important component of human diets in Kenya, it becomes important to determine the quality and quantity of their food items.

1.3 Factors affecting zooplankton community patterns

The ever changing conditions in aquatic environments offer favourable conditions to different species at different times giving rise to both spatial and temporal changes in zooplankton communities. The abundance of a given species is affected by environmental factors such as temperature, dry and wet seasons, water chemistry, depth of water body, turbidity, food conditions, competition and the abundance of predators. (Reid 1961, Beauchamp 1966, Burgis 1971, Green 1972b, Golterman 1975, Mavuti 1983 & 1990). These factors may not operate in the same way or to the same extent for all species.

Various investigators have suggested that temperature is an important factor controlling seasonal variation in the abundance and species composition of zooplankton. Egbore (1978) noted that temperature has a double influence on aquatic production.

Firstly, aquatic organisms are tolerant only of definite ranges of temperature outside which they cannot function. For example, among the rotifers, Lecane species have been described as warm stenotherms while Brachionus falcatus Zacharias is said to be a pantropical thermophile (Ruttner 1964). Dumont (1980) pointed out that temperature has sublethal effects on zooplankton reproduction, via its effects on metabolic processes. Saint-Jean (1983) described effects of temperature on embryonic development and found that, maximal rates of embryonic development were associated with particular temperatures.

Secondly, vertical movement among certain organisms may be limited by thermal stratification brought about by density changes in the water column brought about by thermal variation with depth. This might explain the differences in the density of zooplankton along the vertical temperature gradients in thermally-stratified water bodies. In Lake Volta, plankton were found in surface waters only so long as there was a thermocline (Hickling 1975).

Most tropical rivers, natural and manmade lakes and reservoirs have an annual cycle dictated by rainfall patterns (Payne 1986). The pattern of rainfall will have marked effects on the density and composition of zooplankton. Duncan (1984) cites wash-out and/or dilution of populations resulting from water inputs during the rainy season as factors reducing zooplankton populations. During a plankton study on Broa Reservoir, Brazil, Matsumura-Tundisi & Tundisi (1976) reported irregular fluctuations in total zooplankton numbers in the warm, rainy season, but slowly changing populations with regular changing patterns in abundance probably related to temperature in the cold, dry season.

Significant temporal changes in zooplankton abundance in conjunction with rainfall patterns have also been reported by Mavuti (1983, 1990) and Burgis (1971). Mavuti (op. cit.) reported an increase in rotifers in Lake Naivasha with the onset of rains whereas Burgis (op. cit.) reported an apparent increase in the rotifer population of Lake George in Uganda over the dry season and a decrease during the rains. The latter case is due to a high hydrological turnover rate leading to washout and/or dilution of the population.

In tropical areas, water chemistry in aquatic environments changes seasonally. During the dry season, there is a concentration of solutes through evaporation while dilution of solutes occurs during the wet season. These changing water conditions create favourable conditions for different elements of the biota at different times resulting in temporally-varying densities of plankton taxa. In studies of two soda lakes, Lake Langano and Lake Abiata in Ethiopia, Wodajo and Belay (1984) showed that variation in zooplankton composition was related to conductivity increases or decreases which were related, in turn, to dry and wet seasons.

Physical factors, such as turbidity and water depth, also appear to influence the abundance and diversity of zooplankton. Turbidity in water is caused by suspensions of particulate organic and inorganic matter. Changing concentrations of organic or inorganic particulate matter will affect zooplankton, particularly filter-feeders, by clogging their filtering apparatus (Infante & Riehl 1984). In Lake Turkana Ferguson (1982) suggested that a decrease in the rotifer population at the beginning of the flood season was due to a heavy load of silt which interfered with feeding. Variation in the abundance and composition of zooplankton with depth is caused by vertical variation in such factors as light, availability of food, reduction in dissolved oxygen levels or the presence or absence of predators.

Lewis (1979), reported relationships between the abundance of zooplankton in Lake Lanao in the Philippines. There was a positive relationship between abundance and depth for copepods, but a negative depth/abundance relationship for cladocerans and rotifers. Payne (1986) reported that the depth of descent of the vertically-migrating cyclopoid copepod _Mesocyclops_ _leuckartii_ Claus and the cladoceran _Bosmina longirostris_ O. F. Muller in Lake Kariba was due to the low oxygen levels. The depth of descent was restricted by low dissolved oxygen levels, with these plankton not occupying strata with dissolved oxygen less than 1.5 mgl^{-1} and 2.5 mgl^{-1}, respectively. Thus, these plankters abundance is redistributed depending upon the oxygen level.

Hurlbert _et_ _al._ (1972), working on small freshwater pools, reported a population explosion of _Asplanchna_ brightwelli Gosse associated with an abundance of small rotifers and negative correlation between the abundance of Rotifera and Cladocera. This study suggests that the relative abundance of different zooplankton species is influenced by the presence and/or absence of suitable food and interspecific competition amongst zooplankton species. A theory by Brooks & Dodson (1965) gives an explanation of the relationship between plankton and their food selectivity involving competition and predation.

1.4 Summary of zooplankton studies in tropical Africa

Early scientific work on zooplankton in African fresh waters was typified by field expeditions operating intensively at specific locations for short periods of time. These included the Percy Sladen Expedition to the Rift Valley Lakes in Kenya in 1929 (Jenkins 1934, Lowndes 1933), and the Cambridge University expedition to the lakes of East Africa in 1930-31 (Beadle 1932, Beauchamp 1932, Worthington & Ricardo 1936). These expeditions focused mainly on the composition, and zoogeography of the most common zooplankton species. Data drawn from these expeditions laid a foundation for most of the work that has subsequently been carried out by scientists studying aspects of zooplankton ecology such as abundance, seasonality, and taxonomy.

Considerable progress in the study of African freshwater zooplankton occurred under the auspices of the International Biological Programme (IBP). The IBP stimulated limnological research through the establishment of IBP laboratories on the shores of lakes throughout the world, where long-term studies of lake ecology could be conducted. An IBP study at Lake George, Uganda, found that zooplankton numbers, biomass and production varied only slightly during the year (Burgis 1971).

Voluminous literature on the zooplankton species composition of temperate lakes contains records of many species occupying large geographical regions. Because many studies indicated that cosmopolitanism was common among zooplankton species (Welch 1952, Davis 1955, Hutchinson 1967, Bougis 1976), tropical species came to be classified using temperate keys. More recent studies have, however, shown that many species are restricted to the tropics (Dussart *et al.* 1984) and that inadequate taxonomic knowledge led to the erroneous idea that some species were cosmopolitan (Pejler 1974). Despite an extensive literature on the composition of zooplankton assemblage in the tropics, the taxonomy of tropical zooplankton in Africa is inadequate and lags behind that of other tropical areas such as South America. Studies on tropical zooplankton have, however, been intensified thereby allowing generalisation regarding distribution patterns to be made.

In their review on the systematics, distribution and ecology of tropical freshwater zooplankton, Dussart *et al.* (1984) reported that many tropical water bodies contained many species of *Brachionus* and *Lecane*. "Typical" cladoceran assemblages usually included three species in any one lake with common species including *Ceriodaphnia* species, *Moina cornuta* Sars, *Moina micrura* Kurz and *Diaphanosoma* species. In this report, *Daphnia* species were said to be rare in tropical waters and cyclopoid copepods to be less diverse in tropical than in temperate regions. Cyclopoids, however, tend to be abundant in tropical regions and include genera such as *Mesocyclops* and *Thermocyclops*. Calanoids are often present in tropical waters. This observation though general, is applicable to the African situation. The taxonomic works of some African lakes like the works of Green (1965, 1967b and 1972a) detailing the characteristics of the various species has greatly helped in the identification of the different species.

Present data on the species composition of zooplankton assemblages indicate that the species diversity of rotifers decreases as proximity to the equator increases (Maitland 1978). Furthermore there is a decrease in diversity of rotifers with increased salinities. This has been well-established in Lake Nakuru, Kenya (Pejler 1974, Vareschi & Vareschi 1984) and Lakes Langano and Abiata, Ethiopia (Wodajo and Belay 1984).

In Lake Albert, Uganda, Green (1967a, 1967b, 1972a) like Lewis (1979) observed striking differences in the composition and distribution of zooplankton from inshore to offshore areas of the lake and related distributional patterns in zooplankton to the distributional patterns of planktivorous fish. Green (1976) reported marked historical change in the species composition of the same lake. The seasonal occurrences of the main planktonic species in the lake sources of the White Nile were reported by Green (1967a, 1967b). Results showed that there were differences in the composition of the zooplankton in these lakes with the distribution and abundance of the different species varying between the different lakes.

In Kenya, Pejler (1974) described the composition of Rotifers in Lakes Nakuru, Elementaita, and Baringo. Lakes Elementaita and Nakuru were first studied in 1929 by other limnologists who provided species lists (Jenkin 1932). Subsequent investigators, such as Jacobs (1978), Vareschi & Jacobs (1984) and Vareschi & Vareschi (1984), provided additional information on the zooplankton in these Lakes and reported the absence of cladocera in saline lakes Nakuru and Elementaita. However K. M. Mavuti (pers. comm.) found high densities of Moina micrura in Lake Nakuru in 1988. The most striking biological change reported by Vareschi & Vareschi (1984) over their three years of study was the disappearance of the calanoid copepod Paradiaptomus africanus Daday from Lake Nakuru over the three years of their study. Mavuti

(1983, 1990) gave a list of the limnetic zooplankton in Lake Naivasha and described vertical migration and the ecological role of the zooplankton of this water body. Ferguson (1982) found small but significant seasonal changes in zooplankton abundance and species composition in Lake Turkana associated with changes in the volume and quality of inflowing water from the River Omo.

The creation of a number of manmade lakes in Africa and in other tropical areas in the world has stimulated interest in the hydrobiological features of the reservoirs. Research has been carried out with particular attention to such limnological characteristics as water chemistry, the fish fauna, aquatic weeds and plankton. Admittedly, there has been extensive work on applied hydrobiology, especially in fisheries and medical biology, but there is a dearth of fundamental information on zooplankton in tropical reservoirs. Examples of manmade lakes and reservoirs in Africa whose zooplankton have been studied include: Lake Volta in Ghana (Ewer 1966, Obeng 1966, Hickling 1975); Lake Kariba in Zimbabwe (Balon & Coche 1974, Magadza 1979); and Kamburu Reservoir on the River Tana in Kenya (Odingo 1977).

Kalk (1979), while working on Lake Chilwa in Malawi, recorded numerical peaks in zooplankton abundance during the warm and wet plus the cool and dry seasons. However, there was a drop in the population in the hot and dry season. This study shows that there was temporal variation in the zooplankton abundance over the seasons.

Seasonality of zooplankton is well-established in temperate latitudes (Hutchinson 1967, Welch 1952). Until recently African results have relied on short-term expeditions where sampling has not been frequent or of sufficient duration to provide clear seasonal descriptions of lakes. Even now studies on seasonal variation in populations of tropical freshwater zooplankton are relatively scarce. Some data on seasonal variation in zooplankton population is provided by Burgis (1971) for Lake George in Uganda, Mavuti (1983) for Lake Naivasha in Kenya, Robinson & Robinson (1971) and Carmouze _et_ _al._ (1983) for Lake Chad in Chad. Because there is little information on detailed population dynamics and seasonal succession of zooplankton in small tropical water bodies, the present work attempts to provide a picture of seasonal changes in abundance and species composition of a zooplankton assemblage in such an ecosystem.

1.5 Study objectives

From the foregoing, there are obvious gaps in our knowledge of zooplankton ecology in tropical lakes and reservoirs. Although there is some information on freshwater zooplankton in East Africa, little information on zooplankton in urban reservoirs in the Tropics exists, and no information on detailed population dynamics and seasonal succession of zooplankton in manmade lakes in Kenya. Because of these gaps, this study was undertaken in order to provide information on the seasonal variability of zooplankton of Nairobi Reservoir. The following were the main objectives:

1. to determine the species composition, and examine the relative and absolute abundances of zooplankton in Nairobi Reservoir.
2. to examine seasonal changes in the abundance of the major zooplankton groups (Copepoda, Cladocera, and Rotifera).

3. to concurrently monitor basic limnological parameters such as temperature, chlorophyll _a_ concentrations, dissolved oxygen levels, conductivity and total alkalinity in Nairobi Reservoir.
4. to relate changes in the zooplankton community to the limnological parameters listed in 4 above.

CHAPTER 2

STUDY SITE DESCRIPTION

2.1 Location

Nairobi Dam is located in the South-western suburbs of the City of Nairobi at longitude $36^{o}48'$E, latitude 1^{o} 19′S, and an altitude of 1700 meters above sea level. The reservoir (Fig.1) is surrounded by several human settlements. On the southern bank is the Nairobi Sailing Club and Nairobi Dam Estate, on the northern and North-western banks are the Kibera Line Saba and Kibera High-Rise Estates. On the western bank are Ngei, Otiende, Southlands, Uhuru, and Onyonka estates, and on the eastern shore is a Government Prison.

2.2 History

Nairobi is the largest city in Kenya and, indeed, in the whole of East Africa. Nairobi came into existence when the the construction of the Kenya-Uganda Railway reached the end of the Athi Plains and the site was chosen as the railway headquarters.

From its original nucleus roughly between the Nairobi River to the north and the highland edge to the west the city has expanded by a series of boundary changes to a total area of 693 Km^2. The expansion of the City area was as follows:

Year	Area (Km^2)	Population
1948	83.97	- -
1962	90.65	343,500
1982	693.00	509,286 (source Opinya 1982).

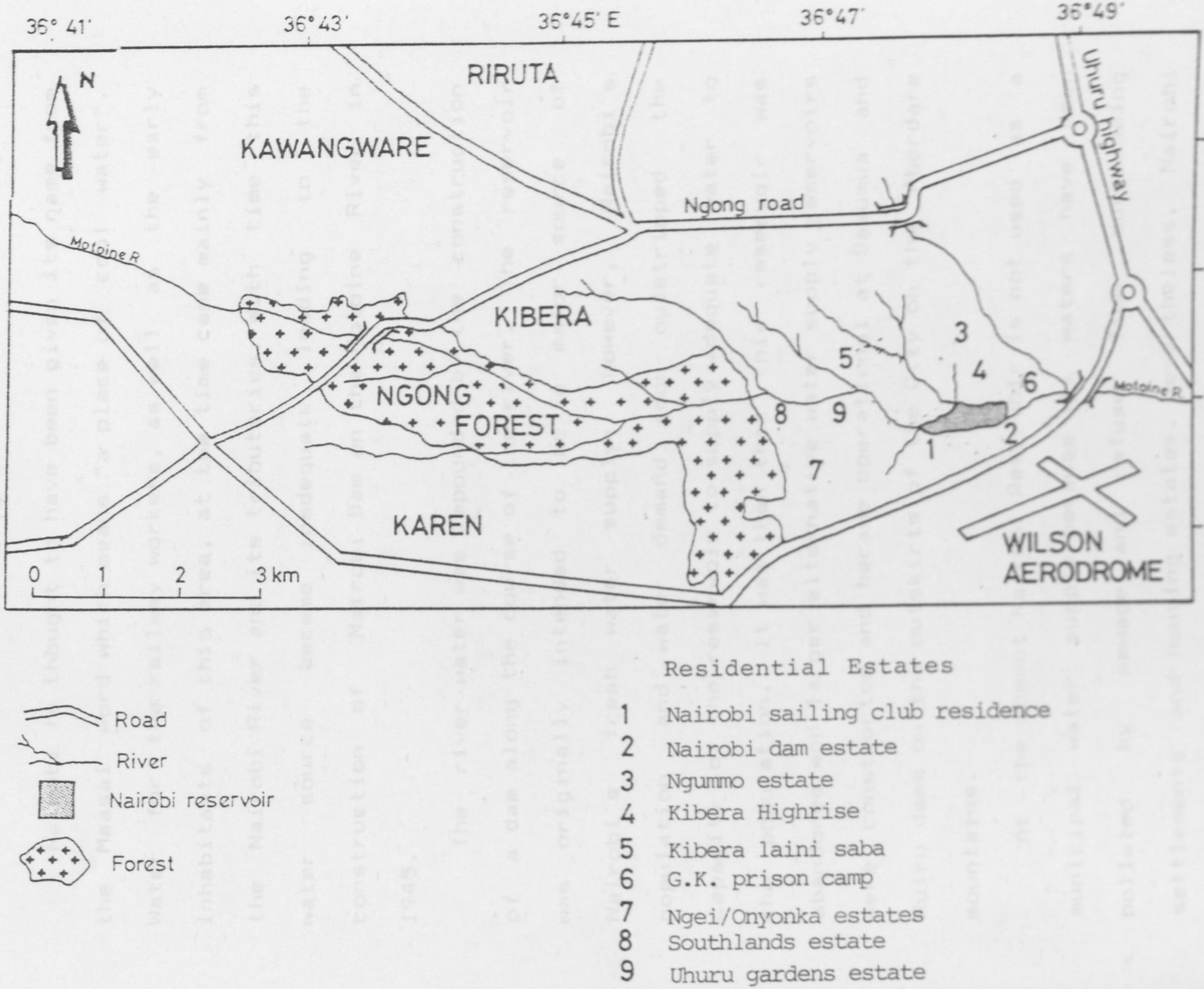


Fig. 1: *Location of Nairobi Reservoir (adopted from the survey maps of Kenya for Ngong and Nairobi)*

Nairobi is thought to have been given its name from the Maasai word which means "a place of cool water". Water for the railway workers, as well as the early inhabitants of this area, at the time came mainly from the Nairobi River and its tributaries. With time this water source became inadequate leading to the construction of Nairobi Dam on the Motoine River in 1945.

The river water was impounded by the construction of a dam along the course of the river. The reservoir was originally intended to be a major source of Nairobi's fresh water supply; however, Nairobi's population and water demand soon outstripped the capacity of the reservoir to supply adequate water to the population. It was then that this reservoir was abandoned and larger alternative water supply reservoirs were constructed and became operational at Sasumua and Ruiru dams on the outskirts of the City on the Aberdare mountains.

At the moment Nairobi Reservoir is not used as a municipal water supply because its waters have been polluted by sewage and refuse from surrounding settlements and housing estates. Nevertheless, Nairobi Reservoir continues to be useful to Nairobi residents as a recreational facility for boating and yatching and as a source of water for domestic use and fishing. The fish caught here include <u>Oreochromis</u> spp., <u>Haplochromis</u> sp., Clarias sp. and Poecilia sp. (K. M. Mavuti, pers. comm.) and is mainly used for domestic consumption by some of the Kibera residents.

2.3 Catchment area

The River Motoine arises in the Dagorreti Forest at an altitude of 1900 meters, flows through the Ngong' Road Forest, and enters Nairobi Reservoir on its western side and leaves it on its north-eastern side. This river is a tributary of the Ngong' River which, in turn, joins the Nairobi-Athi River system. In its upper courses, the Motoine River receives numerous tributary rivulets and streams draining run-off from nearby residential areas such as Kibera Line Saba, Nairobi Dam Estate and Kibera-Highrise Estate. About 14 kilometres from its source, the river discharges its waters into Nairobi Reservoir (Fig. 1).

