EFFECTS OF SOME ABIOTIC AND BIOTIC FACTORS ON THE ZOOPLANKTON COMMUNITY IN LAKE BARINGO, KENYA

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DECLARATION AND RECOMMENDATION

DECLARATION

This thesis is my original work and has not been submitted or presented for examination in any institution.

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RECOMMENDATION

This thesis has been submitted for examination with our approval as University Supervisors.

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ABSTRACT

Lake Baringo is a turbid lake that lies in a closed drainage basin of the Kenyan East African Rift Valley. The lake's water quality has deteriorated in the recent past mainly due to sedimentation from its catchment arising from poor agricultural practices, deforestion and overgrazing. Its fishery has also declined since the 1980s and frequent lake closures to fishing activities have not alleviated the problem. This shows that there may be other critical ecological and environmental factors affecting the ecosystem. To understand problems facing the lake, there is need for well-coordinated and comprehensive ecological investigations considering the complexity of the ecosystem. Zooplankton is important in energy transfer from primary producers and constitute a significant component of the diets of the juveniles and some adults of many fish species. The objective of the present study was to determine the effect of some physical, chemical and biological factors on the spatial and temporal distribution, abundance and biomass of zooplankton in Lake Baringo. Stratified random design was used to allow for statistical comparison between zooplankton abundance and biomass at different stations and months with environmental factors using Analysis of Variance (ANOVA). The relatively stable environmental factors across the sampling stations in the lake were attributed to its small size, shallowness and the daily mixing by wind action. A total of 39 species of zooplankton belonging to Rotifera, Cladocera and Copepoda groups were recorded. The results indicate that distribution, diversity, abundance and biomass of zooplankton were influenced by environmental factors especially depth, conductivity and turbidity. Diel vertical distribution of zooplankton was the reverse of what is reported from clear lakes with organisms congregating to the surface during the day and descending to the bottom at night. Investigations into the diet of three main fish species in the lake showed that *Oreochromis niloticus baringoensis* mostly depended on algae, *Clarias gariepinus* depended on fish while *Protopterus aethiopicus* thrives on molluscs as their dominant food. The growth performance of the once dominant endemic fish, *O. niloticus baringoensis* could be affected by the high turbidity, which reduces primary production. Moreover, reduced clarity hampers the feeding success of this visual feeding fish and has decreased macrophytes to near extinction. There is urgent need for rehabilitation of Lake Baringo and the study recommend afforestation and reduction of livestock numbers in the catchment as some of the ways of reducing soil erosion and sediment input in the lake. The results of the study may be used as an important tool for the detection of stability and trophic levels of the ecosystem and to provide data for models on maximal resource production of the lake.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
APHA	American Public Health Association
CAP	Community Analysis Package
CCA	Canonical Correspondence Analysis
DW	Dry weight
HSD	Honest Significant Difference
NCST	National Council of Science and Technology
NTU	Nephelometric Turbidity Units
PCA	Principal Component Analysis
RAE	Rehabilitation of Arid Environment Trust
SE	Standard Error
WRMA	Water Resources Management Authority

DEFINITION OF TERMS

Abiotic: The non-living, including physical and chemical factors, components of ecosystem.

Anthropogenic: Of or relating to human beings.

Biomass: The total weight of living organisms in a given area or volume.

Biotic: The living components of the ecosystem.

Decomposition: Process by which tissues of dead organisms break down to more simplistic forms of matter or organic material which may be used again by primary producers.

Ecology: Scientific study of interrelationships among and between organisms and between these and all aspects, living and non living, of their environment.

Ecosystem: Discrete unit that consists of living and non living parts interacting to form a stable system.

Ecosystem restoration: To reinstate an entire community of organisms to as near its natural condition as possible.

Endorheic Lake: Lake with no outlet and loss of water is only by evaporation.

Environment: Complete range of external conditions, physical and biological, in which an organism lives.

Fauna: All the animal species in an ecosystem.

Fecundity: The reproductive capacity of an organism i.e the number of eggs that develop in a female over a specified period.

Flora: All the plant species that make up the vegetation of an ecosystem.

Food chain: The transfer of energy from the primary producers through a series of organisms that eats and is eaten, assuming that each organism feeds on only one type of organism.

Food web: A biotic community of organisms where there are several interrelated food chains.

Habitat: The living place of an organism or community, characterized by its physical and biotic properties.

Ions: An atom or group of atoms that is positively or negatively charged as a result of either gaining or losing one or more electrons.

Macrophytes: Higher plants that grow in ecosystems whose formation has been dominated by water and whose processes and characteristics are largely controlled by water.

Nutrient: An element or simple compound that is required for the nourishment of an organism, providing a source of energy or structural components.

Organism: An individual animal, plant or microorganism that is capable of reproduction, growth and maintenance.

pH: The logarithm of the reciprocal of hydrogen-ion concentration in gram atoms per liter; provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution.

Predation: Interraction between species where one organism (the predator) obtains energy by killing and consuming another organism (the prey).

Phytoplankton: The plant plankton and primary producers of aquatic ecosystems.

Trophic level: The number of energy transfers an organism is from the original solar energy entering the food chain.

Turbidity: A measure of the degree to which the water loses its transparency due to the presence of suspended particulates.

Zooplankton: Microscopic invertebrate animals found habitually in the water column and too small or weak as swimmers to dictate their horizontal distribution by their own activities. The horizontal distribution of zooplankton is therefore dictated mainly by the motions and mixing processes of the water body.

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Introduction

Freshwater lake biota are affected by the physical habitat as well as the interactions among individual members in the ecosystems' food web. The physical habitat of a lake mainly depends on external factors such as climatic regime and lake morphometry. Some of these characteristics have been used to classify freshwater lakes (Hwang *et al*., 2010). Additionally, organisms such as fish, benthic invertebrate communities, phytoplankton, macrophytes, and microcrustaceans have been used to distinguish different types of freshwater lakes (Holt & Miller, 2011). Zooplankton, which are microscopic invertebrate animals that swim or drift in water, are important in the functioning of aquatic ecosystems. They comprise major herbivores and important predators in aquatic food webs of lakes (Stella *et al*., 2007; Richardson, 2008). These organisms are important in the structuring and dynamics of aquatic environments through their fundamental role of energy transfer in aquatic food webs (Dejen *et al.,* 2004; Cadjo *et al*., 2007; Imoobe & Akoma, 2008) and nutrient cycling (Makode & Charjan, 2010). Due to these connections, zooplankton are involved in a wide range of ecological processes and mechanisms that structure biotic and abiotic lentic environments.

Zooplankton distribution, composition and abundance in freshwaters are influenced by various factors. Their species richness and abundance have been found to be influenced by lake area and primary productivity (Dodson *et al*., 2000; Hoffmann & Dodson, 2005), water quality (Cottenie *et al*., 2001), lake depth (Hessen *et al*., 2006), nutrients (Lafrancois *et al*., 2004), predation and competition (Isari *et al*., 2007; Larson *et al*., 2009). Abiotic and biotic processes are known to give rise to highly variable and heterogeneous distribution of zooplankton in most lakes resulting in considerable patchiness. Heterogeneous zooplankton distributions in lakes have been attributed to their swimming behavior and also to passive transportation caused by wind-driven water currents (Rinke *et al*., 2009).

Whereas the ecological role of zooplankton in the plankton of clear water lakes is fairly well understood, little is known about their ecological dynamics in turbid lakes. The latter pause challenges to plankton in them in terms of light penetration due to high concentration of suspended solids thereby impacting negatively on primary production, predation and vertical distribution of the organisms therein.

Lake Baringo is a turbid, shallow, warm-water lake in the eastern arm of the Rift Valley in Kenya which has received little attention with respect to zooplankton studies. The lake became a Ramsar site on the 10th January 2002. It is a critical habitat and refuge for more than 500 species of birds and fauna, some of the migratory aquatic bird species being significant regionally and globally. Studies by Kiplagat (1989), Patterson and Kiplagat (1995), Busienei (2003) and Oduor *et al*. (2003) raised pertinent issues regarding conductivity, turbidity, primary production and fish diets in the lake that have exposed gaps in the area of zooplankton ecology. It was therefore imperative to carry out a study of the effects of abiotic and biotic factors on zooplankton community of the lake.

1.2 Statement of the problem

Lake Baringo is an important water body nationally and internationally. It is a source of fish and water, which is used for drinking, irrigation and transport. Because of its aesthetic value, the lake provides revenue through tourism and recreation. The lake is a repository of a large fauna and flora diversity. These services are, however, not fully realized due to the negative effects of anthropogenic activities such as overgrazing and deforestation in the catchment. These have led to major problems in the lake including siltation and deteriorating water quality, which have caused changes in the physico-chemical parameters and plankton communities. Siltation and sedimentation has resulted in increased turbidity which has reduced water transparency thus primary production. Reduced water clarity also hampers feeding success of visual feeding fish. Consequently, these have led to a decline in fish catches which explains the fact that despite periodic closures, no improvement in fish catches have been realized indicating that there are other factors besides fishing which contribute to the low catches. It was therefore, necessary to investigate how the physical, chemical and biological factors interact to influence the ecology of the lake. As a major component of energy transfer in aquatic ecosystem, this study aimed to investigate the effect of some abiotic and biotic factors on the distribution, composition, abundance and biomass of zooplankton community in Lake Baringo.

1.3 Objectives

1.3.1 General objective:

To determine the effect of physico-chemical factors and chlorophyll *a* on the spatial and temporal distribution, composition, abundance and biomass of zooplankton in Lake Baringo.

1.3.2 Specific objectives:

1. To determine the temporal and spatial changes in physico-chemical factors and Chlorophyll *a* in the lake.
2. To determine the temporal and spatial changes in the composition**,** diversity, abundance and biomass of zooplankton in the lake.
3. To relate the diversity, abundance and biomass of zooplankton to physico-chemical parameters and phytoplankton biomass.
4. To determine the diel vertical distribution of zooplankton in the lake.
5. To determine the diet of *Protopterus aethiopicus, Clarias gariepinus* and *Oreochromis niloticus baringoensis* in the lake.

1.4 Hypotheses

1. There are no significant temporal and spatial variations in physico-chemical factors and Chlorophyll *a* in Lake Baringo.
2. There are no significant temporal and spatial variations in the composition**,** diversity, abundance and biomass of zooplankton in Lake Baringo.
3. There are no significant relationships between diversity, abundance and biomass of zooplankton to physico-chemical parameters and phytoplankton biomass in Lake Baringo.
4. There are no significant differences in diel vertical distribution of zooplankton between depths in Lake Baringo.
5. There are no significant differences in the diet of three major fish species, *Protopterus aethiopicus, Clarias gariepinus* and *Oreochromis niloticus,* in Lake Baringo.

1.5 Justification

Siltation and sedimentation in Lake Baringo has resulted in increased turbidity which has reduced water transparency thus primary production. Reduced water clarity also hampers feeding success of visual feeding fish. Consequently, these have led to a decline in fish catches which explains the fact that despite periodic closures, no improvement in fish catches have been realized indicating that there are other factors besides fishing which contribute to the low catches. In order to mitigate the problems of deteriorating water quality and declining fish catches in Lake Baringo, there was need to carry out a well-coordinated and comprehensive ecological study with the view of identifying the underlying causes. Such a study will give meaningful information regarding the relationship between variations in physico-chemical and biological factors including zooplankton community. It will also elucidate the role played by zooplankton in water quality and fish production in the lake. As a major component of the energy transfer system in Lake Baringo food web, zooplankton may be used as an important tool for the detection of the ecological status of the lake. Studies on zooplankton in Lake Baringo have been limited, with conclusions often being drawn from a few samples collected with different methods at different stations mostly during expeditions. There was need for long term studies, both for zooplankton and physico-chemical parameters, at specific sites to ensure meaningful conclusions are made on the lake's ecological changes. The results of the study will *inter alia* contribute to new knowledge on zooplankton ecology in relation to the aquatic environment and fisheries. Furthermore, it will provide useful information to the various stakeholders in formulation of sustainable management practices.

1.6 The scope and limitations of the study

This study was carried out in Lake Baringo a turbid, shallow, warm-water endorheic lake. Sampling was done at five stratified randomly selected stations for a duration of 24 months. For the purpose of this study the physico-chemical and biological parameters studied were limited to temperature, turbidity, depth, pH, dissolved oxygen, conductivity, nutrients, chlorophyll *a* concentration and fish as they relate to zooplankton community. A limitation of this study was that zooplankton samples were collected monthly while most zooplankton processes have a shorter time frame. This made it difficult to interpret the results conclusively. The study did not extend to secondary production and energy flow within the food web.

1.7 Thesis format

The thesis has seven chapters with each following a scientific paper style except chapter 1 (General Introduction), chapter 2 (Literature review) and chapter 7 (General Conclusions and Recommendations). The thesis format is as listed below.

Chapter 1

The chapter briefly presents freshwater communities and their importance in the ecosystem and describes the interactions of the different components with emphasis on zooplankton. The chapter also contains the various sections of the thesis including statement of the problem, objectives, hypotheses, justification and the scope and limitations.

Chapter 2

Chapter 2 gives a review of previous studies on the ecology of zooplankton in different regions of the world. In particular, it describes in detail the impact of various abiotic and biotic components of the aquatic ecosystems on the dynamics of zooplankton in the tropical shallow and deep water lakes. The chapter also presents the physical, climatic and biological characteristics of the study area.

Chapter 3

In this chapter, the physico-chemical factors together with chlorophyll *a* of Lake Baringo are presented. Characteristics of the stations are described. The relationships between the environmental factors and similarity of sampling stations are also provided in the chapter.

Chapter 4

The chapter describe**s** the spatial and temporal structure of zooplankton in Lake Baringo. It presents a checklist of zooplankton taxa recorded during the study followed by their distribution, composition, diversity, abundance and biomass at different sampling sites and months. Lastly, the relationships between physico-chemical factors, chlorophyll *a* and zooplankton are discussed.

Chapter 5

In this chapter the results of the vertical distribution of zooplankters diurnally over 24-hour period in Lake Baringo is presented. The chapter also discusses variation in phys**i**co-chemical parameters such as temperature, conductivity, pH and dissolved oxygen over the

same period. This is the first time such a study was carried out in the lake and the data will be valuable in lake management.

Chapter 6

The chapter delves into the food and feeding habits of the three most abundant fish species in the lake with the intent of determining the importance of zooplankton as their food items. The fish species studied are *Protopterus aethiopicus*, *Clarias gariepinus* and *Oreochromis niloticus baringoensis*.

Chapter 7

This chapter provides the conclusions of the study. It is in this chapter that recommendations for future research, conservation and strategies for lake management are presented.

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CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Formation of Rift Valley and Lake Baringo

Two major theories attempt to explain the formation of the Rift Valley. The first theory is based on forces of tension while the second is based on forces of compression. However, both theories postulate that up-warping on both sides of the rift valley occurred (Bunnet, 2003). The Great Rift Valley is the longest such system in the world. It starts from the Red Sea and runs southwards traversing Ethiopia, Kenya, Tanzania and Mozambique extending for over 5,600 km. The Rift Valley system in Kenya extends about 900 km from the Turkana depression in the north to the Magadi-Natron depression in the south. It contains a chain of freshwater and saline lakes of different origin, morphometric configuration and productivity status. Its drainage system covers a total area of 126,910 km^2 and lies within 4º30' N to 2º00' S and 35º 30' E to 37º E. The major lakes comprise Turkana, Baringo, Bogoria, Nakuru, Elementaita, Naivasha and Magadi while some of the minor ones include Kamnarok, Kwenia, Kabongo, Kijirtit, Solai, Ol Bollossat and Logipi.

The variability in topography, geology and climatic conditions as well as the volcanic landscape in which the lakes occur impart to each lake its unique physical, chemical and biological characteristics. Endorheic nature coupled with high temperatures and high evaporation rates render most of the major lakes salty. It is thought that most of the current lakes are remains of larger lakes that occupied the floor of the valley during the last pluvial period (Beadle, 1932). The Tugen Hills, an uplifted fault block of volcanic and metamorphic rocks, lies west of Lake Baringo at an altitude of 300-1000 m above sea level while Laikipia escarpment lies to the east. The lowlands around the lake have complex soils with various textures and drainage conditions, which have developed alluvial deposits. Some of the soils are saline. A large area is characterized by shallow stony soils with rock outcrops and larva boulders (Onyando *et al.,* 2005).

Lake Baringo waters remain fresh despite lack of surface outlet, shallow depth and high net evaporation that characterizes the rift floor. Recent hydrogeological evidence confirms the original suggestion that some lake water is lost by underground seepage through the fractured lake floor (Onyando *et al*., 2005). Dunkley *et al*. (1993) estimated that this outflow could exceed 108 m^3 $year^{-1}$. Lake Baringo has five islands, with the biggest being the volcanic Kokwa which is the remnant of a small volcano that belongs petrogenetically to the Korosi

volcano that erupted during the Middle Pleistocene, approximately 2.6 million years ago (Cl'ement *et al*., 2003).

The Lake Baringo area is essentially a rangeland and apart from the scattered isolated pockets of subsistence agriculture and small irrigation farming around Marigat, the major socio-economic activities centre on livestock and bee keeping. There is, however, growing pressure on this lake which is linked to global climatic changes and human population growth.

2.2 Physico-chemical factors

Several physical and chemical factors, including light, temperature, turbidity and nutrients among others, influence faunal biomass in lakes (Makode & Charjan, 2010; Warnock & Rasmussen, 2013). The general pattern of seasonal events in temperate lakes is determined by changes in the incident solar radiation and consequent changes in water temperature with the build up and breakdown of thermal stratification. In tropical lakes, however, physical and chemical conditions are remarkably constant with fairly regular changes being determined by the annual wind regimes (Nirmal *et al*., 2011). Talling (1966) showed that the small temperature difference in Lake Victoria separates layers of water leading to seasonal thermal stratification. In Lake George, however, prolonged thermal stratification is precluded by the shallowness of the water (Burgis 1973). The diurnal stratification is of greater significance than seasonal stratification and is usually broken down each day by even light winds. With almost constant mixing, the water of Lake George is an environment of remarkably homogenous and stable physico-chemical conditions. Talling and Lemoalle (1998) and Oduor (2000) showed that water temperature of Lake Baringo is comparable to other tropical lakes but that the difference arises from its shallowness and presence of high amounts of suspended solids.

Solar radiation is the main feature that influences environmental conditions in aquatic ecosystems by provision of energy necessary for photosynthetic process. Underwater light attenuation in turbid systems is largely a function of suspended particle concentration and their resuspension by winds (Gray *et al*., 2011). Autochthonous production alone cannot sustain the energy demands at higher trophic levels in these lakes (Hessen, 1998), and as such food webs are strongly driven by allochthonous organic carbon. Primary production is typically limited to the upper few meters of the water column in brown-water lakes due to strong light attenuation (Arvola *et al*., 1999). However, despite these characteristic physical and chemical features, phytoplankton and zooplankton community structures in turbid lakes seem to be similar to those in clear water lakes (Arvola *et al*., 1999).

Turbidity is an optical property of water that causes light to be scattered and absorbed by particles and molecules. It is highly variable in lakes, due to seasonal changes in algal blooms and wind driven suspension of sediments especially in shallow lakes. There is evidence that human activity increases erosion leading to increased turbidity in aquatic systems. Brown-water lakes have some physical and chemical features which are different from those of clear water lakes which can affect the growth and distribution of planktonic organisms. These lakes are characterised by high concentrations of dissolved inorganic material of allochthonous origin, which together with iron results in their dark brown colour. The latter absorbs solar radiation and results in a steep thermal stratification and high thermal stability, especially in small and sheltered lakes (Eloranta, 1999).

Besides light, nutrient availability is another primary 'bottom-up' force that influences primary production in the pelagial region of lakes. The 'bottom-up' effect is strongest at trophic levels close to primary producers, and it gradually levels off and becomes unpredictable when moving towards the higher trophic levels (McQueen *et al*., 1989). In aquatic ecosystems, phosphorus, nitrogen and silica are the nutrients that most potentially limit phytoplankton growth (Hecky & Kilham, 1988). The nutrient that limits the production rate of a population may also vary between different algal species (Sommer, 1989). Phosphorus is typically the limiting nutrient in tropical lakes (Hecky *et al*., 1993) although in brown-water lakes nitrogen limitation can be frequent (Saunders *et al.,* 2000). The nutrients that limit algal production may, however, vary temporally and spatially in lakes depending on the input of nitrogen and phosphorus from the catchment, sediment and atmosphere (Levine & Schindler, 1992) and nutrient recycling in the lake (Vadstein *et al*., 1995).