The watershed of Nairobi Reservoir is very densely populated in some places, such as at Kibera Line Saba slums, whereas other residential areas such as Karen, Langata, and Woodley have low population densities. Other areas in the watershed are used for agricultural production. The runoff flowing into the reservoir is high in nutrients and sediment. The water chemistry of the Reservoir has probably changed in the past and will probably change in the future as the density of settlements increase. Therefore, there is a need for a baseline study for future reference.

2.4 Vegetation, climate, and geology of the catchment area and reservoir

Most of the indigenous forest trees which survive in the catchment area of the Reservoir are of the dry semi-deciduous type (Trump 1967). The dominant species are *Croton megalocarpus* Hutch., *Brachylaena huillensis* O. Hoffm., *Calodendrum capense* Thunb., *Teclea* spp., *Strychnes henningsii* Gilg and *Diospyros abyssinica* F. White. The area immediately surrounding the reservoir is semi-arid with a sparse vegetation of grasses, including *Themeda triandra* Forsk., *Eragrostri pycnostachys* W.D. Clayton, *Panicum maximum* Jacq., *Setaria plicatilis* Hochst. and *Sporobolus* sp., and scattered bushes and stunted trees, including species such as *Barleria micrantha* C.B.Cl., *Veronia holstii* O. Hoffm., *Grewia similis* K. Sch., *Acalypha volkensii* Pax and *Acacia* sp., particularly on the western side.

The perennial flow of the Motoine River comes from rainfall on the Ngong' Hills. The higher surrounding areas of the drainage basin receive more rainfall than the area around the reservoir and provide most of the water that maintains the reservoir.

The climate of this area is influenced by the monsoonal systems of Asia and the Indian Ocean. Rainfall is strongly influenced by the intertropical convergence zone (ITCZ). The southeast trade winds and northeast trade winds bring rainfall in two seasons. The "long rains" fall from March to May and is followed by a cloudy cool dry season from June to September with the "short rains" comencing in October and ending in December. Another dry season from December to mid March follows. However, the rainfall is not very reliable and shows considerable variability in mean annual rainfall totals from year to year with an average mean of 907 mm per annum. Runoff from the catchment area results in fluctuating volumes of water entering the reservoir, with maximum flows during the rainy season and minimum flows during the dry season. The maximum flows are usually accompanied by floods which lead to flushing of the reservoir. The reservoir waters during the rainy seasons are silt-laden and brown in colour.

Temperatures are not very variable although the months of June and July are normally cold. The mean annual atmospheric temperature is 20°C (Thompson & Samson 1967).

The geology of the area over which the river flows is mainly made up of basalts of the Olorgesaile volcanic series and Nairobi phonolitic trachytes, which are primarily alkaline rocks (Williams 1967).

2.5 Characteristics of the reservoir

The reservoir is a relatively small manmade water body with the following morphometric characteristics:

Catchment area : 21 km^2
Surface area : 0.3 km^2
Maximum length : 1.25 km

contd.

Maximum width : 0.5 km

Maximum depth : 15 m

Mean depth : 5.0 m

Shoreline length : 3 km

The lake is approximately oval in shape with a short dam-wall base about 250 m in length. The lake's substrate consists of fine organic silt. The shoreline is weedy with dense stands of _Typha_ sp. Noticeably absent are submerged and floating macrophytes. During the period of study there was also a faunal assemblage consisting of birds and fish.

Nairobi Reservoir, like many tropical lakes of Africa, exhibits seasonal variation in depth due to evaporation and reduced water inputs in the dry season. Input from rivers, rivulets and streams increases in the wet seasons with consequent increases in water depth and changes in water quality. Due to fluctuating water levels, the marginal vegetation is exposed or submerged depending on the season.

The presence of a slum, Kibera Line Saba, on the North-eastern bank has resulted in an extension of the _Typha_ zone owing to increased nutrient inputs in runoff from this area. A survey of limnological literature on eutrophication (see Hasler 1947) suggests that marked biological changes in shoreline vegetation follow increased nutrient inputs particularly the vegetation found close to the point source. The results from the case histories offer circumstantial evidence that explains this observation with regard to Nairobi Reservoir.

CHAPTER 3

MATERIALS AND METHODS

SAMPLING PLAN

3.1. Description of sampling stations

Sampling was carried out at three stations. shown diagrammatically in Fig. 2. The three stations were selected on the basis of their location in relation to different external influences. Station 1 was a mid-reservoir station of depth 8.5 m. This station was located in mid-lake and was likely to have lacustrine conditions. Station 2 was a littoral station of depth 2.75 m. This station was close to the Kibera slums and likely received urban pollution, and was close to an extensive stand of Typha. Station 3 was located near the mouth of the Motoine River and had a depth of 4.75 m. This station was likely influenced by the inflowing river.

3.2. Frequency and intensity of sampling

Routine sampling was conducted at the three stations in the morning between 8.30 and 12.00 hours at the three stations at fortnightly intervals for one year, from October 1989 to September 1990.

Samples were taken from surface and bottom waters for all stations. In addition, Station 1 was sampled at depths of 1, 2, 3, 5 and 7 m; Station 2 was sampled at 1 and 2 m; depths and Station 3 was sampled at 1, 2 and 3 m depths. One sample was taken per depth.

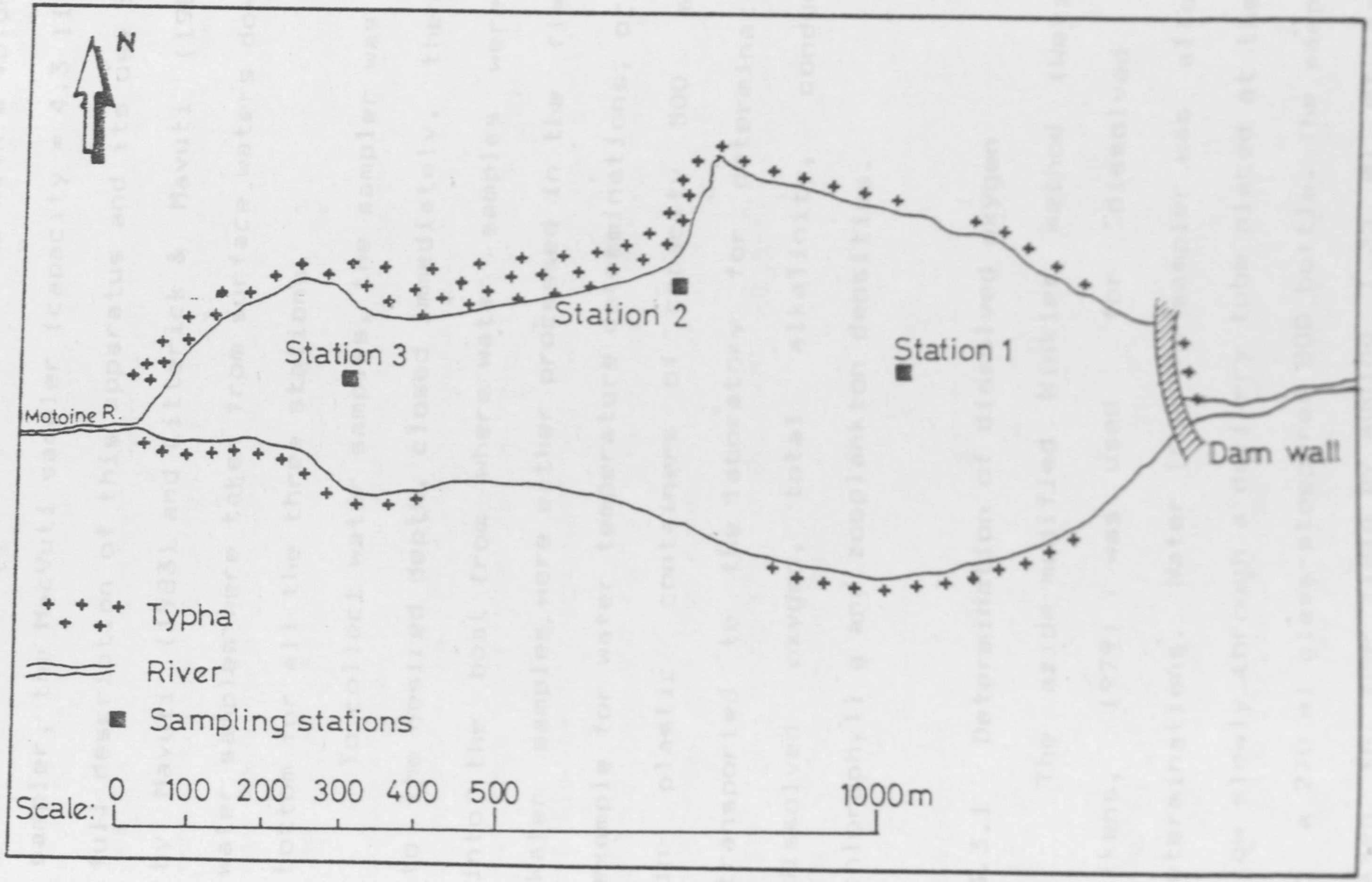


Fig. 2: *Location of sampling stations on Nairobi reservoir.*

3.3. Collection of water samples

Water samples were collected with a volume water sampler, the MacVuti sampler (capacity = 4.3 litres). A full description of this apparatus and its use is given by Mavuti (1983) and Litterick & Mavuti (1985). The water samples were taken from surface waters down to the bottom for all the three stations.

To collect water samples, the sampler was lowered to the desired depth, closed immediately, then hauled into the boat from where water samples were taken. Water samples were either processed in the field, for example for water temperature determinations, or placed in plastic containers of capacity 500 mls and transported to the laboratory for determinations of dissolved oxygen, total alkalinity, conductivity, chlorophyll a and zooplankton densities.

3.3.1 Determination of dissolved oxygen

The azide-modified Winkler method (Wetzel and Likens, 1979) was used for dissolved oxygen determinations. Water from the sampler was allowed to flow slowly through a delivery tube placed at the bottom of a 270 ml glass-stoppered BOD bottle. The sample was fixed in the field by adding 1.35 ml of manganous sulphate solution (Mn_2SO_4) followed immediately by a similar quantity of Winkler reagent (alkaline iodide solution). The bottle was carefully stoppered, and the contents were vigorously mixed by inversion and then allowed to settle.

In the laboratory, samples were shaken and the precipitate allowed to sink to the lower half of the bottle. The stopper was then removed and 2.7 ml of concentrated sulphuric acid quickly added. The stopper was then carefully replaced, the bottle shaken until all the precipitate dissolved, then titrated with standardised 0.01 N sodium thiosulphate solution until a pale straw-yellow colour appeared. Four drops of starch solution were then added resulting in a blue coloration of the sample solution and titration was continued to a colourless end point. The volume of the titrant used was recorded and the formula given by Wetzel & Likens (1979) used to estimate dissolved oxygen concentration in $mg.l^{-1}$ as shown below,

$$mg.\ O_2 l^{-1} = \frac{VT \times NT \times 8000}{VS \times \frac{(VB - VR)}{VB}}$$

where,

NT = normality of thiosulphate

VB = volume of sample bottle (ml)

VR = volume of Mn_2SO_4 + volume of Winkler Reagent (ml)

VT = volume of titrant used (ml)

VS = volume of sample titrated (ml)

3.3.2 Determination of temperature profiles

Temperatures were determined to the nearest $0.1^{o}C$

with a mercury thermometer which was dipped into the sample water immediately after a sample was brought to the surface.

3.3.3 Determination of Total alkalinity

Total alkalinity was assessed through titration of 100 ml of sample water with a 0.1 N solution of hydrochloric acid using methyl orange as an indicator until a pale orange colour appeared, this was the end point. Alkalinity was calculated according to methods described in Mackereth, Heron & Talling (1978) as:

$$\text{meql}^{-1} = (n.1000/v)r$$

where,

v = sample volume (ml)
r = ml of acid used
n = normality of acid.

3.3.4 Determination of conductivity

A YSI model 33S-C-T conductivity meter was used to determine the conductivity of the water samples.

3.3.5 Determination of Chlorophyll a

Sample water was collected in 500 ml plastic bottles from different depths at each of the three stations, labelled, and taken to the laboratory for analysis.

In the laboratory chlorophyll a was determined using the methanol extraction method as described in Strickland & Parsons (1972). Thus, 200 mls of sample was filtered through a GFC glass fibre filter of pore size 0.47 um. After filtering, the filter was removed with forceps and placed in a labelled centrifuge tube containing 10 mls of 90% methanol. Using a pre-heated waterbath, the contents were boiled for 10 seconds. The tube was then left to stand for not less than 30 minutes to allow complete extraction of pigments. The extract was then centrifuged at 3500 r.p.m. for 15 minutes, and the supernatant was decanted into spectrophotometric cuvettes of 1 cm path length.

Using 90% methanol as a blank the absorbance was read at 665 nm. For the samples, the supernatant was poured into cuvettes and absorbances were recorded. Spectrophotometric determinations were done on a Pye Unicam Sp. 550 series spectrophotometer.

Chlorophyll a concentrations were calculated according to the formula given by Talling and Driver (1963) thus:

$$\mu g\ \text{Chl}\ \underline{a}.l^{-1} = \frac{OD_{665}.13.9v}{L.V}$$

where,

v = volume of solvent (10ml methanol)

OD = absorbance at 665 nm

V = volume of water filtered (ml)

L = light path of spectrophotometer cuvette (1 cm)

3.3.6 Processing of samples for zooplankton

For quantitative zooplankton samples, whole water contents from the sampler were emptied into a large bucket. The water was then filtered through a fine plankton strainer of mesh size 60 um, This mesh is small enough to retain most of the rotifers and microcrustacea (Edmondson & Winberg 1971). The plankton were then washed into labelled sample bottles using a wash-bottle, then preserved in 5% neutral formalin.

3.3.7 Sorting and counting zooplankton

At the time of counting the sample was brought to a total volume of 50 ml. The plankton sample was agitated to achieve a random distribution of organisms, and using a wide bore dropper a subsample was taken and put into a 1 ml Sedgewick Rafter (S.R) counting cell (length = 50 mm, width = 20 mm, depth = 1 mm) The counting cell was moved systematically and zooplankton were identified, categorised and counted under a compound microscope at magnification X100. Crustaceans were identified with the use of keys from Pennak (1953) Brooks (1959), Wilson & Yeatman (1959), Yeatman (1959), and Fitter & Manuel (1986) and drawings from Mavuti (unpublished), whereas rotifers were identified using keys from Pennak (1953), Edmondson (1959), and Fitter & Manuel (1986), and plates from Hurlbert _et al_. (1972). Counts were done on three subsamples from each sample with replacement.

The numbers per ml counted were then converted to individuals per litre as shown below:

$$\text{No. individuals per litre} = \frac{\text{average count per S.R. cell} \times 50}{4.3}$$

3.3.8 Determination of Secchi depth

Transparencies were determined using a weighted black and white Secchi disc of diameter 35 cms attached to a calibrated non-stretchable line. The disc was lowered gradually through the water column from the shaded side of the boat until it just disappeared, and this depth was recorded. The disc was then slowly raised until it reappeared and this depth was also recorded. The mean of these two readings was the Secchi depth.

3.4 Rainfall totals

Rainfall data for Nairobi Reservoir and its catchment area were obtained from the Meteorological Headquarters, Nairobi, for two stations in the study area: Dagoretti Corner (Station 9136164) and Wilson Airport (Station 9136130). The two stations are considered to be representative of conditions within the catchment and in the vicinity of the reservoir respectively (Fig.1).

3.5 Statistical analyses

Graphical analyses were conducted by plotting graphs of different parameters against depth and time. Inspection and comparison of these graphs indicated values and relationships among various parameters over time and space. Mean values of these parameters were computed for different depths across stations, for stations across depths, and over time to provide a general measure of variation among stations, among depths, and within stations over time.

To examine relationships among biotic and abiotic factors in time and space; correlation, regression and analysis of variance (ANOVA) were performed on the data.

Correlation analysis was performed on the mean values of zooplankton and for each environmental factor (i.e. average over all depths for each station on each date).

For each species or developmental stage, relationships between zooplankton abundance per unit volume of water and water quality parameters such as dissolved oxygen, total alkalinity, conductivity, Secchi depth, temperature, and chlorophyll a concentration were examined with linear regression and ANOVA in two stages:

1. Individual samples from each depth at each station on each sampling date were used as replicates. This was done in order to ascertain variation within the station resulting from the effect of depth.

2. The mean abundance of zooplankton was calculated and so were the mean levels for each environmental factor at each station on each sampling date (i.e. average over

all depths for each station on each date). Using these means as replicates, regression analysis for each station over time using zooplankton abundance (total and individual taxa) as the dependent variable and environmental factors as the independent variables were performed. This analysis will indicate what environmental factors can perhaps account for most of the variation of zooplankton abundance in this reservoir.

ANOVA was performed on the data in order to partition variation into its components (Hayslett 1981) i.e. variation due to depth (within stations) and variation due to location (between stations). To the observations that gave significant variations between stations, a t-test was performed in order to determine which stations varied significantly.

RESULTS AND DISCUSSION

CHAPTER 4

4.1 RESULTS

4.1 Spatial and temporal variation in environmental factors in Nairobi Reservoir

4.1.1 Dissolved oxygen

Dissolved oxygen often showed distinct changes with depth (Fig 3, 4, 5). There was a consistent zone of low oxygen levels from approximately 3 m below the water surface to the bottom for Stations 1 and 3, and an oxycline at about 1 m depth for Station 2. There was a negative and significant vertical gradient of dissolved oxygen, with the highest concentrations at the surface and lowest concentrations near the bottom for all stations. Vertical ranges in dissolved oxygen concentrations over the three stations during the sampling period are shown in Table 1. There was also more oxygen on average at Station 2 and 3 than at Station 1, this was probably due to their shallow depths and riverine influences respectively. A t-test performed on the mean oxygen concentrations for the three stations indicated that there was a significant difference between stations 1 and 2 ($t = -4.1$, $n = 66$, $p \geq 0.05$) and between stations 1 and 3 ($t = -3.5$, $n = 66$, $p \geq 0.05$), but no significant difference between stations 2 and 3 ($t = 0.45$, $n = 66$, $p \geq 0.05$).

From the C.V. table below there was a high variability in oxygen concentration with depth. Noteworthy was Station 1 which experienced oxygen depletion in bottom waters which were devoid of oxygen on 16 out of the 22 sampling sessions done.