2.3 Biological factors

The diversity of landforms and climatic conditions led to the evolution of a wide range of habitats and diverse flora and fauna in the Rift Valley lakes. The biological diversity of the lakes and wetlands comprises microorganisms, macrophytes, macroinvertebrates, amphibians, reptiles, birds and mammals. Phytoplankton in Lake Baringo is dominated by blue-green algae (Oduor, 2000) while zooplankton community is dominated by copepods (Wahlberg *et al.,* 2003; Omondi *et al*., 2011). The lake hosts a small number of animals including reptiles, amphibians, fishes, birds and mammals. Macroinvertebrates, which form a significant part of aquatic biodiversity, are poorly represented in Lake Baringo. The organisms are characterized by low species richness and abundance that has been attributed to homogenous substratum,

high turbidity and low organic matter in the benthos. Mollusca dominate the macroinvertebrates in the lake (Owili *et al*., 2008).

Lake Baringo is an important bird area with over 470 species of birds found there (www.kenyabirds.org.uk). It is of great ornithological importance as it supports over 20,000 water birds throughout the year most of which are migratory. The Ol' Kokwa Island is an important breeding habitat for the Goliath herons. The lake is a stopover and a wintering ground for palearctic migrants. It has a high avifauna diversity including globally important species such as Lesser Kestril, Lesser flamingo, Madagascar squaco heron and the Palid harrier. A number of regionally threatened species found in the lake are Great crested grebe, African darter, Great egret, Saddle-billed stork, White backed duck, White headed vulture, Martial eagle, Baillon's crake and African skimmer. In addition it is home for many species of animals such as hippopotamus (*Hippopotamus amphibious*), crocodile (*Crocodylus niloticus)* and some species of frogs (*Rana* spp).

The fish community of Lake Baringo comprises seven species (Aloo, 2002; Odada *et al*., 2006). These include *Aplocheliches* sp, *Barbus intermedius australis, B. lineomaculatus, Clarias gariepinus, Labeo cylindricus, Oreochromis niloticus baringoensis* and *Protopterus aethiopicus* (Britton *et al*., 2006). Of these, three species, namely *C. gariepinus, O. niloticus baringoensis* and *P. aethiopicus,* are economically exploited. The fishery of the lake was once dominated by the endemic *O. niloticus baringoensis* but is presently dominated by *P. aethiopicus,* which was introduced in 1975. Annual catches of *O. niloticus baringoensis* exceeded 600 t in the 1960s but this decreased to mean annual catches of below 12 t in 2006 despite a prolonged period of fishery closure (Britton *et al*., 2006).

Most of the rivers and streams enter the lake at the southern and eastern shores where they form swamps harboring different types of macrophytes. The southern swamp, which is the most expansive, is dominated by a species of Poaceae, *Paspalidium geminatum* (Forssk) Stapf while the southeastern swamp is dominated by Typhaceae *Typha domingensis* Pers. The northeastern swamp is dominated by *Aeschynomene pfundii* Taub and lastly there is a low population of *P. geminatum* in the eastern bay. Other macrophytes in the lake include the free floating *Azolla pinnata* R. Br., *Azolla nilotica* Mett and *Pistia stratiotes* L., submerged *Ceratophyllum demersum* L. and *Najas horrida* Magnus, floating leaved *Nymphaea lotus* L. and emergent *Aeschynomene cristata* Vatke (Plate 2.1).

Plate 2.1: Some common macrophytes in Lake Baringo (A) *P. germinatum* and *T. domingensis* (B) *A. pfundii* (C) *C. demersum* and (D) *N. lotus.*

2.4 Relationship between physico-chemical and biological factors

The growth of biological community in freshwater lakes is influenced by the physical habitat as well as direct and indirect interactions among individual members of the food web. Studies on the limnological environment, plankton, and pelagic fisheries have been beneficial in providing information for aquatic ecosystems. Ecological relationships between the abiotic and biotic interactions in lakes are used as tools for prediction of conditions of lakes. The growth patterns and population dynamics of zooplankton are related to changes in the available algae which depend on nutrient supply and detrital matter (Abdel-Aziz & Gharib, 2006). The quality and quantity of available food determine the zooplankton fecundity and abundance. The zooplankton to phytoplankton biomass ration may, therefore, provide information about the ecological efficiency of energy transfer in relation to the trophic status of a water body (Cottenie *et al.*, 2001). Fish can, however, modify zooplankton biomass and lead to increased

phytoplankton concentration due to reduction in the intensity of zooplankton grazing (Ezekiel *et al*., 2011). Seasonal variability in the abundance of tropical zooplankton has been documented in several lakes and in many instances the seasonal zooplankton maxima have been observed to coincide with lake mixing and increased primary productivity but not necessarily with maximum phytoplankton biomass. This is because not all phytoplankton are ingested by zooplankton as demonstrated by the plankton community of Lake Victoria (Branstrator *et al.*, 1996).

A relationship between turbidity and the occurrence of large zooplankton when fish are present has been reported by Cottenie *et al*. (2001). In highly turbid lakes, fish predators may be non-selective, allowing the persistence of large species, while invertebrate predation may be insufficient to remove small species (Geddes, 1984). Schulze (2010), however, reported that the effect of visually foraging planktivorous fish on the size structure of turbid-water zooplankton communities may often be as strong as or even stronger than the effect of fish on clear-water zooplankton communities. Indeed Gliwicz (1986) has showed that even in turbid lakes fish can still regulate zooplankton populations and according to Hart (1988), large cladocerans, the group most likely to benefit from the visual shield, are the most harmed by clay in their diets. Occurrence of large zooplankters in the midst of predation in some lakes can, however, be explained by high turbidity, which limits their visibility.

Freshwater lakes are generally thought to have straight-line food chains, wherein piscivorous fish prey on planktivorous fish, which in turn prey upon zooplankton (Lazzaro *et al*., 2009). Size-selective planktivory by fish results in a zooplankton community dominated by small species (Lazzaro *et al*., 2009). To persist, large zooplankton species have to perform extended diurnal vertical migration, spending daytime in the deep and dark hypolimnion (Ringelberg, 1999). Diurnal vertical migration carries a cost because of low food concentration and low water temperature in deeper water. In clear water lakes, light penetrates deeply, which should facilitate fish predation. Zooplanktons therefore undergo more extensive diurnal vertical migration in clear lakes, and remain lower in the water column during the day (Bezerra-Neto *et al*., 2009). In contrast, in brown water lakes reduced light penetration impair prey perception by planktivorous fish thereby releasing large zooplankton species from predation pressure. Furthermore, altered light, temperature, and oxygen profiles should provide a valuable fish-free refuge, which would allow zooplankton to lessen the degree of diurnal vertical migration. As a result, all fish prey would be exposed to warmer temperature and better food conditions favoring increased growth rates. With reduced fish predation, invertebrate predators should

dominate and the preference of these predators for small-bodied prey should cause a shift in zooplankton composition towards larger species.

The structure of a zooplankton community is determined by the nature of its food supply on one hand and predation pressure on the other (Nirmal *et al*., 2011). There is a consensus that vertebrate predators remove large-bodied zooplankton individuals and species have the potential to deplete crustacean zooplankton in aquatic ecosystems (Cadjo *et al*., 2007). Green (1971) found that the composition of zooplankton in Lake Albert, Uganda was strongly influenced by the distribution of planktivorous fish species. He further attributed the decrease in zooplankton in Lake Kariba between 1972 and 1983 to size selection predation by fish, *Limnothrissa miodon* (Green, 1985).

The lung fish, *P. aethiopicus* is distributed in rivers and lakes of East and Central Africa (Hung *et al.*, 2009; Loong *et al.*, 2012). The fish has two modes of life; the active state that occurs in the water during the rainy season and the dormant state that occurs under the ground during the dry season when it aestivates in the mud. During aestivation, the fish secretes a slimy fluid from its skin, which soon congeals to form a water-proof covering called cocoon that wraps properly the entire body of the fish throughout the period (Loong *et al.*, 2012). It has been established that the cocoon helps to prevent the fish from desiccation (Giusi *et al.*, 2011). When the rainy season comes back, the entire aestivation area is flooded with water. Consequently, the lungfish is 'awakened' and then breaks the cocoon to resume its active aquatic life. Living lungfishes have been classified as omnivores (Daffalla *et al*., 1985; Baer *et al*., 1992). Corbet (1961) showed that *P. aethiopicus* has an ontogenic shift towards preference for molluscs by adult fishes while smaller fishes scavenge on fish and plant materials. Other studies have, however, indicated that the species have a selective preference for fishes besides other items like insects, crustaceans, annelids, molluscs and plant material (Mlewa & Green, 2004).

The African catfish, *C. gariepinus* is widely distributed in African freshwaters in the Niger and Nile River systems, extending to southern Africa, in the Limpopo, Okavango River systems and most of the East African Rift Valley lakes (de Moor & Bruton, 1988). The species is one of the most important commercial freshwater fish species in many parts of Africa (Willoughby & Tweedle, 1978). Various studies have been carried out on the feeding habits of *C. gariepinus* in some African water bodies (Dadebo, 2000). The fish is a benthopelagic fish (Yalcin *et al*., 2002) which is known to be voracious with a wide range of diet. It has been reported to feed on insects, crabs, plankton, snails, fish, young birds, amphibians, reptiles,

plants and fruits (Skelton, 1993). The fish are opportunistic and facultative feeders and respond quickly to newly available food sources and will switch their feeding patterns on the relative abundance of prey. Young fish of *C. gariepinus* feed mostly on small invertebrates in shallow inshore areas (Bruton, 1979). Its wide sub terminal mouth is capable of opening extremely wide for sucking in large amounts of water which is flushed through the gills for filter feeding enabling it to feed on zooplankton.