Table 1. Variation in dissolved oxygen (ug $O_2 l^{-1}$) for Nairobi Reservoir between October 1989 and September 1990

	STATION 1		STATION 2		STATION 3	
	Min.	Max.	Min.	Max.	Min.	Max.
Annual mean	0.7	4.4	1.0	7.9	1.1	7.7
Surface	1.4	13.4	1.5	13.5	2.0	14.9
Bottom	0.0	0.2	0.2	6.42	0.2	2.3
C.V. (%)	66.9	147.0	0.6	130.8	29.0	146.3

4.1.2 Water temperature

Analysis of variance carried out on temperature data showed significant spatial and seasonal variation. There was significant variation with depth (F = 10.9, n = 7; F = 5.5, n = 4; and F = 5.7, n = 5) at $p \geq 0.05$ for Stations 1, 2, and 3 respectively. Vertical temperature profiles (Figs 3, 4, 5) show two different patterns, namely: relatively steep thermal gradients, when surface water temperatures were high with a thermocline near the surface (e.g. Figs. 3a, 3b, 4a, 5a, 5l); isothermy or near isothermy when weak or no thermal stratification developed (e.g. Figs. 4c, 4s, 5c, 5s). However, significant horizontal variation in mean water temperatures occurred between Stations 1 and 2 (t = -2.3, n = 66), and also between Stations 1 and 3 (t =

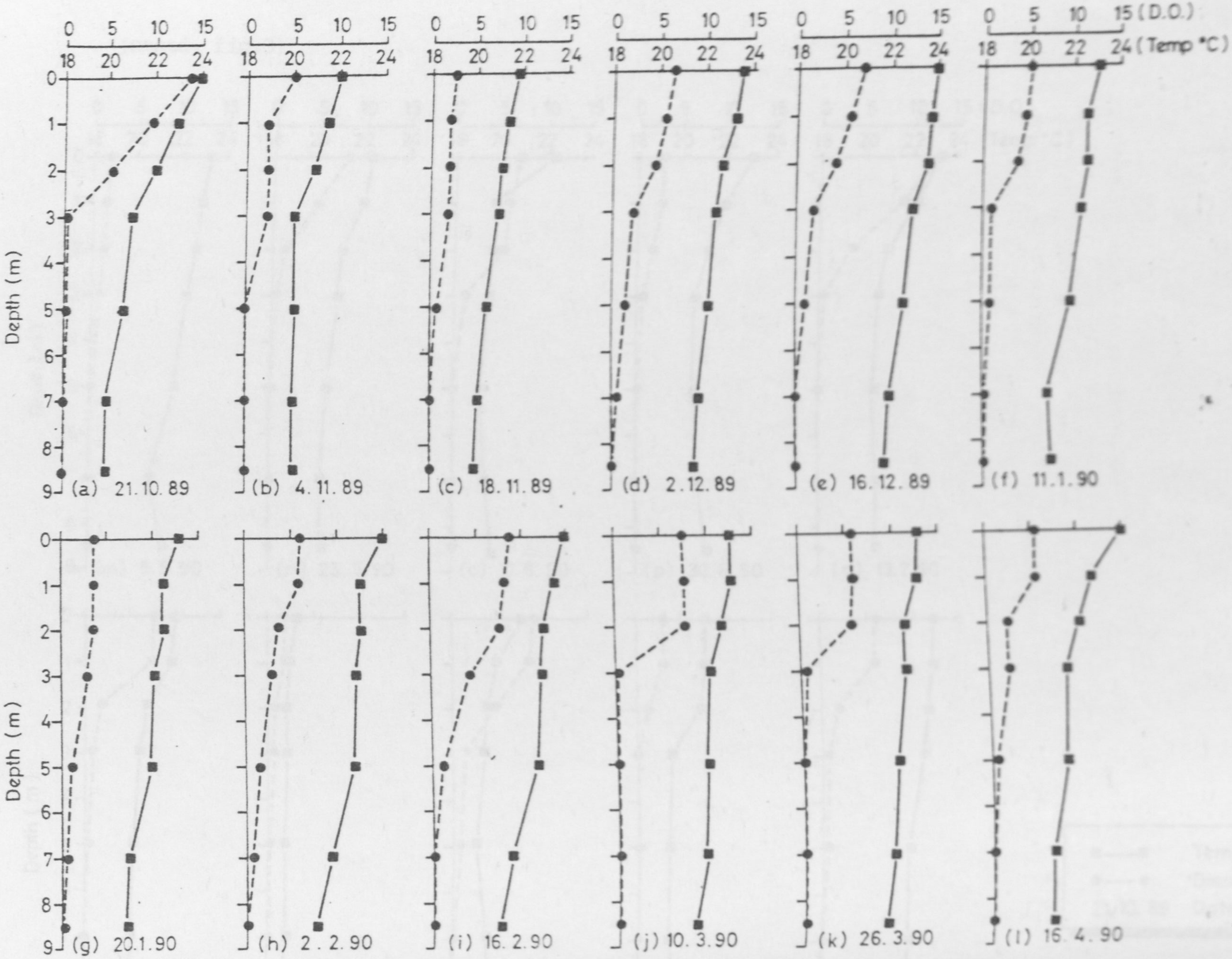
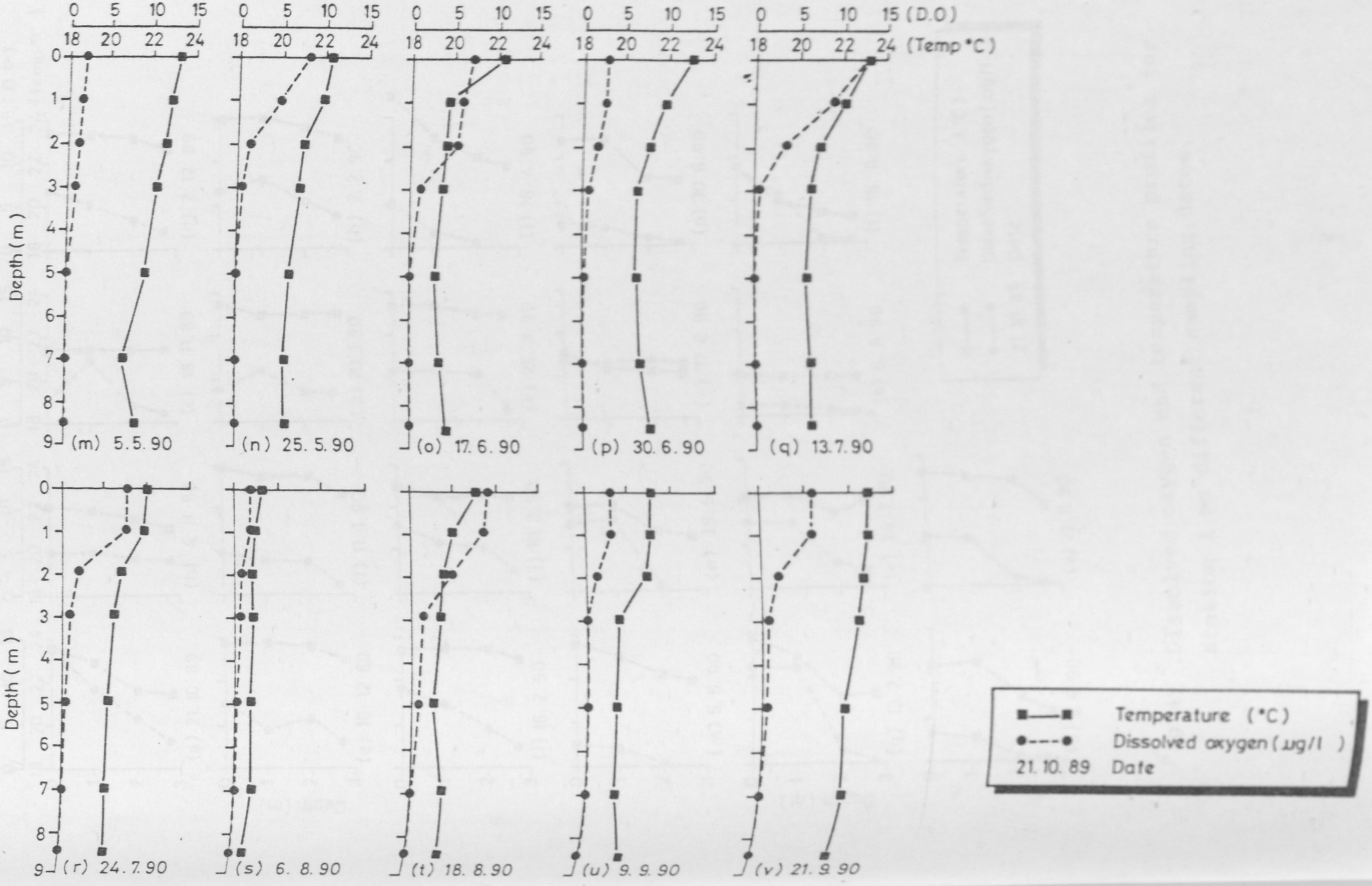


Fig. 3. Dissolved oxygen and temperature profiles for station 1 on different sampling dates.

(contd. fig.3)


0 5 10 15 (D.O)
18 20 22 24 (Temp °C)
Depth (m)
0 1 2 3 4 5 6 7 8 9
(m) 5.5.90
(n) 25. 5.90
(o) 17.6.90
(p) 30.6.90
(q) 13.7.90
(r) 24.7.90
(s) 6. 8.90
(t) 18. 8.90
(u) 9. 9.90
(v) 21. 9.90
Temperature (°C)
Dissolved oxygen (µg/l)
21.10.89 Date

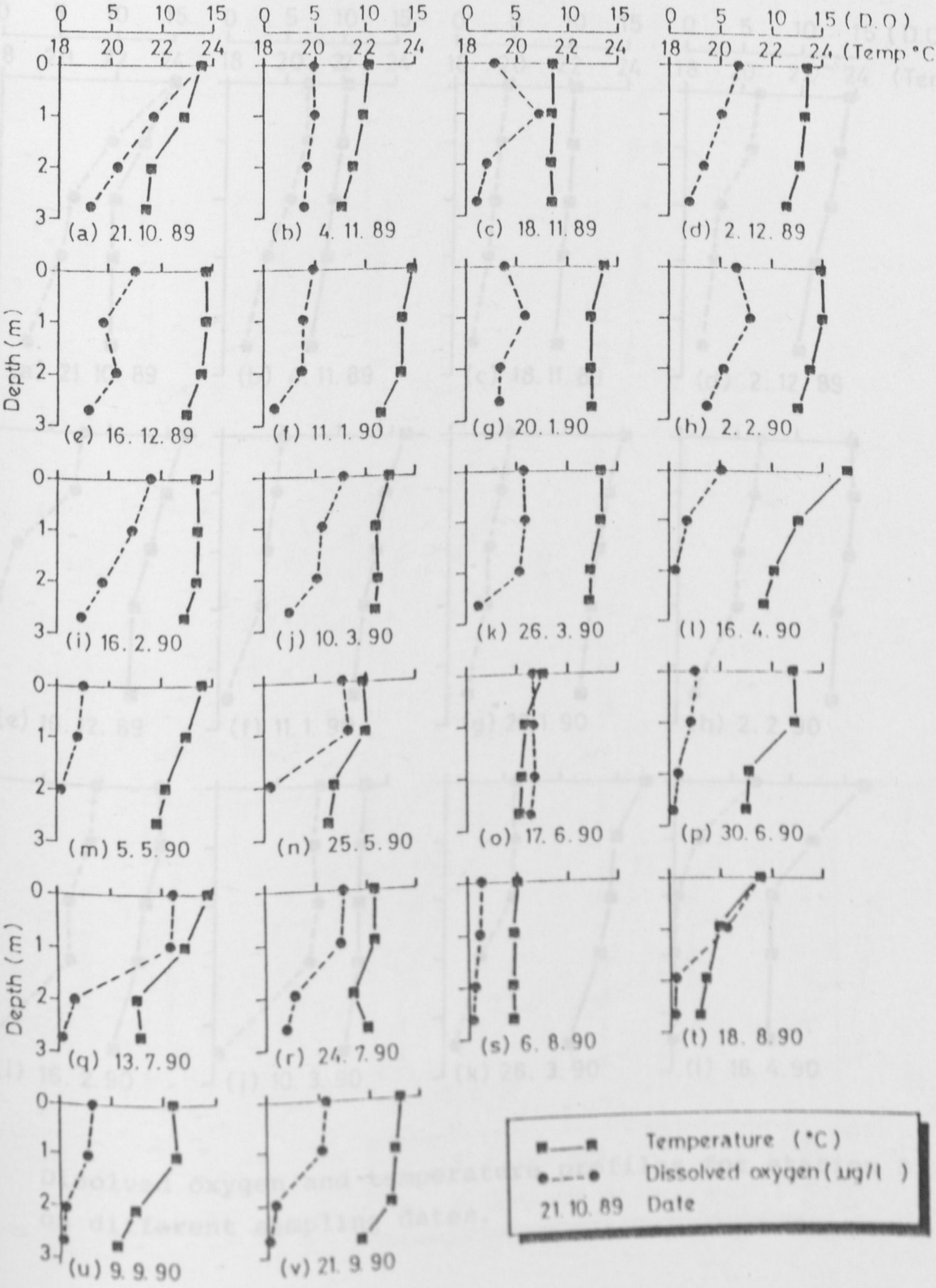


Fig.4: Dissolved oxygen and temperature profiles for station 2 on different sampling dates.

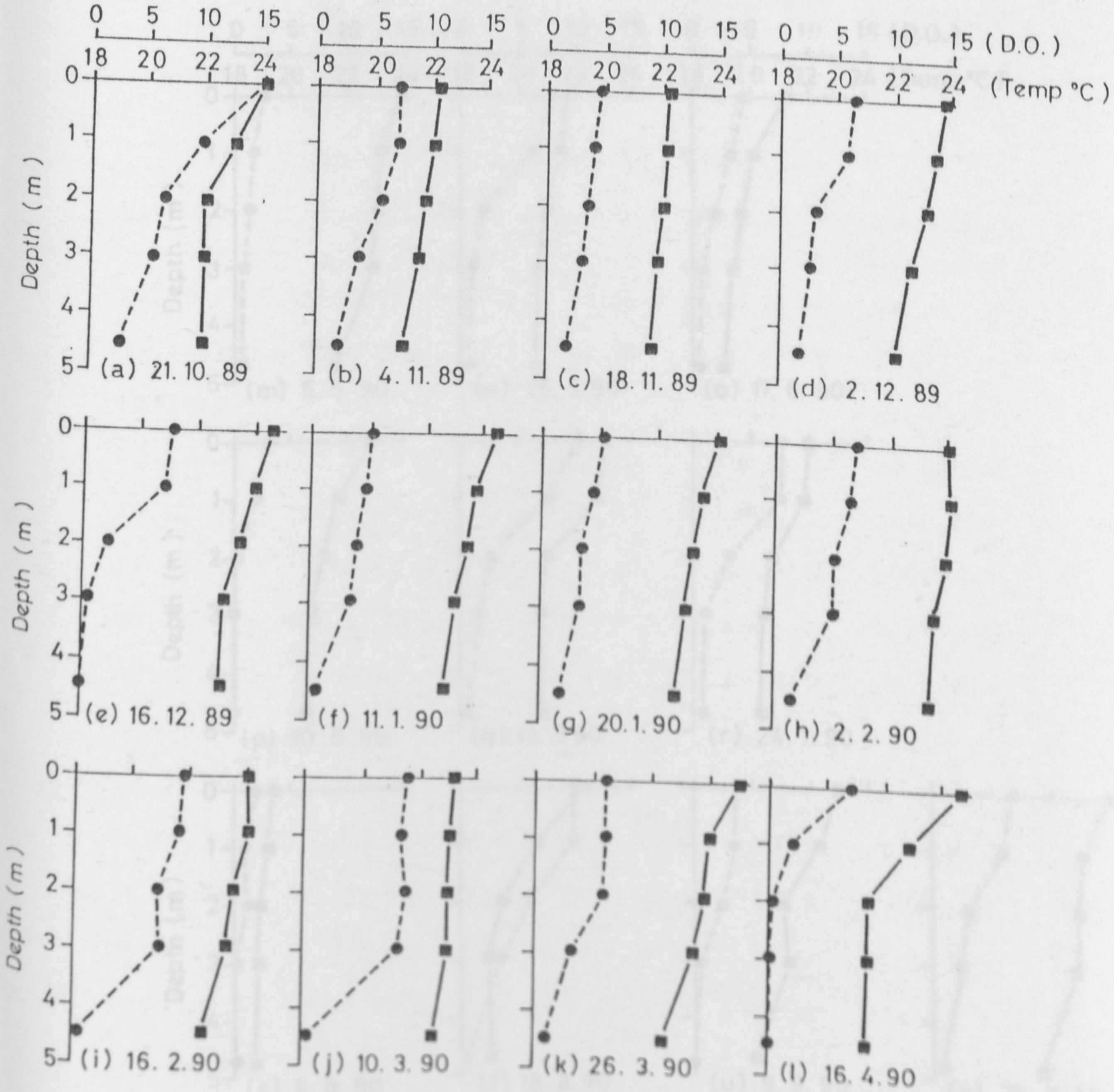


Fig. 5: Disolved oxygen and temperature profiles for station 3 on different sampling dates.

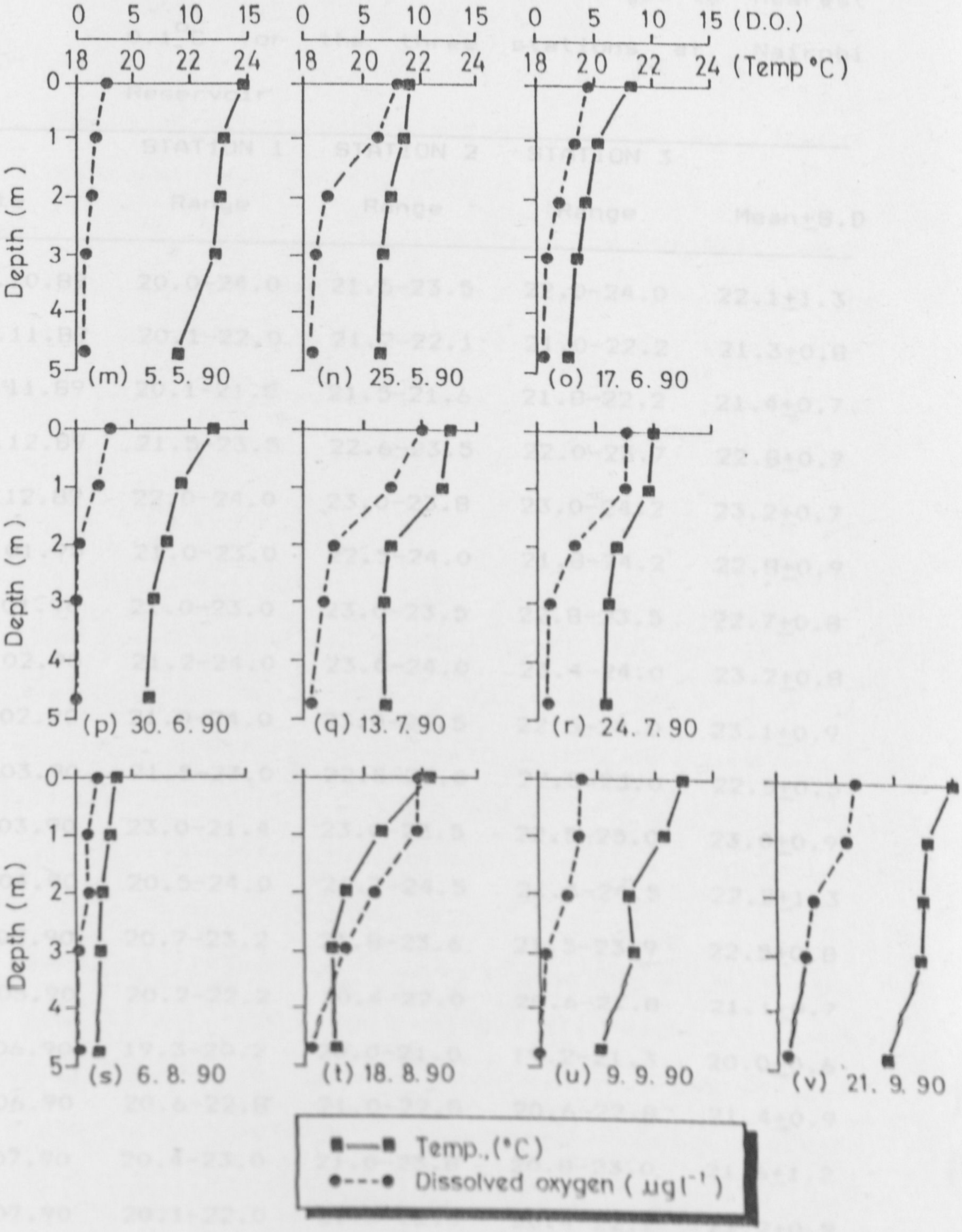


Fig.5: Dissolved oxygen and temperature profiles for station 3 on different sampling dates.

Table 2. Mean water temperatures and ranges to nearest 0.1°C for the three stations at Nairobi Reservoir

	STATION 1	STATION 2	STATION 3	
Date	Range	Range	Range	Mean±S.D
21.10.89	20.0-24.0	21.5-23.5	22.0-24.0	22.1±1.3
01.11.89	20.1-22.0	21.2-22.1	21.0-22.2	21.3±0.8
18.11.89	20.1-21.8	21.5-21.6	21.8-22.2	21.4±0.7
02.12.89	21.5-23.5	22.6-23.5	22.0-23.7	22.8±0.7
16.12.89	22.0-24.0	23.0-23.8	23.0-24.2	23.2±0.7
11.01.90	21.0-23.0	22.5-24.0	21.8-24.2	22.8±0.9
20.01.90	21.0-23.0	23.0-23.5	22.8-23.5	22.7±0.8
02.02.90	21.2-24.0	23.0-24.0	23.4-24.0	23.2±0.8
16.02.90	21.0-24.0	23.0-23.5	22.5-24.0	23.1±0.9
10.03.90	21.5-23.0	22.5-23.0	22.5-23.0	22.5±0.5
26.03.90	23.0-21.4	23.0-23.5	22.5-25.0	23.0±0.9
16.04.90	20.5-24.0	21.7-24.5	21.4-24.5	22.2±1.3
05.05.90	20.7-23.2	21.8-23.6	21.5-23.9	22.5±0.8
25.05.90	20.2-22.2	20.4-22.0	20.6-21.8	21.1±0.7
17.06.90	19.3-20.2	20.0-21.0	19.2-21.3	20.0±0.6
30.06.90	20.6-22.8	21.0-22.8	20.6-22.8	21.4±0.9
13.07.90	20.4-23.0	21.0-23.8	20.8-23.0	21.6±1.2
24.07.90	20.1-22.0	21.3-22.4	20.4-22.2	21.2±0.9
06.08.90	18.3-19.2	18.8-19.0	18.8-19.4	18.9±0.2
18.08.90	18.9-21.1	19.4-21.7	18.9-22.2	19.9±1.0
09.09.90	19.3-21.1	20.2-22.2	20.0-22.8	20.7±1.1
21.09.90	21.5-23.0	21.6-23.2	21.8-23.8	22.5±0.7

2.3, n = 66), with no significant difference between Stations 2 and 3 (t = - 0.01, n = 66) at $p \geq 0.05$.

The mean water temperature was 21.9°C, the lowest mean temperatures for the Reservoir were recorded in August (X = 19.6±0.93°C), whereas the highest mean temperatures for the Reservoir were recorded in February and December (X = 23.1±0.8, and 23.1±0.4°C respectively). The greatest range with depth occurred in April while the lowest range with depth occurred on August 6 (Table 2).

4.1.3 Total alkalinity

There was little and insignificant horizontal and vertical variation in total alkalinity (Table 3). The correlation coefficient between stations was not significant (r = 0.004, n = 66, $p \geq 0.05$). Due to this, the alkalinity of the three stations was averaged and presented as one graph (Fig. 6).

Temporal changes in alkalinity were substantial, and significant. The drop in alkalinity that followed the long rains (March to April) was quite large, so was the steady rise from June to September when it was dry.

Table 3. Summary of mean Total alkalinity changes for Nairobi Reservoir (Oct. 1989 to Sept. 1990)

	STATION 1	STATION 2	STATION 3
Annual minimum (meq l^{-1})	1.43±0.5	1.68±0.1	1.56±0.1
Annual maximum (meq l^{-1})	4.04±0.1	3.99±0.1	3.98±0.1
Annual mean (meq l^{-1})	2.87±0.7	2.90±0.6	2.82±0.7

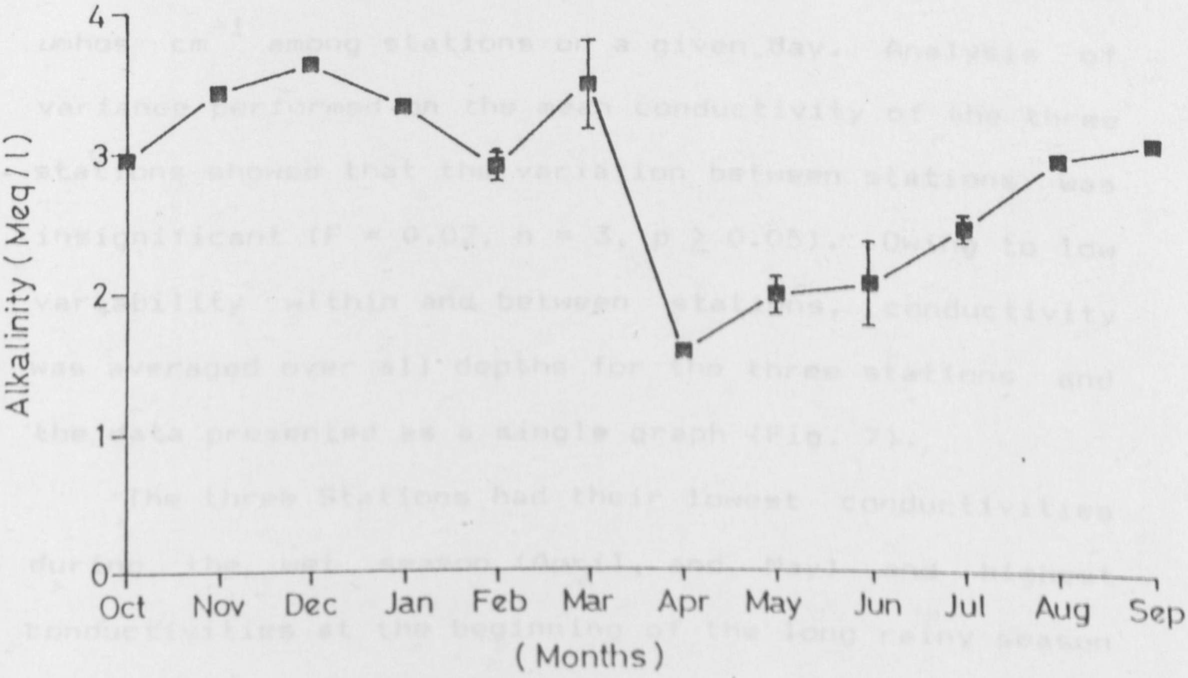


Fig.6: Mean alkalinity for Nairobi reservoir between October 1989 and September 1990.

4.1.4 Conductivity

Conductivity ranges in Nairobi Reservoir were quite small and insignificant with depth (see C.Vs Table 4). There was also little and insignificant horizontal variation in conductivity with a maximum range of 50 umhos cm^{-1} among stations on a given day. Analysis of variance performed on the mean conductivity of the three stations showed that the variation between stations was insignificant ($F = 0.02$, $n = 3$, $p \geq 0.05$). Owing to low variability within and between stations, conductivity was averaged over all depths for the three stations and the data presented as a single graph (Fig. 7).

The three Stations had their lowest conductivities during the wet season (April, and May) and highest conductivities at the beginning of the long rainy season (March), and during the dry seasons (June to September) (compare Figs. 7 & 9). There was nevertheless, an exception to this observation when high conductivities were recorded during the short rains (November to December).

Table 4. Summary of conductivity changes for Stations 1, 2, and 3, from October 1989 to September 1990 (umhos cm^{-1})

	STATION 1 Min.- Max.	STATION 2 Min.-Max	STATION 3 Min.-Max.
Range	237 - 520	262 - 520	248 - 520
C.V (%)	0.2 - 4.7	0.2 - 4.9	0.2 - 4.3
Annual (X)	349.8 ± 85.3	352.1 ± 83.5	353.8 ± 90.2

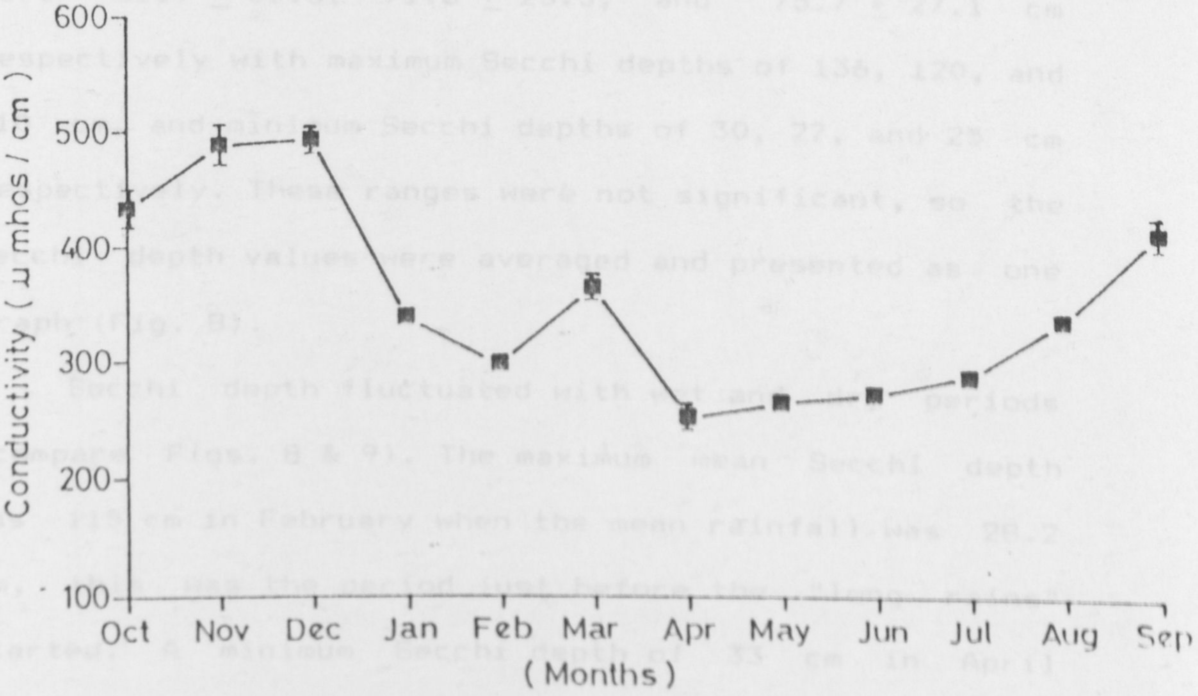


Fig.7: Mean conductivity for Nairobi reservoir between October 1989 and September 1990.

4.1.5 Secchi depth

Horizontal Secchi depth variability was low, with C.Vs ranging between 1.3 and 15.6 % between stations. The annual mean Secchi depths for Stations 1, 2, and 3 were 81.9 ± 30.6, 71.6 ± 25.5, and 75.7 ± 27.1 cm respectively with maximum Secchi depths of 136, 120, and 110 cm, and minimum Secchi depths of 30, 27, and 25 cm respectively. These ranges were not significant, so the Secchi depth values were averaged and presented as one graph (Fig. 8).

Secchi depth fluctuated with wet and dry periods (compare Figs. 8 & 9). The maximum mean Secchi depth was 115 cm in February when the mean rainfall was 28.2 mm, this was the period just before the "long rains" started. A minimum Secchi depth of 33 cm in April coincided with the rainy season when 209.6 mm of rain was recorded. July, August, and September experienced an increase in Secchi depth with diminished rainfall, from an average Secchi depth of 47.7cm to 104.0cm in September (see Fig. 8). The mean Secchi depth over all dates for the three stations was 76.4 ± 28.2 cm.

4.1.6 Rainfall

The rainfall distribution over the year for Dagoretti Corner and Wilson Airport stations was bimodal, with the principal pattern consisting of two rainy and two dry seasons. The months with the highest rainfall were March, April, and May during the long rains, and November and December during the short rains.

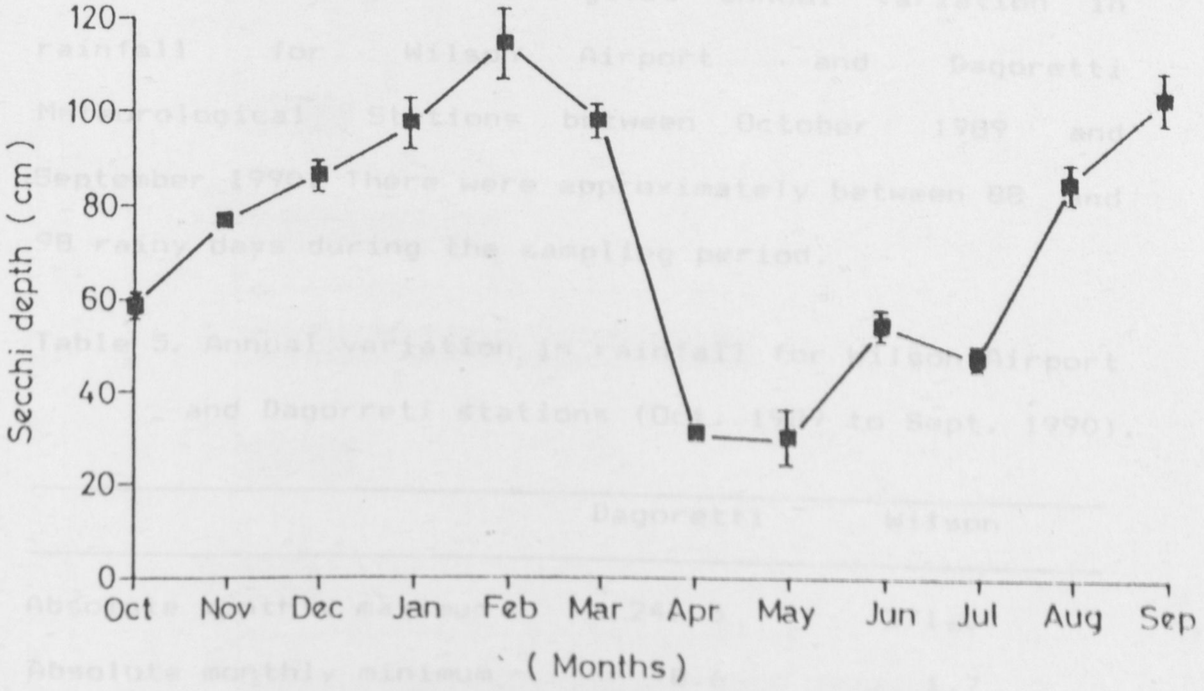


Fig. 8: Mean secchi depth for stations Nairobi reservoir between October 1989 and September 1990.

There was a long dry spell between June and October and a shorter dry spell in January and February (Fig. 9)

Analysis of rainfall totals for 1989-90 show an annual precipitation of about 1072 mm with 55% falling from March to May. Table 5 gives annual variation in rainfall for Wilson Airport and Dagoretti Meteorological Stations between October 1989 and September 1990. There were approximately between 88 and 98 rainy days during the sampling period.

Table 5. Annual variation in rainfall for Wilson Airport and Dagorreti stations (Oct. 1989 to Sept. 1990).

		Dagoretti	Wilson
Absolute monthly maximum		247.3	271.0
Absolute monthly minimum		8.6	1.7
Upper quartile		183.95	139.75
Monthly mean		95.45	83.15
Lower quartile		20.25	8.85
"Long rains" (March-May 1990)	Total	626.4	588.5
"Long rains"	Mean	208.8	196.2
"Short rains" (Nov.-Dec. 1989)	Total	319.5	304.9
"Long rains"	Mean	159.8	152.48
Long dry spell (June-Sept. 1990)	Total	58.8	21.6
Long dry spell	Mean	14.7	5.4
Short dry spell (Jan.-Feb. 1990)	Total	80.3	75.0
Short dry spell	Mean	40.2	37.5
Total number of rainy days		98	88
Annual rainfall		1145.4	997.8

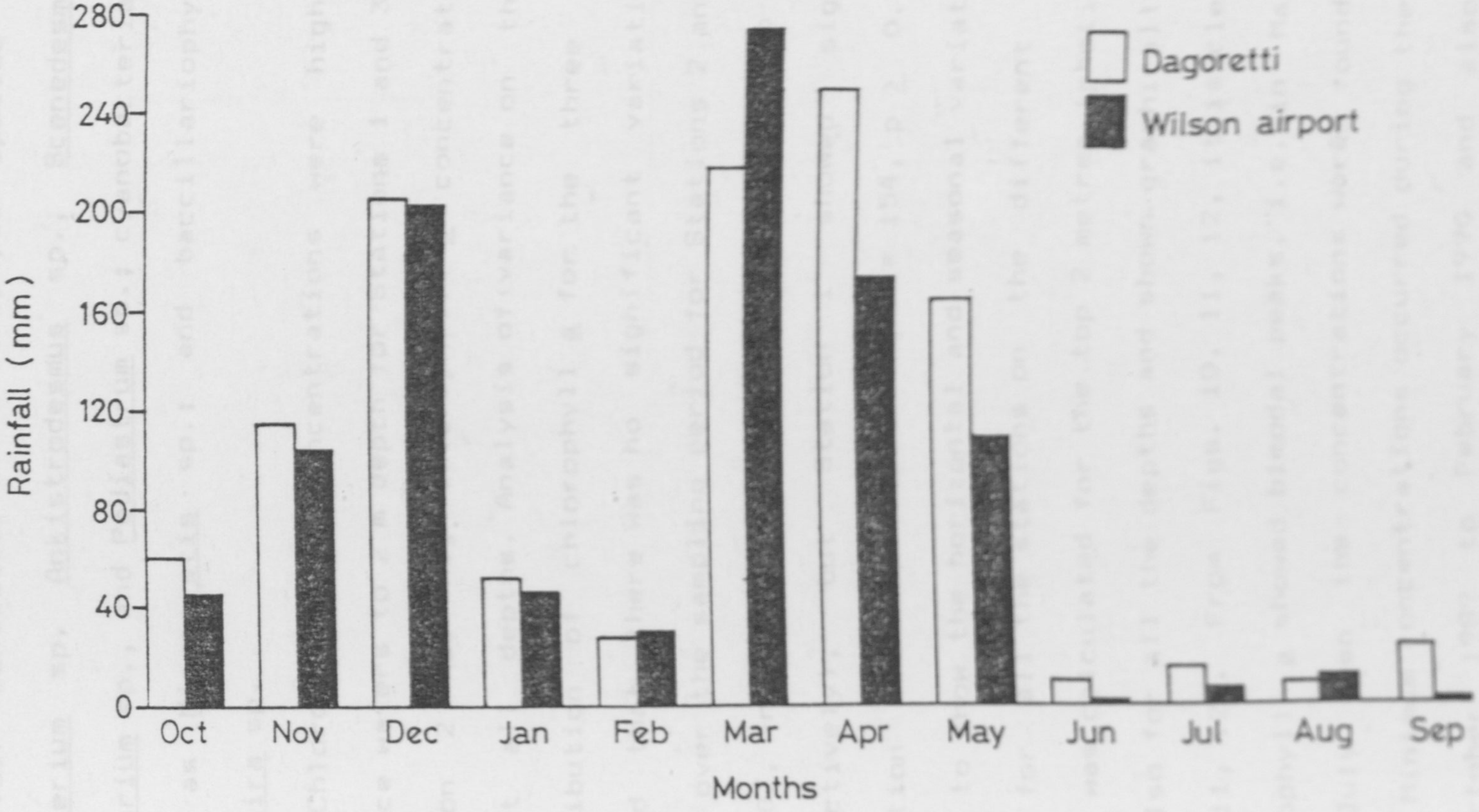


Fig. 9: Monthly rainfall totals for Dagoretti Corner and Wilson Airport between October 1989 and September 1990.