Earlier studies on the food of *O. niloticus* showed that the species is capable of using a wide range of food resources, but becomes herbivorous when it is 5 cm in length (Beveridge, 1984; Njiru *et al*., 2004). The young are omnivorous, which actively feed on zooplankton and both aquatic and terrestrial insects that fall on the water. Lowe-McConnell (1955) observed that there is a relationship between the nature and quantity of food available and the sizes the fishes attain in different water bodies. Lakes rich in diatoms were found to have higher fish production than smaller eutrophic enclosed water bodies. This was attributed to inability of *O. niloticus* to digest blue-green algae that usually dominates the algal biomass in eutrophic water bodies (Fish, 1955). Moriarty and Moriarty (1973), however, found that the species readily digested blue-green algae in Lake George, Uganda.

2.5 Lake Baringo catchment activities

The biodiversity of Lake Baringo faces threats from a wide range of sources but most can be attributed to anthropogenic activities within the lake and its catchment. Overgrazing in the catchment has resulted in pressure on the pastures, a situation which has been worsened by land demarcation, and lack of willingness by the inhabitants to change their attitude towards keeping large numbers of livestock. Hard pans, soil erosion, loss of ground cover and increased surface runoff resulting in deposition of soils in the lake. Soil erosion and the subsequent deposition of the eroded materials in waterways and water bodies is one of the most serious environmental problems facing Lake Baringo Basin. Studies by Onyando *et al*. (2005) showed that some areas in the catchment have high erosion potential of up to 115 tones $ha^{-1}year^{-1}$. The study further revealed that sediment delivery from River Perkerra catchment into the lake alone was 1.43 million tones $year^{-1}$. Not only does the loss of valuable topsoil result in reduced agricultural yields or even complete loss of land for agriculture, but it also causes siltation and other adverse effects on the receiving water bodies. The erosion has damaged land and deposited the silt into Lake Baringo causing serious turbidity and siltation problems. Growing human and livestock populations, drainage basin destruction, indiscriminate cutting of

vegetation especially for charcoal burning, and animal poaching have since reduced this richness.

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CHAPTER THREE

3.0 PHYSICO-CHEMICAL FACTORS AND CHLOROPHYLL *A* IN LAKE BARINGO

Abstract

Temporal and spatial changes of some physico-chemical factors and chlorophyll *a* were determined at five sampling stations in Lake Baringo on monthly basis from April 2008 and March 2010. Most of the parameters were measured *in situ* while standard methods were used to analyse water samples for alkalinity, hardness, silicates, soluble reactive phosphorus, nitrates, ammonium and chlorophyll *a.* The depth of the lake varied from 2.5 to 6.1 m with a mean of 4.29 ± 0.25 m (± SE) while transparency as Secchi depth ranged from 7.33 to 41.67 cm with a mean of 26.56 ± 0.92 cm (± SE). Conductivity of the lake water ranged from 466.33 to 866.67 µS cm^{-1} with a mean value of 677.19 ± 1.70 µS cm^{-1} (± SE). Temperature ranged from 24.17 to 32.90 ºC with mean of 27.19 ± 0.41ºC (± SE) while turbidity ranged from 54.33 to 263.0 NTU with a mean of 102.55 ± 3.02 NTU (± SE). Dissolved oxygen ranged from 3.10 to 8.77 mg l^{-1} with a mean of 6.79 ± 0.12 mg l^{-1} (± SE) and pH had a range of 7.39 to 9.92. Chlorophyll *a* concentration ranged from 3.68 to 49.91 µg l^{-1} with a mean of 15.48 ± 0.98 µg l^{-1}(± SE). Depth of the lake negatively correlated with conductivity (r = -0.69) but positively correlated with Secchi (r = 0.62). Chlorophyll *a* concentration did not significantly correlate with any physico-chemical factor. The physico-chemical parameters varied among sampling stations. However, these spatial variations were not significant. These modest spatial variations can be attributed to the small size and shallowness of the lake as well as daily mixing of water by wind action. There were significant temporal variations in physico-chemical factors and chlorophyll *a* among sampling stations. These differences were mainly caused by changes in the rainfall regime in the catchment.

Key words: Lake Baringo, physico-chemical factors, chlorophyll *a*.

3.1 Introduction

Changes in the composition, abundance and biomass of zooplankton and other aquatic organisms in the higher trophic levels in freshwater lakes are influenced by interactions in physico-chemical and biological factors (Silva *et al*., 2009; Rachman & Fitriya, 2012). Physical and chemical factors include light, temperature, turbidity, depth, conductivity, alkalinity, and nutrients (Bailey & Davignon, 1999). The interactions among these factors are, however, complex and the relative importance of each factor varies within and between lakes.

Kallqvist (1987) found that the water temperature and dissolved oxygen in Lake Baringo were fairly uniform and averaged 25 ºC and 6 mg l^{-1}, respectively. He attributed the uniform temperature and dissolved oxygen over time to the efficient mixing of the lake. Talling and Lemoalle (1998) and Oduor (2000) showed that water temperature of Lake Baringo is comparable to other tropical lakes but only differs from them due to its shallowness and presence of high amounts of suspended solids. Like in other shallow lakes in the region seasonal limnological patterns are not evident in this lake and the most marked cycle is dictated by changes in the diel climate (Patterson & Kiplagat, 1995).

Lake Baringo has low phytoplankton productivity and diversity (Kiplagat, 1989). Kiplagat (1989) reported a mean productivity of 0.8g O_2 m^2 while Kallqvist (1987) found a range of 0.2 to 1g O_2 m^2. The low productivity in the lake had been attributed to the high turbidity which leads to reduced rates of photosynthesis. It is uncertain as to whether similar productivity still exists in view of the climatic changes that have occurred in the lake and its catchment.

Autochthonous primary production alone cannot sustain the productivity at higher trophic levels in oligotrophic lakes (Hessen, 1998), and as such, food webs are strongly driven by allochthonous organic carbon. Besides the allochthonous materials from the catchment, the high turbidity in Lake Baringo has been attributed to the resuspension of the sediment daily by winds. The suspended solids influence the Secchi depth, euphotic zone and light attenuation coefficients (Oduor, 2000).

Past studies indicate variations in conductivity of Lake Baringo. Talling & Talling (1965) recorded a low conductivity of 416µS cm^{-1} in the lake. Kiplagat (1989) found values ranging from 980 to 1200µS cm^{-1} while Oduor (2000) reported a mean value of 1200µS cm^{-1}. Kiplagat *et al*. (1999) concluded that these variations were due to the nature of flow regimes of the inflowing rivers. Despite being an endorheic lake, the conductivity is within the range

of freshwater lakes. It is suspected that underground outflow and crystallization of solutes may be the cause of the low salinity. Moreover, Beadle (1932) showed that the bulk of the salts in Lake Baringo are derived from the underground sources through hot saline springs on the Kokwa Island. The high evaporation rate, coupled with the underground sources of salts, in the lake is responsible for the relatively high pH and conductivity.

In this chapter, data on the spatial distribution and temporal variations in physico-chemical factors and phytoplankton biomass in Lake Baringo during the study period are presented and discussed.

3.2 Materials and Methods

3.2.1 Study Area

Lake Baringo is a freshwater lake in the eastern arm of the Great Rift Valley in Kenya (Fig. 3 1). It is located between latitude 0˚30' N and 0˚45' N and longitude 36˚ 00' E and 36˚ 10' E and lies approximately 60 Km north of the equator at an altitude of 975 m above sea level (Kallqvist, 1987). The lake has a surface area of approximately 130 Km^2 and a catchment of 6,820 Km^2. It has a mean depth of 3 m with the deepest point being about 7 m at high water levels.

The lake is located in an arid area characterized by dry and wet seasons. The dry season usually starts from September to February while wet season occurs between March and August (Fig. 3.2). Rainfall ranges from about 600 mm on the east and south of the lake to 1500 mm on the west. Lake Baringo experiences very high annual evaporation rates of 1650-2300 mm (Odada *et al*., 2006) and its survival depends on the inflows from rivers originating from the hilly basin where rainfall varies from 1100 mm to 2700 mm. The lake is fed by several seasonal rivers including Ol Arabel, Mukutan, Endao and Chemeron while Molo and Perkerra are perennial though with reduced discharges during dry seasons.