4.1.7 Temporal and spatial distribution of chlorophyll *a*.

In general, the phytoplankton community of Nairobi Reservoir consisted of chlorophyta species such as *Closterium* sp. *Ankistrodesmus* sp., *Scenedesmus* sp. *Cosmarium* sp., and *Pediastrum* sp.; cyanobacteria species such as *Microcystis* sp.; and baccillariophyta e.g. *Melosira* sp.

Chlorophyll *a* concentrations were highest in surface waters to 2 m depth for Stations 1 and 3 whereas Station 2 had high chlorophyll *a* concentrations at almost all depths. Analysis of variance on the depth distribution of chlorophyll *a* for the three stations showed that there was no significant variation with depth over the sampling period for Stations 2 and 3 ($F = 0.07$, $n = 88$ and $F = 1.6$, $n = 110$ at $p \geq 0.05$ respectively), but Station 1 showed significant variation with depth ($F = 4.4$, $n = 154$, $p \geq 0.05$). In order to show the horizontal and seasonal variation, the mean for all the stations on the different sampling dates was calculated for the top 2 metres (photic zone) and also for all the depths and shown graphically (Figs. 10, 11, 12). From Figs. 10, 11, 12, it is clear that chlorophyll *a* showed bimodal peaks, i.e. in March and June/July when the concentrations were found to be high. Minimum concentrations occurred during the months of October 1989 to February 1990 and also during September, 1990. The maximum mean concentrations of

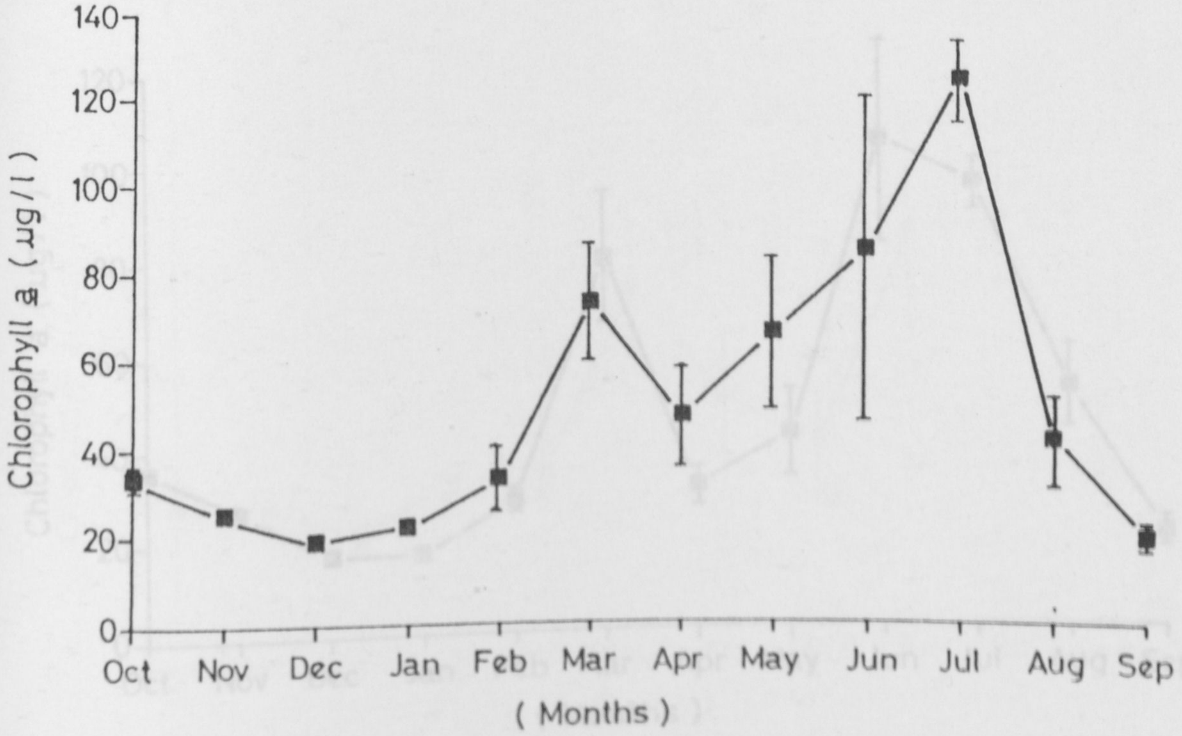


Fig. 10: Mean chlorophyll a concentrations for the photic zone (0-2m) for station 1.

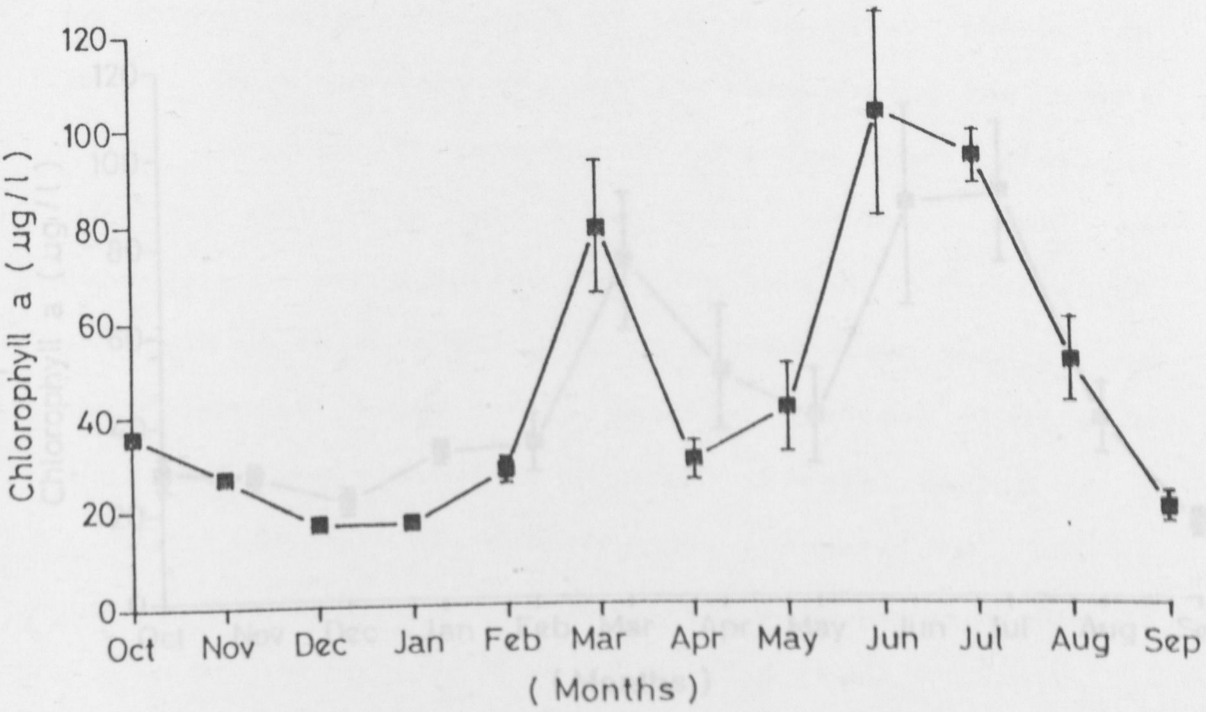


Fig.11: Mean chlorophyll a concentration for the photic zone (0-2m) for station 2.

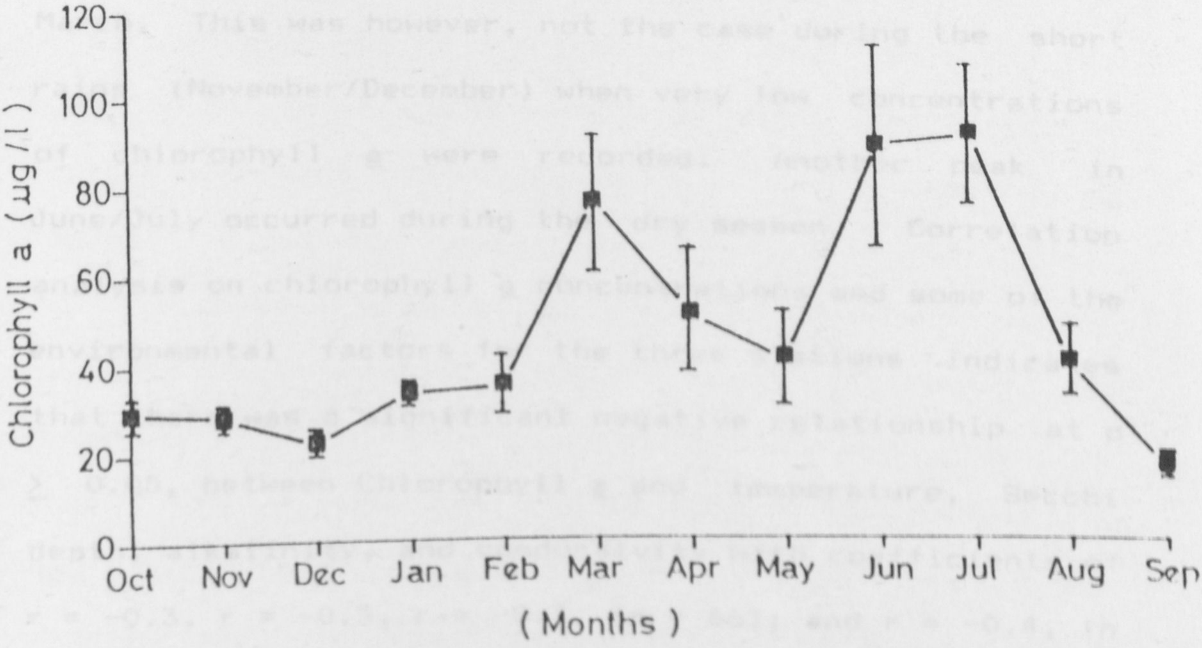


Fig.12: Mean chlorophyll a concentration for the photic zone (0-2m) for station 3.

Chlorophyll a for Stations 1, 2, and 3 on any given day were 104, 123, and 106 ugl^{-1} respectively. An observation of Figs. 10, 11, and 12 when compared with Fig. 9 shows that a peak of chlorophyll a concentration coincided with the onset of the long rainy season in March. This was however, not the case during the short rains (November/December) when very low concentrations of chlorophyll a were recorded. Another peak in June/July occurred during the dry season. Correlation analysis on chlorophyll a concentrations and some of the environmental factors for the three stations indicates that there was a significant negative relationship at $p \geq 0.05$, between Chlorophyll a and temperature, Secchi depth, alkalinity, and conductivity with coefficients of $r = -0.3$, $r = -0.3$, $r = -0.3$, $(n = 66)$; and $r = -0.4$, $(n = 12)$ respectively.

4.2 DISCUSSIONS

Of all dissolved substances in water, oxygen is one of the most important because it influences chemical and biological components of freshwater. Vertical changes in oxygen concentration were typically clinograde for station 1 and 3. This is indicative of oxidative processes in the hypolimnion which use up oxygen resulting in an anaerobic hypolimnion. Station 2 deviated from this pattern on some occasions with subsurface oxygen maxima. Reduced surface oxygen concentrations (Figs. 4g, 4h) may have been due to high surface temperatures. Another pattern (Fig. 4e) describes subsurface minima whereby there was little oxygen in the metalimnetic region. This may be as a result of metalimnetic decomposition. In Nairobi Reservoir, the high level of detritus which consists of both allochthonous and autochthonus material in the hypolimnion and heavy organic breakdown (characterised by the presence of Hydrogen sulphide) appears to deplete the dissolved oxygen levels in the hypolimnion.

The overall temporal variation in dissolved oxygen may be accounted for by the variation in overall air temperature, and other environmental factors such as wind. This is shown by the fact that there seems to have been circulation of water in August (on 6.8.90) when surface dissolved oxygen levels recorded were $\leq$ 2ug O_2l^{-1}. The low oxygen levels may be as a result of mixing of the anoxic bottom waters with oxygenated surface waters. The prevalence of clinograde oxygen curves and anoxic or near anoxic hypolimnion in Nairobi Reservoir are a reliable indication of eutrophy of this Reservoir.

Temperatures showed significant variation with depth and time. Heat absorption at the surface water probably led to a vertical density gradient on several occasions, while on some occasions wind action may have brought about isothermy.

Temporal variation in temperatures was significant. The variation was mainly as a result of weather conditions prevailing in the vicinity of the Reservoir as well as in the catchment area. Atmospheric temperature, wind, cloud cover, and rainfall most likely affected the temperature regime of this Reservoir. Low atmospheric temperatures and persistent overcast clouds during the months of June to August during the sampling period which also agree with the works reported by Thompson & Samson (1967), led to the decreased water temperatures experienced during this period. Similarly, the hot or relatively higher temperatures and clear skies during December to February during this study led to relatively higher mean water temperatures. A correlation analysis performed on data for the monthly mean water temperatures for all stations and the mean monthly rainfall totals for Wilson Airport and Dagorreti corner stations indicated that there was a positive and significant relationship between the water temperature and rainfall totals at $p \geq 0.05$ ($r = 0.4$, $n = 12$).

Total alkalinity and conductivity are dependent on total ions present in a solution and are therefore a rapid estimate of dissolved solids. Analysis of variance performed on the mean values of these two parameters during the sampling period showed that there was no significant variation between the stations ($F = 0.1$, $F = 0.02$), $n = 3$, at $p \geq 0.05$ respectively. Nevertheless, variation was significant for the means of these parameters over the sampling period ($F = 11.6$, $F = 18.2$, $n = 66$, $p \geq 0.05$). This indicates that there was seasonality in these parameters. The small variation horizontally and vertically could be due to the small size of the reservoir and relatively shallow depths respectively, whereas the substantial seasonal variation was due to the effect of dilution and evaporation. Similar results were observed for the Ngong' River (which the Motoine is a tributary of) by Odipo (1987). The rapid increase in these two parameters during the "Short rains" (November and December) and at the beginning of the "Long rains" (early March) may have been due to nutrients brought in from the catchment area. Minimum readings in April were as a result of dilution from the increased inflow of water. The steady increase in conductivity and alkalinity from June to September was possibly due to concentration of the ions in water due to the dry weather conditions during this period.

Analysis of variance on Secchi depth indicated that this physical parameter did not vary much between stations but there were large differences in secchi depth extinction levels with time for the three Stations with ranges of 30 to 136, 27 to 120, and 25 to 109 cms for Stations 1, 2, and 3 respectively. Rain storms likely caused turbulence that stirred up sediments and also brought in allochthonous material from the catchment causing reductions in secchi depth during the months of March to April. An increase during the short rains could be due to the decreased chlorophyll a concentrations during this period.

Chlorophyll a concentrations gave large differences in temporal distributions, these may have been due to changes in the quantity and quality of phytoplankton. The absence of significant vertical distribution at Stations 2 and 3 was due to shallow depths at these Stations. The highest concentrations occurred in June to August. Correlation analysis on the means of Secchi depth, temperature, total alkalinity, conductivity and rain indicates that these factors are negatively related to chlorophyll a concentrations with the first four parameters being significant (r = -0.3, -0.3, -0.3, 0.4) at $p \geq 0.05$, n = 66. Since phytoplankton suffers increasing light limitation from suspended sediments (indicated by low Secchi depth readings), the declining chlorophyll a concentrations during April was due to dilution as well as interference in light penetration.

The results of the physico-chemical and biotic characteristics described above are very similar to those recorded for Lake Naivasha in 1982 & 1984 (Brierley et al. 1987). Lake Naivasha like Nairobi Reservoir exhibited vertical variation in dissolved oxygen levels, temperature and light penetration (measured as Secchi depth). The only exception in the parameters compared is that mean Chlorophyll a levels for Nairobi Reservoir are slightly higher than those recorded for Lake Naivasha.

C H A P T E R 5

RESULTS

5.1 CHARACTERISTICS OF THE ZOOPLANKTON COMMUNITY IN NAIROBI RESERVOIR.

5.1.1 Zooplankton composition and abundance

A list of zooplankton species collected in Nairobi Reservoir is given in Table 6. The community consists mainly of the holoplanktonic Rotifera, Cladocera, Copepoda, and the meroplanktonic larvae of Chaoborus.

Twelve genera of Rotifera were present. Brachionus was represented by six species, which showed seasonal succession. Brachionus angularis Gosse was most abundant in April and May, during the long rains when it attained densities of over 250 individuals per litre. Brachionus dimidiatus Bryce was abundant in October and November 1989 when it reached densities of 250 individuals per litre and also became abundant from July to September 1990 at the close of this study. Brachionus calyciflorus Pallas achieved maximum abundance in May when the population reached a maximum of 500 individuals per litre. Brachionus quadridentatus Hermann was very rare throughout the sampling period, whereas Brachionus caudatus Barrois & Daddy and Brachionus falcatus occurred frequently but at low concentrations. Hexarthra sp., Epiphanes macrourus Barrois & Daddy, Filinia opeliensis Ehrenberg, Asplanchna brightwelli, and Polyarthra sp. occurred in large numbers and exhibited blooms during different months of the year (Table 6), while Lecane luna O.F. Muller, Monostyla sp., Keratella

Table 6: Zooplankton abundance and presence/absence on different sampling dates.