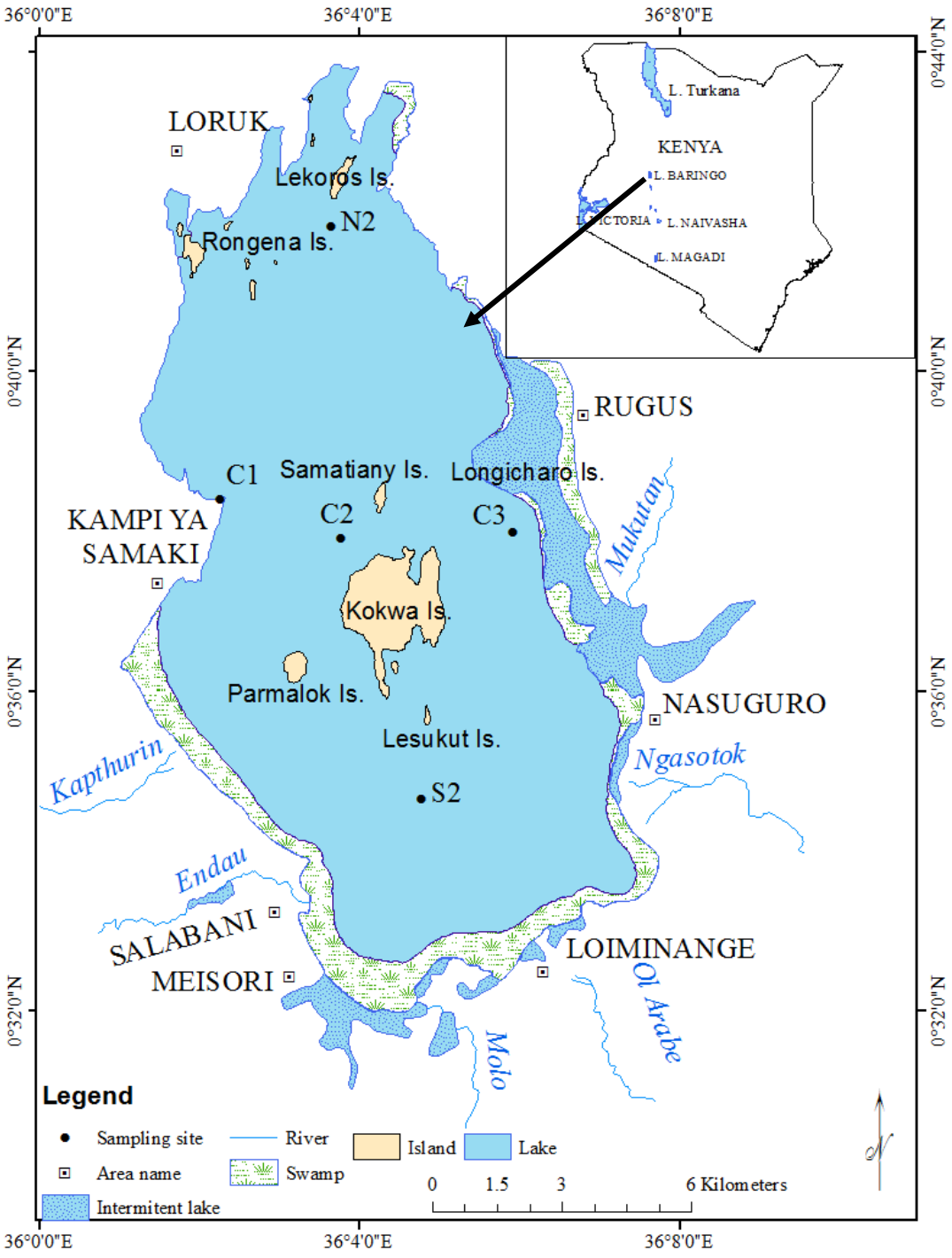

Figure 3.1: A map of Lake Baringo showing the stations, S2, C1, C2, C3 and N2, sampled during the study from April 2008 to March 2010. (Redrawn from Survey of Kenya Map Sheet 91/3)

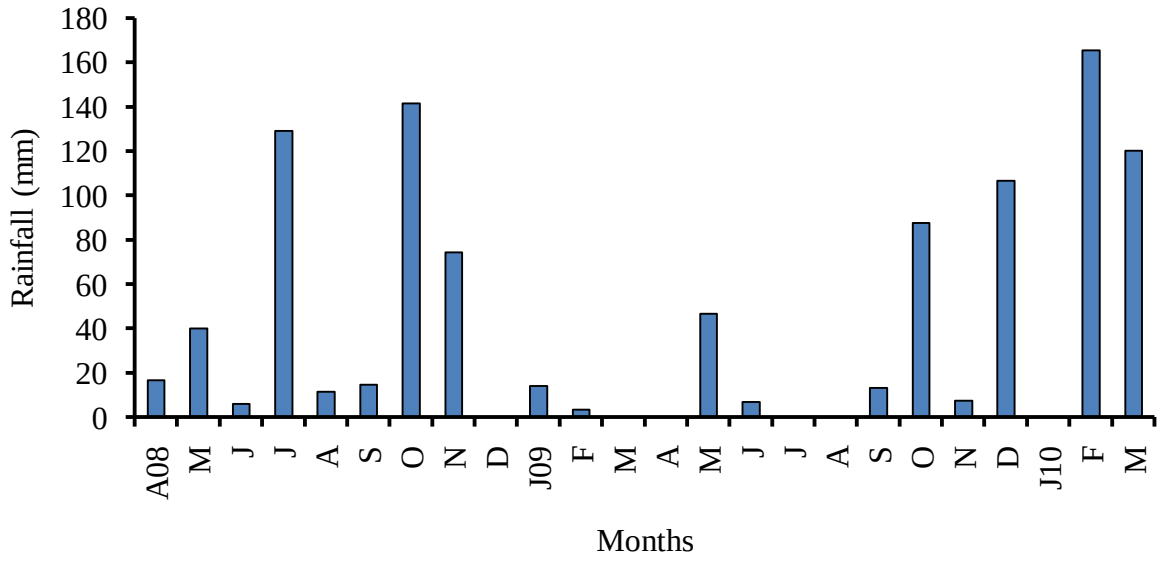

Figure 3.2: Monthly rainfall (mm) measured at Lake Baringo weather station from April 2008 to March 2010. (Source: WRMA-Kabarnet, 2011).

River Molo drains from the Mau hills near Molo and Elburgon area while River Perkerra is formed by the union of several radial streams from the Lembus forest. Its water is used for irrigation in Perkerra scheme around Marigat. This abstraction and damming of River Endao has reduced the amount of water reaching the lake. Besides the water flowing through the rivers, precipitation also contributes directly to the lake water, with most rain falling between March and August. These factors influence the ecological changes that occur in Lake Baringo.

3.2.2 Sampling stations

Stratified random design sampling was used in this study (Kothari, 1990). The lake was divided into five sectors, each with unique physico-chemical characteristics based on proximity to river mouths, that is, Rivers Perkerra, Molo and Mukutan. The actual sampling stations within the sectors were determined using a table of random numbers ranging from 0 to 360 and a compass. Global positioning system (GPS) navigational unit (Garmin II model) was used to locate the most central position of each sector. In each case, actual sampling station was chosen by moving 500 m from the central position of each sector based on two randomly selected numbers. Stations S2, C2 and N2 lying on the S-N transects while C3, C2 and C1 lying on the E-W transects were chosen (Fig. 3.1 and Table 3.1). Stations S2 and C3 have the influence of rivers Molo and Mukutan, respectively. Station C2 is at the centre of the lake, C1 in the west adjacent to rocky shores while N2 lies in the north. The stations were marked with fluorescent orange buoys.

Table 3.1: The geographical positions of the sampling stations in Lake Baringo.

Station	Position	
S2	00º 34’38. 7’’ N	036º 04’ 47.3’’ E
C1	00º 38’13. 0’’ N	036º 02’ 42.1’’ E
C2	00º 38’ 0.1’’ N	036º 03’ 53.2’’ E
C3	00º 37’59. 0’’ N	036º 05’ 54.4’’ E
N2	00º 41’33. 4’’ N	036º 03’ 27.2’’ E

3.2.3 Sampling protocol

Samples were collected monthly for two consecutive years from April 2008 to March 2010 at the five stations. Depth was determined using a marked rope weighted at one end while a 20 cm diameter black and white Secchi disc was used to determine transparency. Turbidity was measured *in situ* using a HACH 2100P turbidimeter. 500 ml lake water samples for nutrients and chlorophyll *a* analyses were collected using a four litre Van Dorn sampler. These were kept in a cool box at 4°C and transported to the laboratory where they were immediately filtered into 250 ml glass flasks using 0.45 μm pore size filter papers to remove phytoplankton before analysis.

Conductivity, temperature, dissolved oxygen and pH were measured *in situ* using a Surveyor II model hydrolab. The concentrations of ammonium nitrogen (NH_4-N), nitrates nitrogen (NO_3-N), soluble reactive phosphorus (PO_4-P) and silicates (SiO_4) were determined spectrophotometrically according to APHA (2000). The rainfall data were provided by Water Resources Management Authority (WARMA), Lake Baringo weather station registration number 610. Chlorophyll-*a* concentration was determined through extraction with acetone, centrifugation followed by measurement of absorbance at different wavelengths using a Genesys 10S Vis spectrophotomer based on the procedures described in APHA (2000).

3.2.4 Data analyses

Statistical computing language and environment R 2.15.0 (R Development Core Team, 2012) package was employed in data analyses. Analysis of Variance (ANOVA) was used in determining significant differences between spatial and temporal variation in physico-chemical factors and Chlorophyll *a*. Values with $P < 0.05$ were considered significant. In cases where there were significant differences, Tukey’s Multiple Range Test was used to separate the

means. Principle Components Analysis (PCA) was performed to establish the correlation of the physico-chemical and biological parameters among sampling stations. Community Analysis Package (CAP) was used to group stations with similar physico-chemical parameters.

3.3 Results

3.3.1 Physico-chemical factors and chlorophyll *a*

The spatial values of physico-chemical factors measured during the study are shown in Table 3.2. The mean depth of the lake was 4.3 ± 0.25 m (± SE). Spatial values ranged from 2.5 to 6.1 m at C3 and N2, respectively. The depth increased from south to north of the lake. There were significant differences in depth among stations (F = 15.51, $P < 0.05$). Temporally the depth of the lake ranged from 3.3 in December 2009 to 5.2 m in November 2008 (Fig. 3.3). There were significant temporal differences in depth with highest values coinciding with the highest rainfall (F = 20.40, $P < 0.05$). Tukey's pairwise test showed that all pairs of stations were significantly different in depth except C1 and C2 ($P > 0.05$).

The mean Secchi depth for the lake was 26.6 ± 1.7 cm (± SE). Values ranged from 7.3 to 41.7 cm at C3 and N2, respectively (Table 3.2). The spatial Secchi depths were significantly different among stations (F = 4.66, $P < 0.05$) with Tukey's pairwise test showing that Secchi depths was significantly different in the following pairs of stations; S2 and C1 ($P < 0.05$), S2 and N2 ($P < 0.05$) and S2 and C2 ($P < 0.05$). Water transparency increased from south to north and decreased from west to east (Table 3.2). Temporally, Secchi depth values ranged from 9.8 cm in March, 2010 to 36.8 cm in January, 2009 (Fig. 3.3). It was noted that the lowest Secchi depth coincided with the rainy season whereas the highest coincided with the dry season. There were significant variations in temporal Secchi depths (F = 68.77, $P < 0.05$).

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Table 3.1: Physico-chemical parameters (mean ± SE) at the five stations sampled in Lake Baringo between April 2008 and March 2010.