Months/dates	Oct 1989	Nov 1989		Dec 1989		Jan 1990		Feb 1990		Mar 1990		Apr 1990	May 1990		Jun 1990		Jul 1990		Aug 1990		Sept 1990	
Class/species	21	4	18	2	16	11	20	2	16	10	26	16	5	25	17	30	13	24	6	18	9	21
INSECTA																						
Chaoborus sp.**	+	+	+	+	+	+	+	+	+	+	−	+	−	−	+	+	+	+	−	−	−	−
CLADOCERA																						
Daphnia pulex	2+	2+	2+	+	−	2+	2+	+	2+	2+	+	2+	−	−	−	−	−	−	−	+	+	2+
Ephippia	−	−	−	−	−	−	−	−	−	+	−	−	+	−	−	+	−	−	−	−	−	−
Diaphanosoma sp.	−	−	−	−	−	−	−	−	+	+	−	−	+	−	−	+	−	−	−	−	−	−
Ceriodaphnia rigaudi	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	+	+	−	−	−	−
Moina micrura	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	3+	2+	+	4+	4+	3+	+
COPEPODA																						
Thermocyclops Oblongatus	−	+	+	+	+	+	+	+	−	−	−	+	2+	2+	2+	3+	+	3+	2+	2+	2+	2+
Mesocyclops equitorialis	−	−	−	−	+	+	−	−	−	−	−	−	+		−	−	−	−	−	−	−	−
Copepodites	−	−	−	+	+	−	+	+	−	−	−	+	2+	3+	2+	+	4+	4+	2+	2+	3+	2+
Nauplii	−	+	−	+	+	+	+	+	+	−	−	+	4+	4+	2+	3+	4+	4+	4+	4+	4+	3+
ROTIFERA																						
Asplanchna brightwelli	+	−	−	+	−	+	−	−	−	2+	2+	+	−	−	−	−	−	−	+	+	−	+
Branchionus angularis	−	−	−	−	−	−	−	−	−	−	−	3+	4+	+	+	3+	+	+	+	2+	+	2+
B. calyciflorus	+	+	2+	+	2+	−	+	+	+	+	−	+	3+	−	+	+	+	−	2+	2+	2+	2+
B. caudatus	+	+	−	−	−	−	−	−	−	+	−	+	2+	+	+	2+	+	+	+	+	−	−
B. dimidiatus	2+	2+	+	+	+	+	+	+	+	−	−	+	+	−	−	2+	3+	2+	2+	2+	2+	+
B. falcatus	−	−	+	−	+	+	−	−	+	+	−	+	+	+	2+	2+	−	+	+	+	+	+
B. quadridentatus	−	−	+	+	−	−	−	−	−	−	−	−	−	−	+	+	+	+	−	+	−	−

Table 6 (cont.)

Months/dates	Oct 1989	Nov 1989		Dec 1989		Jan 1990		Feb 1990		Mar 1990		Apr 1990	May 1990		Jun 1990		Jul 1990		Aug 1990		Sept 1990	
Class/species	21	4	18	2	16	11	20	2	16	10	26	16	5	25	17	30	13	24	6	18	9	21
ROTIFERA																						
Epiphanes macrourus	+	2+	2+	4+	4+	2+	+	+	+	+	+	–	+	–	+	+	–	–	–	–	+	+
Elosa woralli	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	+	–	–	+	+	+	–
Filinia opoliensis	–	–	–	2+	2+	2+	+	–	–	–	+	+	3+	–	+	+	–	–	–	–	–	–
Hexarthra sp.	+	+	+	2+	2+	+	–	–	–	–	–	3+	+	+	+	+	+	+	2+	2+	+	+
Keratella tropica	+	+	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lecane luna	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+	–	+	+	+	+
Monostyla sp.	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	+	+	+
Platyias quadricornis	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	+	+
Polyarthra sp.	–	–	+	+	+	–	+	+	–	+	–	+	+	+	–	–	–	–	–	–	–	–
Rotaria sp.	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	+	–	–	+	+	+
Trichocerca sp.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–

Key

4+ - predominant (over 500 individuals/L)
3+ - dominant (251 - 500 individuals/L)
2+ - abundant (51 - 250 individuals/L)
+ - present (upto 50 individuals/L)
- . absent
* - did not count

tropica Apstein, *Elosa woralli* Lord, *Platyias quadricornis* Ehrenberg, *Trichocerca* sp. and *Rotaria* sp. were rare and occurred only sporadically. The crustacean taxa included two cyclopoid copepods and five cladocerans but no calanoid copepods. The copepods were represented by *Thermocyclops oblongatus* Sars and *Mesocyclops equitorialis* Kiefer, with the former being consistently abundant. *Mesocyclops* was less abundant and rare during the entire sampling period. Cyclopoid copepod nauplii peaks coincided with peaks of later stages. There was a population explosion of nauplii and copepodites during the relatively cooler months of May to August when nauplii contributed over 50% numerically to the total zooplankton population.

Cladocera were represented by 4 species, namely *Ceriodaphnia rigaudi* Richard, *Moina micrura* Kurz, *Diaphanosoma excisum* Sars, and *Daphnia pulex* Sars (Table 6). Cladoceran species exhibited seasonal succession with dominant species varying from one sampling session to the next. *Daphnia* was abundant in October to February, disappearing with ephippia production in March. The existence of diapause here may help elucidate the reasons for its decline and subsequent disappearance between May and early August. *Daphnia* was observed in the samples at the at the close of this study. *Moina* on the other hand became abundant in June to early August when temperatures were at their lowest. It seems likely that these two species do not occur at the same time. It is possible that the driving force here is temperature. The other species were rare and less abundant.

5.1.2 Spatial variation in zooplankton densities

Zooplankton in Nairobi Reservoir exhibited both vertical and horizontal variation in abundance. The numbers varied inversely with depth in a statistically significant way for all the stations. ANOVA performed on the data per station indicated that there was a highly significant variation of total zooplankton with depth ((F = 17.8, n = 7, p = 0.00, (Station 1); F = 7.7, n = 4, p = 0.00, (Station 2); F = 9.3, n = 5, p = 0.00 (Station 3)). Regression analysis showed that abundance is linearly related to depth for all taxa and juvenile stages of copepods (copepodites and nauplius) and this situation is quite stable through time. Maximum concentrations of zooplankton were found between the surface and two metre depths for most species (Fig. 13, 14, 15). The only zooplankter that did not follow this distribution pattern was <u>Chaoborus</u> larvae which were concentrated in bottom waters and were rarely found in surface to 2 m depth levels during the day.

ANOVA carried out on the means of these three stations over the sampling period showed that there was no significant difference between stations for the number of adult copepods, copepodites, nauplius, cladocerans, and rotifers (F = 1.5, F = 1.3, F = 1.5, F

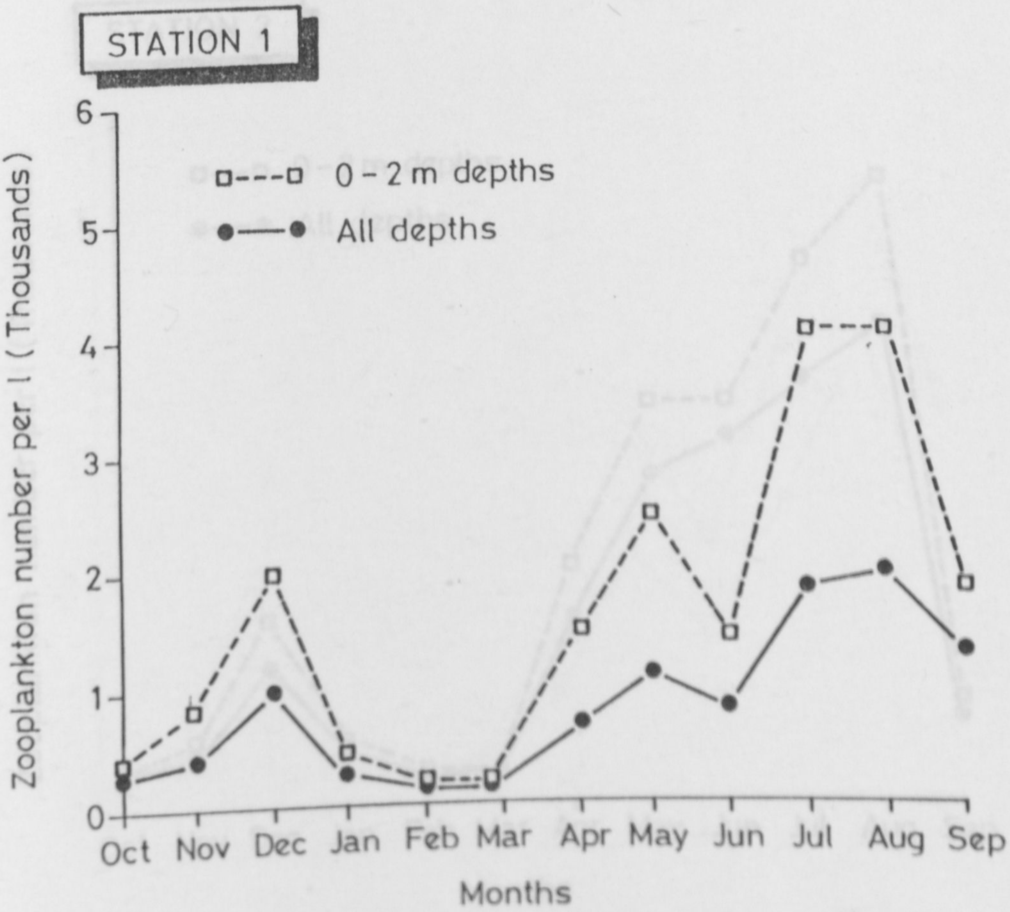


Fig.13: Spatial variation of zooplankton densities in station 1 between October 1989 and September 1990.

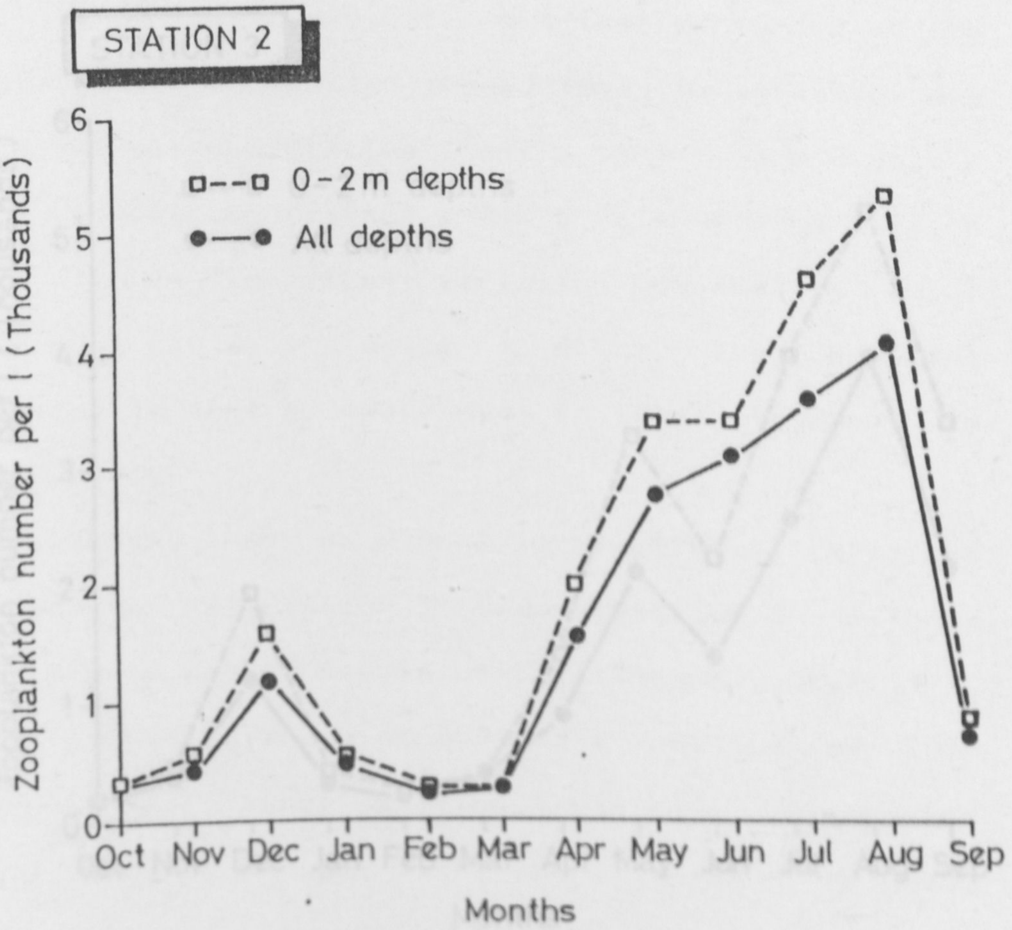


Fig. 14: Spatial variation of zooplankton densities in station 2 between October 1989 and September 1990.

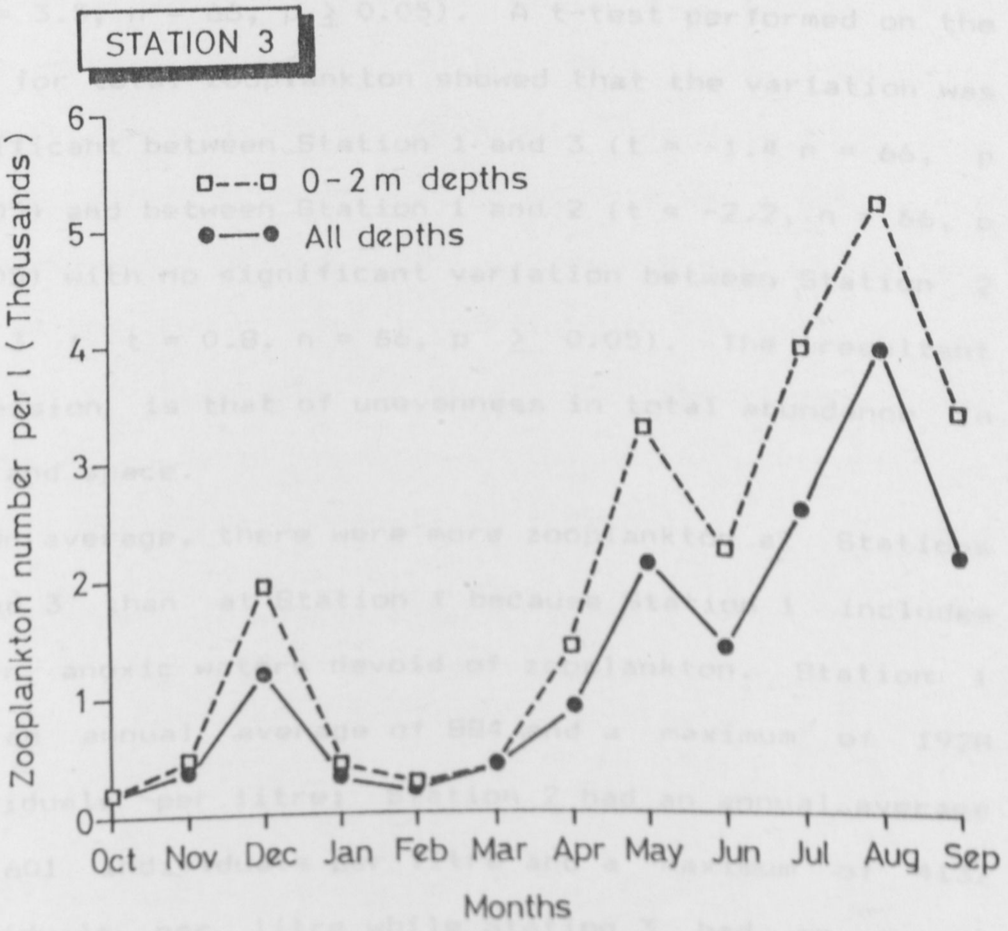


Fig. 15: **Spatial variation of zooplankton densities in station 3 between October 1989 and September 1990.**

$= 2.55$, $F = 2.6$, $n = 66$, $p \geq 0.05$) respectively. However, there was a significant difference between the mean total number of zooplankton at the three stations ($F = 3.5$, $n = 66$, $p \geq 0.05$). A t-test performed on the data for total zooplankton showed that the variation was significant between Station 1 and 3 ($t = -1.4$ $n = 66$, $p \geq 0.05$) and between Station 1 and 2 ($t = -2.2$, $n = 66$, $p \geq 0.05$) with no significant variation between Station 2 and 3 ($t = 0.8$, $n = 66$, $p \geq 0.05$). The resultant impression is that of unevenness in total abundance in time and space.

On average, there were more zooplankton at Stations 2 and 3 than at Station 1 because Station 1 includes deeper anoxic waters devoid of zooplankton. Station 1 had an annual average of 884 and a maximum of 1928 individuals per litre; Station 2 had an annual average of 1601 individuals per litre and a maximum of 4132 individuals per litre while Station 3 had an annual average of 1397 individuals per litre and an annual maximum of 4063 individuals per litre.

5.1.3 Temporal variation in zooplankton densities

There was considerable seasonal variation in the abundance of zooplankton at all the three stations over time. These variations were largely due to changing abundances of Cyclopoidae juvenile stages and Rotifera (Table 6). Cladocera occurred in relatively smaller numbers at the beginning of the study period but blooms of <u>Moina micrura</u> between June and August brought the Cladocera densities up. This increase in density did not show proportional increases in percent populations (Table 7) since there was an extremely high production of nauplii and copepodites which led to the high percentage of copepods during this time. Copepods reached their highest percent proportions in July when the percentage recorded was 88.6% this was a period of high copepodite and nauplii production. Rotifera achieved maximum percent proportions in December due to blooms of <u>Epiphanes</u> <u>Filinia</u> and <u>Hexarthra</u> whereas Cladocera achieved maximum relative proportions in December due to high densities of <u>Daphnia</u>.

Table 7. Percent number of zooplankton

Month	Copepoda	Cladocera	Rotifera
October	0.0	57.8	42.2
November	0.2	75.6	24.2
December	1.6	96.6	1.5
January	3.6	41.2	55.5
February	1.6	55.4	43.0
March	0.0	72.8	27.8
April	3.2	78.7	18.1
May	51.3	47.9	0.8
June	62.5	22.8	14.7
July	88.6	8.58	2.9
August	61.3	10.9	27.8
September	61.7	26.1	12.2

There was a trimodal distribution of abundance with time in the total zooplankton population. The population showed a broad peak in July to August dominated by cyclopoid nauplii, and in December owing to high rotifer densities. Another peak in May was dominated by copepoda.