	Stations							
Parameter	S2	C1	C2	C3	N2	Df	F	*P*
Depth (m)	3.95±0.13	4.4±0.16	4.60±0.13	3.53±0.14	5.01±0.14	4	51.51	<0.05
Secchi depth (cm)	23.38±1.51	27.62±1.96	27.45±1.86	25.74±1.75	28.63±1.81	4	4.66	<0.05
Turbidity (NTU)	107.85±9.99	95.12±7.88	103.22±9.27	110.27±51.2	96.30±8.39	4	23.15	<0.05
Temperature (°C)	26.08±0.29	28.53±0.24	27.37±0.42	26.60±1.26	27.38±0.34	4	21.01	<0.05
DO (mg l^{-1})	6.38±0.16	6.94±0.20	7.07±0.21	6.64±0.21	6.92±0.22	4	4.95	<0.05
pH (range)	8.18-9.92	8.16-9.46	8.41-9.73	8.24-9.78	7.39-9.56	-	-	-
Conductivity (µS cm^{-1})	680.3±22.78	673.6±21.65	676.1±20.95	682.0±19.93	674.0±20.67	4	0.11	>0.05
NH_4 (µg l^{-1})	61.05±14.02	46.46±7.62	44.51±5.41	47.41±7.19	41.05±3.81	4	2.57	<0.05
NO_3 (µg l^{-1})	8.72±1.54	7.92±1.51	8.29±1.43	6.85±1.11	7.31±1.43	4	0.87	>0.05
SRP (µg l^{-1})	52.46±20.38	27.53±6.23	19.70±3.86	20.70±2.79	17.51±2.00	4	4.51	<0.05
Silicates (mg l^{-1})	27.28±0.90	28.75±1.05	27.16±0.92	27.26±0.59	28.21±0.84	4	3.51	>0.05
Chl *a* (µg l^{-1})	17.57±2.60	13.08±1.20	15.20±1.40	17.89±2.03	13.65±1.58	4	4.43	<0.05

The mean turbidity of the lake was 102.6 ± 3.02 NTU (± SE). Values ranged from 54.3 to 263.0 NTU at C1 and C3, respectively (Table 3.2). There were significant differences in turbidity among stations (F= 23.15, $P < 0.05$). Tukey's Multiple Range test indicated significant differences in stations S2, C3 and N2. Turbidity decreased from south to north and also from east to west in the lake. The temporal turbidity ranged from 61.6 NTU in July, 2009 to 210.7 NTU in January, 2010. There were significant temporal differences (F = 202.7, $P < 0.05$). The lowest turbidity coincided with the rainy season whereas the highest occurred in dry season.

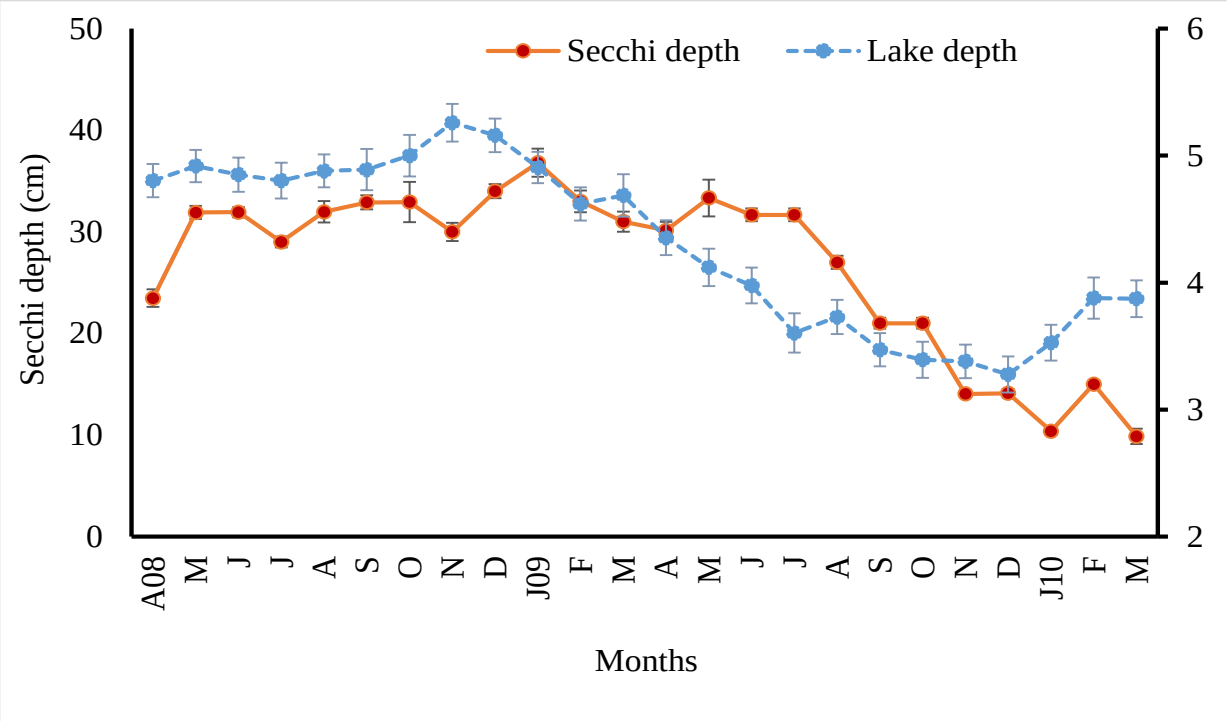

Figure 12.3: Temporal variations in depth and Secchi depth (mean ± SE) recorded at the sampling stations from April 2008 to March 2010.

Spatial water temperatures ranged from 24.2 ºC at S2 to 32.9 ºC at C1 with a mean temperature of 27.2 ± 0.41 ºC. There was a significant difference in the mean temperature between stations (F = 21.01, $P < 0.05$). All pairs of stations in Tukey test were significantly different except C3-C2 ($P = 0.06$), N2-C2 ($P = 0.99$), N2-C3 ($P = 0.06$ and S2-C3 ($P = 0.36$). Temporally temperature ranged from 24.3 ºC in February 2010 to 30 ºC in March

2010. There was a significant difference in the mean temperature between months ($F = 11.70$, $P < 0.05$).

Spatially dissolved oxygen concentration ranged from 3.1 mg l^{-1} to 8.8 mg l^{-1} at stations N2 and C1, respectively (Table 3.2) with a mean of 6.8 ± 0.12 mg l^{-1}. There was a significant difference in concentrations of dissolved oxygen between the sampling stations ($F = 4.95$, $P < 0.05$). Further analysis showed that there were only significant differences in mean dissolved concentration in two pairs of stations S2 and C2 ($P < 0.05$) and S2 and N2 ($P < 0.05$). Temporally, dissolved oxygen concentration ranged from 4.3 mg l^{-1} in February 2010 to 8.3 mg l^{-1} in March 2010. There were significant differences in dissolved oxygen concentrations between the months. ($F = 26.10$, $P < 0.05$). Spatially pH ranged from 7.4 at station N2 to 9.9 at station S2 while temporally this varied from 8.4 to 9.7 in September 2008 and March 2010, respectively.

Conductivity values during the study ranged from 466.3 µS cm^{-1} at C1 to 866.7 µS cm^{-1} at C3 with a mean of 677.2 ± 1.70 µS cm^{-1}. Although there was no statistically significant difference in conductivity between sampling stations ($F = 0.11$, $P < 0.05$), there was a decreasing trend of conductivity values from south to north and from east to west (Table 3.2). Temporally, conductivity values ranged from 476.3 µS cm^{-1} to 846.9 µS cm^{-1} in April 2008 and December 2009, respectively. This was thereafter followed by a slight decrease up to the end of the study in March 2010 (Fig 3.4). Significant differences were recorded in mean conductivity between the months ($F = 76.59$, $P < 0.05$)

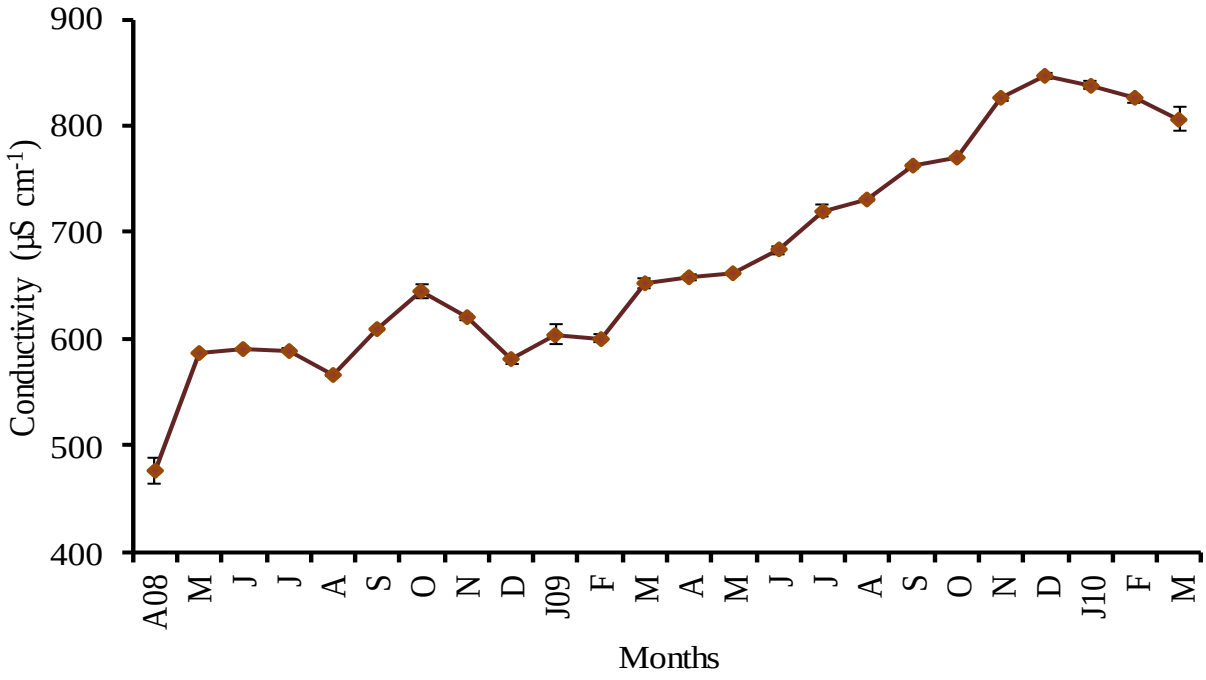

Figure 3.13: Conductivity values recorded at the sampling stations from April 2008 to March 2010.