Low zooplankton densities were recorded during the months of January, February, and March. The number of organisms reduced from a mean of 359 individuals per litre at the beginning of the rainy season (late February) dropped to a minimum of 168 individuals per litre in March and there was a steady increase when the dry season set in. Developmental stages of cyclopoid copepods showed similar patterns over time for all the three stations. This shows that there was some kind of succession in the development of copepods since peaks of nauplii coincided with peaks of copepodites and mature females carrying sacs of eggs.

The temporal variation in the densities of Copepoda, Cladocera, and Rotifera exhibit a generalized seasonal cycle in their abundance and distribution patterns during the year. These observations suggest that, like other tropical African water bodies for example Lake George (Burgis 1971 & 1974), Lake Naivasha (Mavuti 1983 & 1990) and Lake Chad (Robinson & Robinson 1971 and Carmouze et al. 1983) where sampling was of a long duration, the zooplankton communities show seasonality.

5.2 DISCUSSION

5.2.1 Zooplankton and environmental interactions in Nairobi Reservoir

Water quality changed due to evaporation or dilution. Many correlations between water quality parameters and zooplankton species or group abundance were detected.

The 18 - 24°C annual water temperature range is an obvious source of environmental variability. Occurrence of seasonal variation in mean water temperature seems to have had an impact on zooplankton abundance and composition. Regression analyses indicated that cladocerans were affected by temperature. It is probable that the dominance of Daphnia pulex during the months of October, November, December and Moina micrura during August were related to the absolute annual variation in reservoir water temperature. Although no experimental evidence of temperature dependence is available for the Nairobi Reservoir zooplankton community, the dependence of the growth rate on temperature has been noted in the genus Moina (Hutchinson 1967). Similarly experimental data by Gras & Saint Jean (1976, 1978) cited from Carmouze *et al.* (1983), suggest that the optimum temperature for embryonic development for Daphnia is higher than that for Moina. This observation might explain the above results whereby the presence and abundance of these two species seemed to alternate with the warm and relatively cooler months. Green (1965) suggested that the production of copepod nauplii increased during the cold months. Results from this research are in conformity with this observation as the population of nauplii increased tremendously during the months of June to September when temperatures were relatively low.

Direct influence of conductivity and total alkalinity changes was detected with regression analyses with cladocerans. Similar results have been reported elsewhere between some species and conductivity and alkalinity (e.g. Belay & Wodajo 1984; Ferguson 1982). The presence of high concentrations of *Brachionus dimidiatus* during the months of November (182 individuals per litre) and early July (307 individuals per litre) might be due to the relatively higher conductivity and alkalinity levels during this period. This rotifer is said to be adapted in saline or highly alkaline waters (Vareschi & vareschi 1984, Wodajo & Belay 1984).

Food, particularly for the herbivores was probably not limiting to the Nairobi Reservoir zooplankton community. Spearman Rank correlation coefficient for total zooplankton, adult copepods, copepodites, nauplii, Cladocera, and Rotifera with chlorophyll *a* concentration were 0.2, 0.4, 0.4, 0.4, -0.2, and -0.31 respectively and were significant at $p \geq 0.05$, n = 66. Although Tait *et al.* (1984) gave indications of the usefulness of this kind of relationships, there are inherent difficulties in accepting these correlations outright since zooplankton subsist on other food materials like detritus and suspended organic matter.

In the present study, changes in phytoplankton quality and quantity caused changes in zooplankton communities of the Reservoir. Observation of results from Bilings Reservoir in Brazil showed that changes in phytoplankton quality and quantity caused changes in zooplankton communities (Sendacz 1984).

In Nairobi Reservoir, measurements of algal biomass through chlorophyll a determinations showed seasonal variations. There was an increase in chlorophyll a concentrations between 16th December and 10th March 1990, this increase in chlorophyll a levels coincided with generally reduced numbers of zooplankton. During the same study period, there was a brief but significant increase in the chlorophyll a concentrations from late May to early June, a drop in late June, a rise to a peak in early July, followed by a steady drop to a minimum in September (at the close of this study) (Fig. 16). During this same period, zooplankton densities droped briefly in late may, then increased to a maximum on 18th of August, before a sudden and steep drop in September (at the close of this study). The positive influence of chlorophyll a (late June to early July) simply reflects the increase in availability of algal food particles to the herbivores. The reduction in phytoplankton biomass in August is possibly due to the depletion of plant

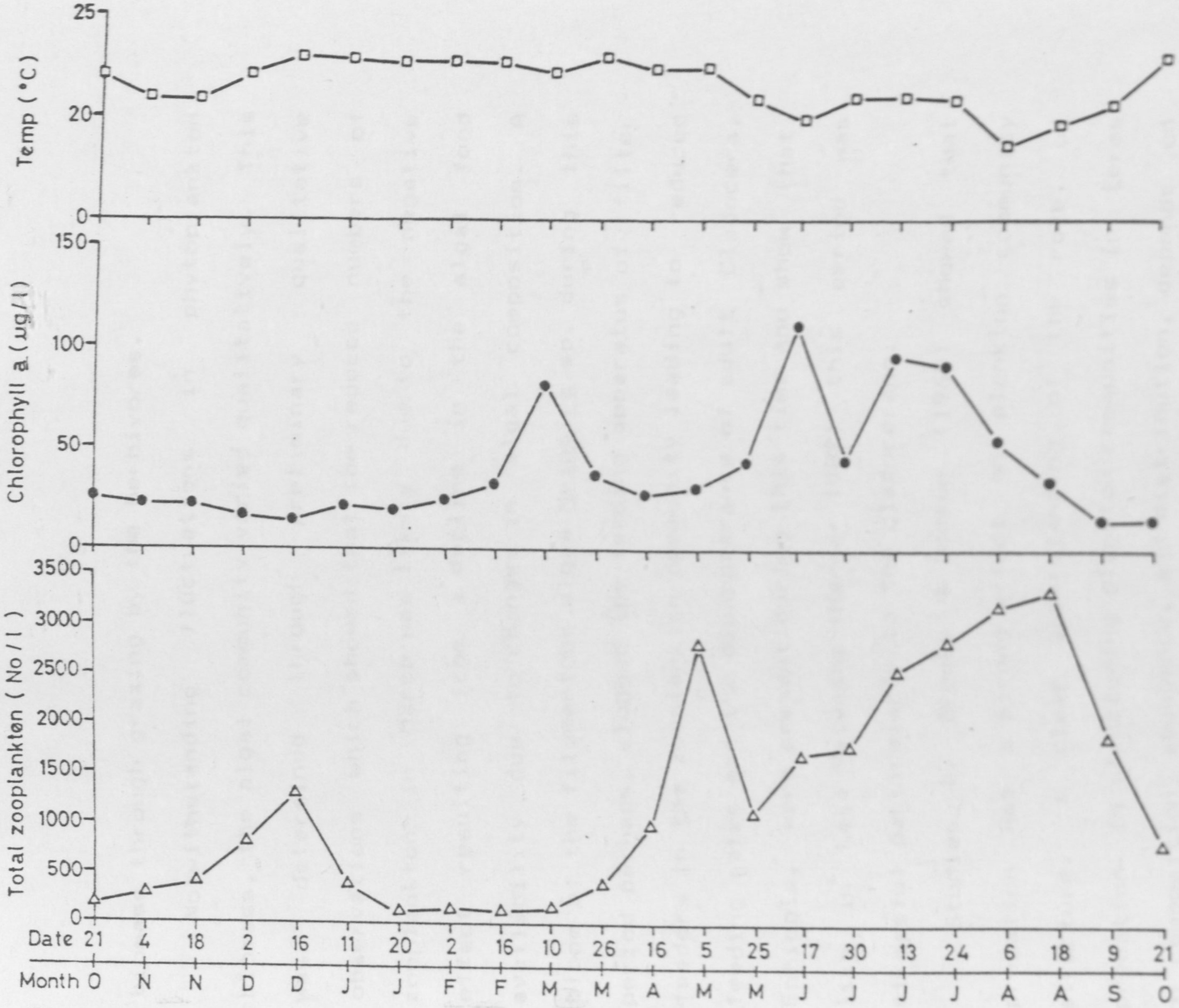


Fig. 16. Temporal variation of mean total zooplankton, mean chlorophyll a concentrations and mean temperature *in Nairobi reservoir between October 1989 and Semptember 1990*

biomass through grazing by the herbivores.

Notwithstanding fluctuations in phytoplankton biomass, the algal community varied qualitatively. This was determined through preliminary qualitative observations which showed that the reduced numbers of zooplankton in March was likely due to the negative effect resulting from a decline in the algal food availability due to changes in algal composition. A bloom of the filamentous algae <u>Melosira</u> sp. during this period perhaps, clogged the feeding apparatus of filter feeders in the zooplankton community leading to reduced feeding rates and the disappearance of adult Cladocera. Ephippia, were present during this time and show that, like in Lake Naivasha (Harper 1987) this period was stressful particularly to the cladocerans.

Studies by Brooks & Dodson (1965) showed that predation has a strong effect on plankton community structure. A clear understanding of the role of predation in structuring plankton communities in terms of composition, abundance, and distribution, depends on an accurate evaluation of the effects of predation on the population dynamics of their prey (Taylor 1980). Predators of fresh water zooplankton can be divided into two broad categories, invertebrate predators and vertebrate predators.

A predominant invertebrate predator for the Nairobi Reservoir community was <u>Asplanchna brightwelli</u>. A bloom of the carnivore <u>A. brightwelli</u> during April, coincided with a depressed population of rotifers. This observation, suggests that predation by this carnivore reduced the zooplankton density. The presence of this rotifer and its association with the adventitious rotifer Polyarthra, was probably due to selective predation. The density of smaller rotifers, such as B. angularis, which were depressed during the bloom of Asplanchna was similar to the case reported by Hurlbert et al. in 1972.

Vertebrate predators in this Reservoir consisted mainly of fish fry, juveniles, and adult fish. A survey of literature on the feeding habits of fish that are resident in this Reservoir indicates that there is normally a change in diet with the size of fish. In the genera Clarias, fry and juveniles < 3 cm are known to feed on zooplankton (Clay 1977), thus the abundance of fry and juveniles of this fish are likely to reduce zooplankton densities. Zooplankton are said to be an important food source of Oreochromis spp. (Kalk 1979, Mavuti & Litterick 1991). In Lake Malawi, Kalk (1979) showed that the abundance of fry, and juveniles inreased predation by Oreochromis so that high densities of zooplankton could not be maintained. This is likely to be the case for the Nairobi Reservoir zooplankton community since there was a marked fall in the number of zooplankton during the period of January/February when fish fry and juveniles were most abundant. In Lake Victoria, zooplankton are also an important food item for both adults and juveniles of the pelagic fish sp. Haplochromis (Mavuti & Litterick 1991). It is probable that the Haplochromis species in Nairobi Reservoir is zooplanktivorus. Since there has been no work done on the feeding habits of fish from this Reservoir, it would be interesting for this to be done particularly if the fishery resources of this Reservoir are to be developed and exploited adequately.

Rainfall is one of the factors controlling annual river discharge. In this Reservoir, floods occured on average in April (Fig. 9). The massive rain water amounts brought into the Reservoir may have also brought about dilution and flushing out of some zooplankton in the reservoir leading to the relatively low total zooplankton populations experienced during the Month of March. The massive arrival of very muddy rain water in March/April during the long rains led to low transparencies, dilution and flushing out of zooplankton.

Transparency is linked to the quantity of suspended food and silt particles. The vulnerability of zooplankton to visual predation rises with increased transparencies (Kerfoot 1980). In this study, the increase in water clarity (reflected in the increased Secchi depth readings) reflects a possible decrease in the amount of suspended inorganic and organic food particles. Consequently, the decrease in zooplankton density as Secchi depth rose in January/February can be attributed to predation effects by both vertebrate and invertebrate predators while the relatively low counts in March/April is due to interference with feeding.

Water depth was one of the most important factors causing zooplankton differences among stations. One can attempt to relate the differences between lower volumetric densities observed at Station 1, relative to 2 and 3 as resulting from the increased depth of Station 1 (5.75 m greater than station 2, and 3.75 m greater than station 3). A possible explanation is that by averaging the deeper anoxic depths at Station 1 where zooplankton were absent it was inevitable to get lower mean values for this Station. Carmouze _et al_. (1983) reported that an increase in depth corresponded with a decrease in the numbers of zooplankton per unit surface area. This authors observation in effect also mean that there is a decrease in the volumetric concentration with depth.

Vertical variation in dissolved oxygen may have limited most zooplankton species to the upper 2 to 3 m of the water column. This is because most zooplankton are aerobic and cannot survive in anoxic conditions. The presence of _Chaoborus_ larvae in the lower water layers is due to the fact that they are adapted to a benthic existence and hence to low oxygen concentrations.

Changes in the total zooplankton densities that occurred seasonally were associated mainly with thermal and water regime in and around the Reservoir and in the catchment area. Both factors seemed to affect characteristics of the water chemistry in the reservoir which, in turn caused temporal changes in species composition, relative proportions of the three major groups and the resulting absolute abundances of zooplankton. The paucity of rotifers during the month of July may have been due to low algal biomass and low water temperatures, whereas high rotifer densities in November and December were probably related to higher water temperatures.

From the foregoing and the graphical presentation (Fig.16) above, the patterns of abundance can be explained as follows; the different parameters investigated appeared to govern the level of zooplankton abundance, distribution patterns, species composition and succession of the different zooplankters in Nairobi Reservoir. Lack of significant variation between stations in most of the parameters investigated may be due to the small size of the Reservoir. Among the factors cited, temperature and dissolved Oxygen profiles, water regime and the related transparency level, predation, food availability, conductivity and total alkalinity seem to influence the zooplankton assemblage of the Reservoir. This is because there existed succession of the different zooplankton species and taxa with varying intensities of each one of these parameters during the sampling period. Thus, the distribution patterns and abundance or scarcity of the different zooplankton species or taxa were dependent on the most critical factor at the different times. The graphical presentation above (Fig. 16) and Table 6 indicates that these parameters did affect the zooplankton population composition and annual distribution patterns after some time. That is, the effect was not that immediate or direct.

CHAPTER 6

GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

6.1 Comparison with other tropical and temperate lakes and reservoirs

The marked contrast between temperate and Tropical regions in annual variability in insolation intensity and temperature leads naturally to the hypothesis that, the magnitude of variability in these regions differ greatly. However, since there is documented evidence to show that there is a great deal of taxanomic overlap in the community structure and composition of zooplankton species of temperate and tropical areas and also within given latitudes (e.g. within the Tropics), it is important to attempt to identify factors controlling variability, or factors that bring about similarities between zooplankton communities from temperate regions and those from tropical regions or between different tropical lakes and reservoirs.

In recognition of both temperate and tropical zone findings, several authors, such as Hutchinson (1967) and Welch (1952), have made remarks on the latitudinal distribution, composition, abundance and seasonality of zooplankton in tropical versus temperate lakes. These authors concluded that spatial and temporal variation in both temperate and tropical lakes occur but with varying intensities due to differences in environmental characteristics such as grazing, competition, predation and abiotic conditions. This has been summarised by

Nilssen (1984). Similar conditions have been found to affect the Nairobi Reservoir community.

In temperate lakes, results on the horizontal distribution of zooplankton show that there is lack of uniformity in the water with the prime determinants of this pattern being wind action, inflow influence, depth of water, and predation pressure (Welch 1952). On the other hand vertical distribution of zooplankton varies seasonally as a consequence of seasonal changes in weather conditions and resultant stratification or overturns.

In general, in temperate lands, zooplankton become abundant during or immediately after autumn and spring overturns, then decline during winter and summer. During the winter, temperate lakes may be dominated by cold water forms, such as Polyarthra dolichoptera Idelson and Filinia terminalis Plate. Such lakes will in summer have an abundance of Moina micrura which are adapted to conditions of higher water temperatures (Hutchinson 1967).

In the tropics detailed zooplankton work has been done on a number of lakes including Lake Chad (Carmouze et al. 1983), Lake George (Burgis 1971, 1974), Lake Lanao (Lewis 1979), Lake Naivasha (Mavuti 1983, Harper 1987) and several man-made lakes in South America particularly Brazil (Arcifa 1984) and Africa (Obeng 1966). These authors works gave species lists, and distribution patterns in these water bodies. Although the knowledge of zooplankton species composition, diversity, and population dynamics in most tropical lakes lagged behind that in temperate ones, some work has nonetheless been done. The extensive literature emanating from investigations carried out on the major lakes of East Africa has been reviewed by Mavuti (1983).

Results from the African continent where species composition and diversity have been carried out indicate that the zooplankton consists of three major groups: Copepoda, Cladocera, and Rotifera. The Copepoda consists of cyclopoids, and calanoids. This is the case for lakes Naivasha (Mavuti 1983, Mavuti & Litterick 1981), Turkana (Ferguson 1982), Victoria (Mavuti & Litterick 1991), Chad (Robinson & Robinson 1971 and Carmouze et al. 1983) and George (Burgis 1971 & 1974) among other lakes sampled. A common feature for these lakes is the occurence of the following cladoceran genera: Bosmina, Daphnia, Diaphanosoma, Ceriodaphnia, and Moina. Other genera that have been recorded though in small numbers are Macrothrix, and chydorus. Compared to some well studied African lakes, (cf. Carmouze et al. 1983, Table 9), the Nairobi Reservoir zooplankton community seems typical for the microcrustacea. Like other African lakes, this reservoir has the simultaneous presence of Thermocyclops and Mesocyclops (Beadle 1974). The major difference is that other works found calanoids which were absent from the Nairobi assemblage. These investigators found a higher diversity of

Table 8. Composition of communities of dominant or abundant planktonic microcrustacea from well-sampled African lakes

Species	1	2	3	4	5	6	7
Diaphanosoma excisum Sars	+	−	+	+	+	+	+
Daphnia barbata Weltner	+	+	+	−	−	+	+
Daphnia longispina O.F.M.	+	−	−	−	−	+	−
Daphnia lumholtzi Sars	+	−	−	−	+	−	−
Ceriodaphnia cornuta Sars	+	+	+	−	−	−	+
Moina (dubia) micrura Kurz	+	+	+	+	+	+	−
Bosmina longirostris O.F. M.	+	−	−	−	+	+	−
Tropodiaptomus incognitus Dussart & Gras	+	−	−	−	−	−	−
Thermocyclops neglectus Sars	+	−	−	−	−	−	−
Thermocyclops incisus sp. nov.	+	−	−	−	−	−	−
Thermocyclops tchadensis sp. nov.	+	−	−	−	−	+	−
Mesocyclops leuckartii Claus	+	+	+	+	+	−	+
Thermocyclops hyalinus Rehberg	−	+	−	−	−	−	+
Tropodiaptomus kraepelini Pope & Mrazek	−	−	+	−	−	−	−
Simocephalus vetulus King	−	−	−	+	−	−	−
Thermocyclops (schurmanni) oblongatus Sars	−	−	−	+	−	−	−
Daphnia laevis Sars	−	−	−	+	+	−	−
Ceriodaphnia dubia Richard	−	−	−	−	+	−	−
Daphnia pulex Sars	−	−	−	+	−	+	−
Moina brachiata Jurine	−	−	−	−	−	−	+
Tropodiaptomus banforanus Kf.	−	−	−	+	−	−	+

Key to Table 8

1: L. Chad (Chad)
2: L. George (Uganda)
3: L. Chilwa (Malawi)
4: L. Naivasha (kenya)
Kf. Kiefer
O.F.M. O.F. Muller
5: L. McIlwaine (Zimbabwe)
6: L. Midmar (South Africa)
7: L. Turkana (Kenya).
\+ present
\- absent

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microcrustacean species than was found in this reservoir probably because of the larger size of water bodies involved in the other studies.

Data from well sampled lakes within the tropics indicate that Rotifera contribute the highest number of species i. e. they are normally very diverse. The genera Brachionus is normally very diverse and common. This has been the case for this reservoir.

Contrary to the common belief of many temperate limnologists, seasonal fluctuations in zooplankton abundance, and the succession of different species, are characteristic of tropical lakes (Beadle 1974, Lewis 1979). Of those tropical lakes where detailed and long-term investigations have been carried out, such as Lake Chad, Lake George, Lake Lanao, Lake Naivasha and Lake Valencia, only Lake George lacks notable seasonal variation. Lake George may be anomalous owing to its shallow depth, and regional diurnal wind patterns that stir the whole water column, and maintenance of a stable water level (cf. Beadle 1974). Nairobi Reservoir, like most other tropical lakes, shows seasonal variation in both composition and abundance. The pattern of seasonal species succession was similar to that described for lakes Barombo Mbo, Mboandong, Kotto, and Soden in Cameroon (Green 1972b). As in Lake Naivasha (Harper 1987), Daphnia pulex population peaks seem to follow hatching from resting eggs, because a population outbreak of this species in Nairobi Reservoir occurred in the apparent absence of adults, and population declines were associated with a high production of ephippia.

Fernando and Kanduru (1984) looked at the latitudinal distribution of cladocera on the Indian subcontinent and found that very few cladocera were present in the equatorial region (<12^{o}N). There was a particular paucity of Daphnia spp., which are well represented at latitudes greater than 23^{o}N in the tropics. The zone south of 22^{o}N was also characterised by a complete absence of Polyphemidae and Leptodoridae. The Nairobi Reservoir assemblage is in conformity with these findings since there were relatively few cladocera with one species of Daphnia. The complete absence of Polyphemidae and Leptodoridae also confirm the findings of these authors.

Research carried out on Lake Lanao, a large tropical lake in the Philippines (Lewis 1979), revealed pronounced spatial variation in zooplankton. Work in Nairobi Reservoir did not indicate a pronounced horizontal variation in zooplankton composition. However, there were differences in the total zooplankton at the three stations with Station 3 having a higher annual mean number of zooplankton than stations 2 and 1.

The horizontal spatial variation of Nairobi Reservoir is similar to that of two Kenyan lakes; Lake Turkana and Lake Naivasha. Like Lake Turkana where Ferguson (1982) ascribed horizontal variation of zooplankton abundance to inflows of nutrient-rich water from the River Omo, and Lake Naivasha, where the Gilgil estuary supported a total zooplankton density greater than the open water density in the Main Lake (Harper 1987), the Nairobi Reservoir had a high zooplankton density at Station 3 which was located at the entrance of the Motoine River into this reservoir.

Vertical distribution of zooplankton in Nairobi Reservoir was similar to that reported for Lake Naivasha (Harper 1987), where most species achieved population maxima in the upper three metres of the water column. The only animal that showed a different vertical distribution pattern was Chaoborus larvae which concentrated in the lower water column. These results however, contrasted with those of Worthington and Ricardo (1936) which found that the daytime density maxima of Cyclops and Moina were below 10 m.

Other studies on tropical African lakes, such as L. George (Burgis 1974), L. Malawi (Kalk 1979), (L. Naivasha (Mavuti 1983), and L. Chad (Carmouze et al.

1983), indicate that the major determinant of faunal succession in these lakes is the alternating wet and dry seasons. Relationships between the rainfall pattern and the different zooplankton taxa indicates that rainfall is a factor driving seasonal succession in Nairobi Reservoir.

6.2 Conclusions

Hydrobiological observations on Nairobi Reservoir have shown that a number of physical, chemical, and biological changes take place both spatially and seasonally.

The large influx of water during the rainy seasons lowed phytoplankton biomass, reduced water temperatures, caused increased turbidity, and also increased alkalinity, and conductivity values. After the rains, the water cleared, phytoplankton blooms were observed, and there was a decline in alkalinity and conductivity. The high chlorophyll a levels, clinograde oxygen curves, low Secchi depth readings, and anoxic hypolimnion are a reliable indication of the eutrophy of this Reservoir.

The present investigation has established distinct seasonality in temporal variation of zooplankton abundance in Nairobi Reservoir. Nairobi Reservoir has a zooplankton species composition similar to that found in other tropical lakes and reservoirs. Rotifers were the most diverse group, while Cladocera and Copepoda were less diverse. Among the Rotifera, it was observed that the genus Brachionus was very diverse in species representation. Three of the commonest tropical cladocera species namely: Diaphanosoma excisum, Moina micrura, and Ceriodaphnia rigaudi were present. The presence of only one species of the genus Daphnia (a species said to be rare within lowland tropics) was also noted. Observations of the copepod community indicated that there was a simultaneous presence of the genera Thermocyclops and Mesocyclops. Clearly, the taxa composition and succession was influenced by the seasonal rainfall and other environmental factors.

Although juveniles of Clarias sp., Oreochromis spp. and the juveniles and adults of Haplochromis sp. (fishes resident in this Reservoir) feed on zooplankton, the effect of predation by these fishes may be small especially since they feed on various food items as they grow. The large population of cladocerans and copepods during the cool and dry months of June to August, appear to be due to an almost completely unutilised source of food. It is also possible that the zooplankton numbers build up when fish migrate to the Typha swamps to spawn because they are no longer feeding on zooplankton from the open water, but on other food items as they are adults now. Observations made during this study period suggest that changes in zooplankton composition and abundance were dependent on fluctuations in environmental factors and that the high abundance of zooplankton throughout the year, provides a sure food resource for the Reservoirs fishery. This study though preliminary provides a strong baseline for the Reservoirs water quality and fisheries research in the future.

6.3 Recommendations

1. Since this study has given basic taxonomic information as well as details of temporal and spatial distributions as affected by different environmental factors, more specialized investigations of individual species versus the various varying environmental factors is recommended.
2. Results from the survey of limnological parameters which show that this Reservoir is eutrophied through nutrients brought in from the catchment area and the surrounding residential estates, have further applications in providing a scientific rationale for the control of water quality for purposes of avoiding problems such as those resulting from pollution. Continued monitoring of these parameters is recommended for the proper utilization of this water bodys resources such as recreation, and quality water for use at home and in industry.
3. Continued monitoring of the zooplankton community is recommended as it will provide comparative data for future studies and to a certain extent provide a basis for testing the validity of conclusions derived from earlier works, for example: zooplankton species composition as indicators of pollution.

4. It has been shown elsewhere (Green 1976, Vareschi & Vareschi 1984, Mavuti 1983 and Harper 1987), that changes are taking place in some African lakes in response to human activities, so there is need for more researches on African lakes before major changes occur in these lakes. It is therefore recommended here that, for purposes of literature on the ecology of tropical zooplankton, samples of zooplankton be taken from time to time.
5. Since there is no data on the ecological significance of zooplankton to fish species resident in this Reservoir, i recommend an undertaking of this nature so that any new introductions of fish in this Reservoir will be productive as they will be based on scientifically proven resource management.
6. Data on the zooplankton densities available from this study indicate that zooplankton are abundant because they are under utilised. Data from fishermen on this Reservoir also indicate that the catch is quite low. From these two observations, it is clear that the introduction of a zooplanktivore could easily improve the fishery resources of this Reservoir. I recommend the introduction of the clupeoid fish Limnothrissa miodon which has shown success in Lake Kariba (a tropical manmade lake with characteristics similar to Nairobi Reservoir).

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The survey maps of Kenya for Ngong and Nairobi (Sheet 148/3, 148/4).

APPENDICES

APPENDIX 1. Temporal variation (mean ± S.D) Chlorophyll *a* concentration ($\mu g.l^{-1}$) for Nairobi Reservoir between Oct. 1989 and Sept. 1990.

Date	Mean ± S.D
21.10.89	27 ± 1.8
4.11.89	24 ± 5.2
18.11.89	24 ± 5.7
2.12.89	16 ± 5.7
16.12.89	15 ± 4.9
11.1.90	23 ± 12.7
20.1.90	21 ± 6.9
2.2.90	26 ± 11.3
16.2.90	32 ± 2.5
10.3.90	83 ± 16.6
26.3.90	40 ± 6.8
16.4.90	30 ± 10.7
5.5.90	34 ± 3.0
25.5.90	45 ± 7.7
17.6.90	111 ± 10.6
30.6.90	47 ± 6.9
13.7.90	98 ± 18.2
24.7.90	91 ± 23.6
6.8.90	53 ± 8.2
18.8.90	35 ± 4.8
9.9.90	16 ± 2.4
21.9.90	17 ± 2.6

APPENDIX 2. Temporal variation (mean ± S.D.) total zooplankton (No. ind. per litre) for Nairobi Reservoir between Oct. 1989 to Sept. 1990.

Date	Mean ± S.D
21.10.89	226 ± 73
4.11.89	348 ± 89
18.11.89	457 ± 35
2.12.89	873 ± 100
16.12.89	1374 ± 172
11.1.90	482 ± 147
20.1.90	142 ± 45
2.2.90	154 ± 81
16.2.90	140 ± 89
10.3.90	168 ± 101
26.3.90	445 ± 370
16.4.90	1022 ± 439
5.5.90	2811 ± 245
25.5.90	1164 ± 647
17.6.90	1719 ± 1121
30.6.90	1821 ± 1256
13.7.90	2558 ± 752
24.7.90	2806 ± 1026
6.8.90	3271 ± 1163
18.8.90	3392 ± 1292
9.9.90	1965 ± 941
21.9.90	866 ± 620

APPENDIX 3. Correlation matrix for the relationship between zooplankton and environmental factors

	adult cops	Copd.	Naup.	Rot.	Clad.	Total zoop.
Chl a	0.23	0.48	0.51	-0.24	0.00	0.19
	(0.60)	(0.00)	(0.00)	(0.05)	(0.99)	(0.12)
Temp.	-0.41	-0.34	-0.55	0.24	-0.43	-0.46
	(0.00)	(0.01)	(0.00)	(0.06)	(0.00)	(0.00)
S.D.	-0.31	-0.31	-0.33	-0.31	0.05	-0.35
	(0.01)	(0.01)	(0.01)	(0.01)	(0.70)	(0.0)
D.O.	-0.30	0.07	0.01	-0.22	-0.20	-0.18
	(0.10)	(0.56)	(0.93)	(0.07)	(0.11)	(0.15)
Cond.	-0.35	-0.28	-0.34	0.06	-0.07	-0.25
	(0.00)	(0.02)	(0.01)	(0.62)	(0.57)	(0.05)
Alk.	-0.36	-0.30	-0.35	-0.03	0.07	-0.26
	(0.00)	(0.01)	(0.00)	(0.80)	(0.54)	(0.04)

Coefficient (significance level) , n = 66.

Key to abbreviations used in the table.

Adult cop. (Adult copepods), Copd. (copepodites), Naup. (Nauplii), Rot. (Rotifera), Clad. (Cladocera), Total zoop. (Total zooplankton), Chl a (Chlorophyll a), Temp. (Temperature), S. D. (Secchi depth), D.O. (Dissolved oxygen), Cond. (Conductivity), Alk. (Total alkalinity).

APPENDIX 4. Correlation matrix for the relationship between the different zooplankton taxa/group.

	adult cops.	Copd.	Naup.	Rot.	Clad.	Total zoop.
Adult cops.	1.00	0.50	0.57	0.13	0.32	0.59
	(0.00)	(0.00)	(0.00)	(0.30)	(0.01)	(0.00)
Copd.	0.50	1.00	0.83	-0.04	0.04	0.57
	(0.00)	(0.00)	(0.00)	(0.73)	(0.72)	(0.00)
Naup.	0.57	0.83	1.00	-0.00	0.35	0.77
	(0.00)	(0.00)	(0.00)	(0.99)	(0.00)	(0.00)
Rot.	0.13	-0.04	-0.00	1.00	0.08	0.47
	(0.30)	(0.73)	(0.99)	(0.00)	(0.53)	(0.0)
Clad.	0.33	0.44	0.35	0.08	1.00	0.58
	(0.01)	(0.72)	(0.00)	(0.53)	(0.00)	(0.00)
Total zoop.	0.59	0.57	0.77	0.47	0.58	1.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Coefficient (significance level), n = 66.

Key to abbreviations used in the table.

Adult cop. (Adult copepods), Copd. (copepodites), Naup. (Nauplii), Rot. (Rotifera), Clad. (Cladocera), Total zoop. (Total zooplankton).

APPENDIX 5. Correlation matrix for the relationship between different environmental factors.

	Temp.	S.D	D.O.	Chl a	Cond.	Alk.
Temp	1.00	0.24	0.35	-0.30	0.13	0.32
	(0.00)	(0.06)	(0.00)	(0.01)	(0.30)	(0.01)
S.D	0.24	1.00	0.06	-0.33	0.34	0.68
	(0.06)	(0.00)	(0.61)	(0.01)	(0.05)	(0.00)
D.O.	0.35	0.06	1.00	0.16	0.11	0.20
	(0.00)	(0.61)	(0.00)	(0.21)	(0.36)	(0.10)
chl a	-0.30	-0.33	0.16	1.00	-0.38	-0.33
	(0.01)	(0.01)	(0.21)	(0.00)	(0.00)	(0.01)
Cond.	0.13	0.34	0.12	-0.38	1.00	0.74
	(0.31)	(0.01)	(0.36)	(0.00)	(0.00)	(0.00)
Alk.	0.32	0.68	0.20	0.33	0.74	1.00
	(0.01)	(0.00)	(0.10)	(0.01)	(0.00)	(0.00)

Coefficient (significance level), n = 66.

Key to abbreviations used in the table.

Chl a (Chlorophyll a), Temp. (Temperature), S. D. (Secchi depth), D.O. (Dissolved oxygen), Cond. (Conductivity), Alk. (Total alkalinity).

APPENDIX 6. Temporal variation (mean ± S.D.) for chemical and biotic factors (top 2 m) affecting zooplankton populations in Nairobi Reservoir between Oct. 1989 and Sept. 1990.

Date	chl. _a_ (ug. l^{-1})	Temp. (^{o}C)	D.O. (mg.l^{-1})	T.A. (meq l^{-1})	cond. (umhos cm^{-1})
21.10.89	32.9±5.3	22.9±0.9	9.6±3.6	3.0±0.0	433.3±28.9
4.11.89	26.6±2.6	21.8±0.4	4.9±1.5	3.4±0.0	510.0±17.3
18.11.89	26.6±5.2	21.7±0.4	3.6±1.8	3.5±0.0	466.7±28.9
2.12.89	20.7±5.6	23.3±0.3	5.2±1.1	3.6±0.0	493.3±23.3
16.12.89	18.0±4.6	23.8±0.2	5.8±1.8	3.7±0.1	493.3±23.1
11.1.90	25.1±9.0	23.2±0.5	4.3±0.6	3.3±0.0	343.1±5.3
20.1.90	23.3±7.5	23.1±0.4	4.3±0.8	3.3±0.1	331.7±14.4
2.2.90	32.0±7.9	23.7±0.4	5.9±1.3	2.8±0.2	296.1±6.7
16.2.90	31.7±12.6	23.6±0.3	8.0±1.6	3.0±0.1	270.4±14.3
10.3.90	102.7±17.4	22.8±0.3	6.0±1.7	4.0±0.0	382.3±2.2
26.3.90	49.4±6.2	23.5±0.7	5.4±1.3	3.0±0.1	345.3±10.2
16.4.90	42.5±22.6	22.9±1.1	3.4±2.5	1.6±0.1	250.1±14.0
5.5.90	44.0±18.8	23.1±0.5	2.4±2.3	2.2±0.1	263.7±2.1
25.5.90	66.3±31.9	21.6±0.5	5.3±3.2	1.7±0.0	261.9±8.1
17.6.90	140.4±8.0	20.3±0.6	5.3±1.6	1.6±0.1	271.7±0.8
30.6.90	37.1±20.2	21.9±0.8	1.9±0.9	2.5±0.7	268.1±3.0
13.7.90	119.5±24.9	22.2±1.1	7.4±4.0	2.3±0.2	279.3±9.1
24.7.90	116.1±37.1	21.7±0.7	6.0±2.5	2.6±0.0	290.9±3.9
6.8.90	58.8±16.4	18.9±0.4	1.4±0.4	2.9±0.1	325.0±6.4
18.8.90	30.2±10.5	20.5±1.0	7.0±3.0	3.0±0.1	342.6±3.4
9.9.90	15.8±6.1	21.6±0.8	2.6±1.2	3.1±0.2	384.0±3.9
21.9.90	21.6±3.4	23.0± 0.4	4.7±2.0	3.1±0.1	438.0±2.0

APPENDIX 7. Temporal variation (mean ± S.D.) for the zooplankton population (top 2 m) in Nairobi Reservoir between Oct. 1989 and Sept. 1990.

Date	Cladocera	Rotifera	Copepoda	Total zooplankton
21.10.89	185±137	139±67	0±0	302±131
4.11.89	123±95	366±248	2±4	498±242
18.11.89	178±225	545±430	0±0	648±673
2.12.89	54±57	1371±517	19±15	1214±587
16.12.89	0±0	2189±889	26±21	1765±1184
11.1.90	121±147	444±367	97±94	694±451
20.1.90	91±121	63±44	27±23	181±102
2.2.90	56±45	85±62	61±51	209±115
16.2.90	74±39	98±111	12±6	183±127
10.3.90	166±91	6±8	0±0	172±89
26.3.90	1±2	434±284	0±0	435±283
16.4.90	233±200	1318±886	65±44	1615±1106
5.5.90	50±26	2799±2337	1464±1114	4313±2743
25.5.90	0±0	93±79	1651±587	1744±1177
17.6.90	26±8	238±46	1612±728	1976±819
30.6.90	809±993	939±726	841±63	2589±1915
13.7.90	189±285	445±790	3299±607	3933±2205
24.7.90	32±28	161±160	430±94	4499±2219
6.8.90	1418±1264	472±291	2942±908	4834±1691
18.8.90	1275±1058	374±301	3379±714	4928±1459
9.9.90	411±335	856±663	1456±1371	2723±1722
21.9.90	142±110	352±349	464±343	958±675