There were significant spatial and temporal variations in the concentrations of the nutrients measured during the study (Table 3.2). Between stations, the highest concentrations of all the nutrients, except silicates, were realized at S2 sampling station. For all the nutrients, except silicates, there was a decreasing trend from south-north and from east - west. Temporally the nutrient concentrations varied between minima of 15.1 ± 1.1 µg l^{-1}, 2.1 ± 0.3 µg l^{-1}, 4.5 ± 0.66 µg l^{-1} and 22.4 ± 1.03 mg l^{-1} and a maxima of 134.1 ± 24.4 µg l^{-1}, 15.3 ± 0.94 µg l^{-1}, 73.4 ± 10.8 µg l^{-1} and 33.6 ± 0.81 mg l^{-1} for ammonium, nitrates, soluble reactive phosphates and silicates, respectively (Fig. 3.5).

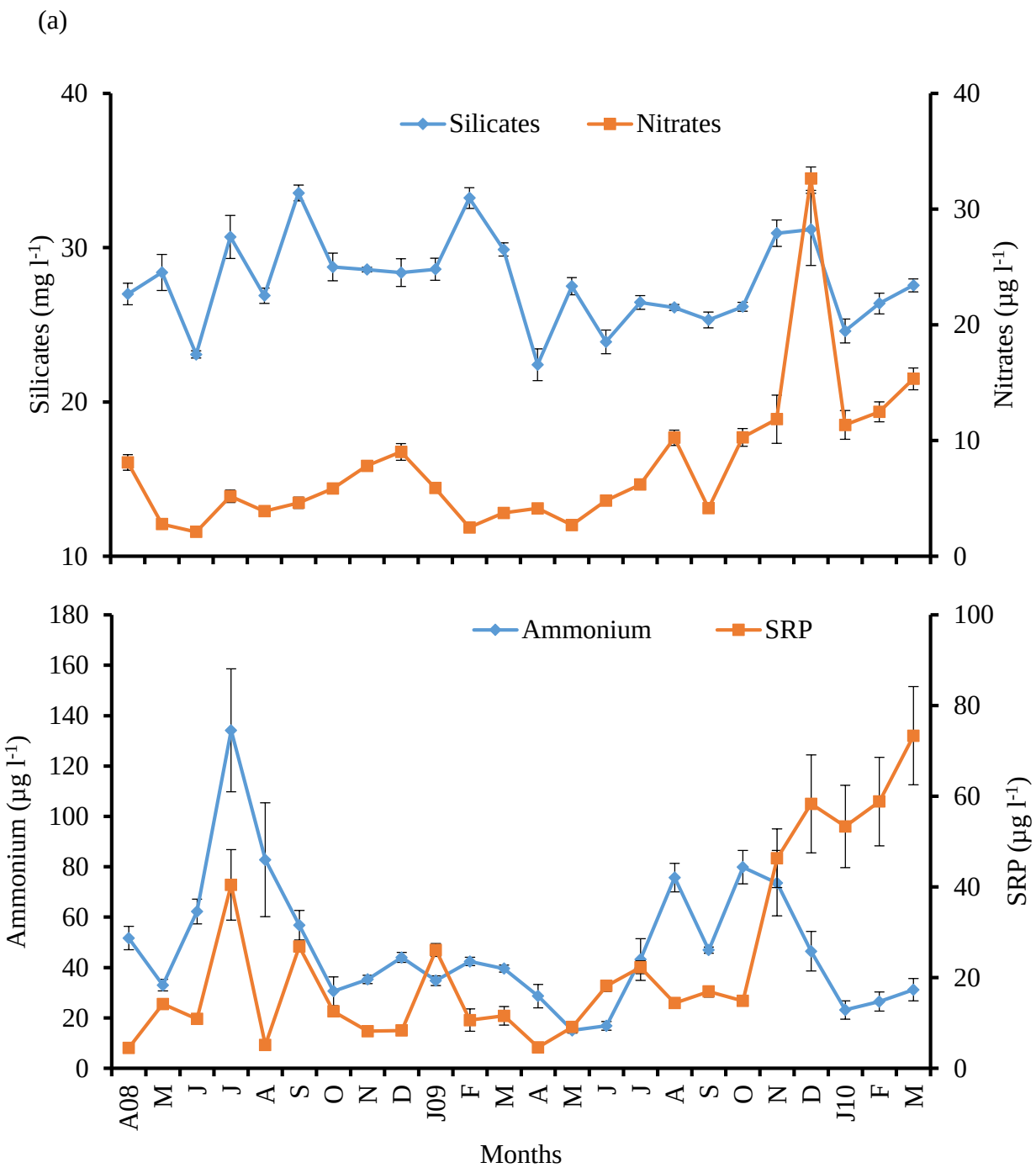

Figure 3.14: Nutrients concentrations (mean ± SE) values recorded at the sampling stations from April 2008 to March 2010.

Spatially, the amount of Chlorophyll *a* concentration ranged from 3.68 at N2 to 49.91µg l^{-1} at S2 with a mean of 15.48 ± 0.98 µg l^{-1}(± SE). It was higher at the river mouth sampling stations,

S2 and C3 than at other stations. There was a significant difference in the Chlorophyll *a* concentration between stations (F = 4.43, $P < 0.05$). Temporally, Chlorophyll *a* concentration ranged from 4.86 in June 2009 to 30.7 µg l^{-1} in November 2009 (Fig. 3.6). There was also a significant difference in the mean Chlorophyll *a* concentration between the sampling months (F = 19.22, $P < 0.05$).

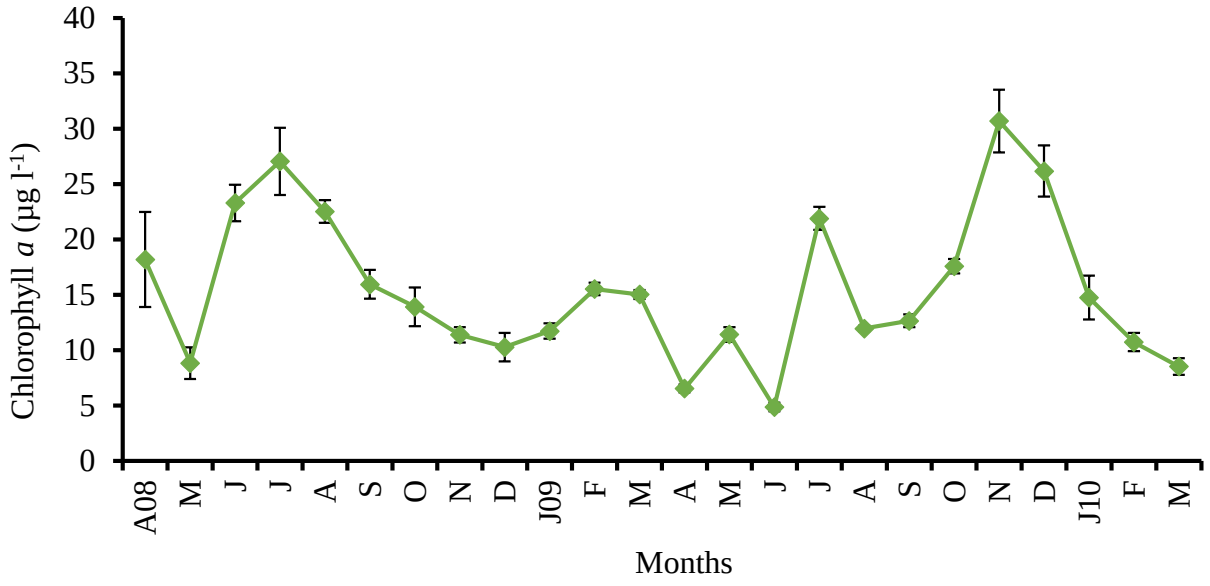

Figure 3.15: Temporal trends in Chlorophyll *a* concentration (mean ± SE) recorded in Lake Baringo between April 2008 and March 2010.

3.3.2 Relationships between physico-chemical parameters

The correlation between the physico-chemical parameters are shown in Table 3.3. The depth of the lake was significantly and negatively with conductivity (r = -0.70) and water hardness (r = -0.58). Depth was also positively correlated, albeit weakly, with temperature (r = 0.18) and negatively with the various nutrients. There were no correlations between temperature and nutrients and other variables. Conductivity was positively correlated to both turbidity (r = 0.63) and nitrates (r = 0.58).

Table 2.3: Correlation matrix between environmental variables. Dep = Depth, Tur = Turbidity, Tem = Temperature, Con = Conductivity, Har = Hardness, Alk = Alkalinity, DO = Dissolved oxygen, SRP = Soluble reactive phosphate, NH_4 = Ammonium, NO_3 = Nitrates.

	Dep	Turb	Tem	pH	Con	Har	Alk	DO	SRP	NH_4	NO_3
Dep	1										
Turb	-0.38	1									
Tem	0.149	-0.07	1								
pH	-0.28	0.35	0.22	1							
Con	-0.70*	0.63*	-0.03	0.28	1						
Har	-0.59*	0.27	0.13	0.38	0.65*	1					
Alk	-0.28	0.169	-0.04	-0.11	0.38	0.01	1				
DO	0.089	-0.04	0.46	0.103	-0.07	0.16	0.099	1			
SRP	-0.18	0.25	-0.06	0.097	0.24	0.05	0.145	-0.09	1		
NH_4	-0.04	-0.15	-0.17	-0.11	-0.09	-0.15	0.058	-0.08	0.06	1	
NO_3	-0.36	0.46	0.15	0.26	0.58*	0.36	0.106	-0.02	0.17	-0.01	1

- *Significant correlation

3.3.3 Similarity of sampling stations

The similarity of sampling stations based on environmental variables was analyzed by PCA (Fig. 3.7). On the ordination diagram sampling stations are represented by clear dots while environmental variables are represented by lines. The PCA showed that the important environmental factors in the characterization of Station C3, on Axis 1, are turbidity, Conductivity and Chlorophyll *a*. Sampling stations C1and N2 were characterized by low values of the same variables thus occurred in the opposite quarter of the diagram. On axis 2, sampling station S2 had high values of ammonium and soluble reactive phosphorus while station C2 on the other hand had low values of the variables.

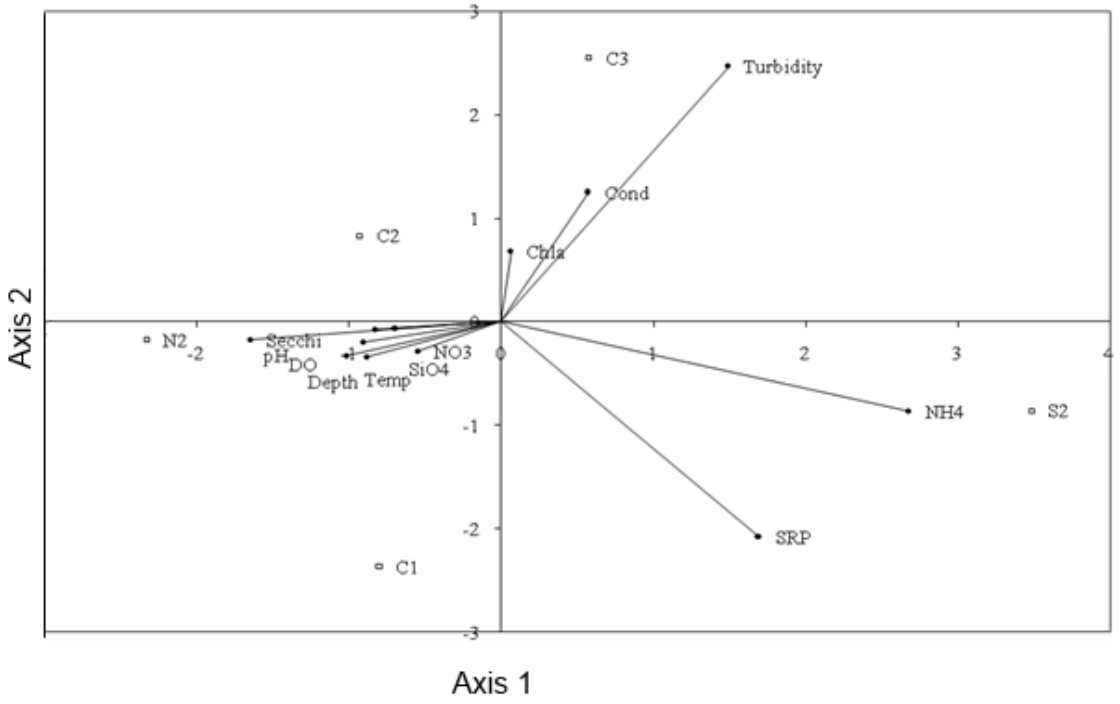

Figure 3.16: Principal Component Analyses (PCA) for sampling stations and environmental variables in Lake Baringo between April 2008 and March 2010.

Table 3.4 shows that the first and second axes accounted for 71.7% and 26.7% of the total variance of the physico-chemical variables at the sampling stations. The environmental parameters contributing most ordination of axis 1 were ammonium (r = 0.67), SRP (r = 0.47) and turbidity (r = 0.45). Turbidity (r = 0.66) and SRP (r = -0.57) showed the highest correlation on axis 2.

Table 3.3: Principle component loadings of a PCA performed on physicho-chemical parameters in Lake Baringo between April 2008 and March 2010.

	Axis 1	Axis 2
Depth	-0.04	-0.03
Secchi	-0.18	-0.02
Temperature	-0.06	-0.07
Dissolve oxygen	-0.03	-0.04
pH	-0.02	-0.01
Conductivity	0.26	0.34
Ammonium	0.67*	-0.25
Nitrates	0.03	-0.06
Soluble Reactive Phosphates	0.47	-0.57*
Silicates	-0.03	-0.07
Turbidity	0.45	0.66*
Chlorophyll_*a*	0.16	0.19
Explained variance (%)	71.73	26.75

*Denotes parameter that has significant influence on the sampling stations

Agglomerative clustering of the sampling stations based on the physico-chemical variables showed that there were four groups of stations (Fig. 3.8). Station S2 was in the first group which was the most different from other groups (Euclidean distance 391).

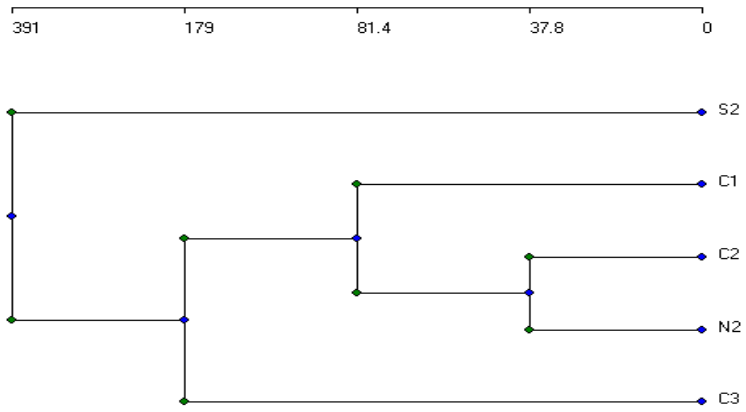

Figure 3.17: Hierarchical agglomerative clustering (Ward's method) of sampling stations using Euclidean distance of physico-chemical factors in Lake Baringo between April 2008 and March 2010.

Station C1, in the second group, was closest to the third group of stations C2 and N2 with a distance of 81.4. Station C2 and N2 were the most similar stations with a Euclidean distance of 37.8. In the last group was station C3. The station was closer to groups two and three (Euclidean distance 179).

Characterization of sampling stations based on the environmental variables confirms the outcome of PCA analyses (Figure 3.6) that grouped C2 and N2 closer to C1 while S2 and C3 lie on different axes suggesting they have very different physico-chemical variables.

3.4 Discussion

Lakes are said to be ephemeral features of a landscape. They show remarkable variability with time in their morphometry, physical, chemical and biological factors. Such variations are mainly induced by climatic changes and anthropogenic activities in the catchment area. In the last half of the 20th century, there have been remarkable variations in climatic patterns, which have impacted negatively on the lake ecosystems (Ngaira, 2006). Such effects include frequent fluctuation in water levels, increased salinity and turbidity, among others. In the tropics, rainfall remains the major weather factor influencing changes in characteristics of water bodies in arid and semi-arid areas such as that of Lake Baringo. The minimal differences in environmental variables across the sampling stations in Lake Baringo can be attributed to its small size and shallowness and also to the daily mixing of the lake water by wind action. Similar results have been reported for other lakes (Sarma *et al*., 2005) in which difficulty in establishing large scale spatial heterogeneity in tropical lakes is attributed to their small size and shallowness.

In this study, the depth of Lake Baringo was variable spatially and temporally. Siltation from the deposition of allochthonous materials carried by River Molo and River Perkerra to the south and Mukutan stream to the west probably account for the low lake depths recorded in these areas. Furthermore, established macrophytic communities in the two zones contribute to accumulation of silt by acting as traps for the incoming materials. The type of geology, topography and meteorology (Onyando *et al*., 2005) coupled with anthropogenic activities; especially overgrazing and deforestation expose Lake Baringo catchment to high erosion. The resulting sediments and suspended solids in turn influence the lake's depth. The temporal variations were more pronounced with the highest depth coinciding with the rainfall season and the lowest with the dry season. Reduced depth is therefore a normal cycle observed during dry season that has reduced rainfall, high evaporation rate and also water abstraction from incoming rivers and the lake. On the other hand, high water levels were associated with high rainfall, increased inflows and reduced evaporation. Generally, water level increased after rains due to flash floods, which are common in arid areas with poor vegetation cover (Aloo, 2002). Incoming sediments results in decreased transparency which could in turn reduce primary production.

The low Secchi depths close to the mouths of rivers Molo/Perkerra and Mukutan were attributed to suspended solids brought into the lake by the rivers which reduces transparency. The

amount of deposited suspended solids diminished with distance from the river mouths, explaining the increase in transparency from south to north and from east to west. Oduor (2000) and Wahlberg *et al* (2003) attributed the low transparency in the lake to resuspension of sediments by wind action. Shallowness of lakes have been reported to lead to unpredictability of seasonal events especially in windy, unstratified water bodies where resuspension of bottom sediments results in reduced water transparency (Sampaio *et al*., 1986). The resuspension of the bottom sediments into the water column which is a common feature in such ecosystems represents a major physical factor which can impact on other abiotic and biotic variables.

Turbidity results from the scattering of light in water by organic and inorganic particles. High turbidities are usually caused by suspended inorganic particles, particularly sediments. The relative high turbidity in Lake Baringo may be attributed to the high rates of sedimentation resulting from increased soil erosion in the catchment. These are mainly transported into the lake through rivers and streams hence the higher turbidity recorded at the sampling stations adjacent to the river mouths, however, presence of macrophytes may lower turbidity by enhancing sedimentation, as observed by Busienei (2003) who reported lower turbidity at the mouth of River Molo which he attributed to the presence of the wetland at the river mouth. The variation is a pointer to the degradation of wetlands at the river mouths in the lake with time. Further, the high amounts of suspended solids of inorganic origin could be attributed to the resuspension of sediments from the bottom by effect of wind, a phenomenon particularly important in shallow lakes (Borell Lovstedt and Bengtsson, 2008). In Lake Baringo, this was favoured by exposure to near-daily winds and low populations of macrophytes, especially in the open waters, that could reduce waves (Moss *et al.*, 1996). Oduor (2000) and Wahlberg *et al*. (2003) also attributed turbidity of Lake Baringo to resuspension of the sediments by wind action. Resuspension and turbidity have been found to be significant contributors to declining populations of aquatic organisms (Henley *et al*., 2000).

The high water temperatures recorded in this study were mainly due to the high intensity of solar radiation in the area. Studies by Ngaira (2006) showed that air temperatures in the area during the day ranged between 35 ºC and 39 ºC. The high concentration of suspended solids also enhances absorption of solar energy (Wetzel, 2001). Patterson and Kiplagat (1995) attributed the high temperatures in Lake Baringo with ranges of 21.2 ºC to 33.3 ºC to dissolved and suspended materials. The significant variation in temperatures at different stations was due to the different

times of sampling with stations sampled early in the morning recording lower temperatures than those sampled later in the day. Temporal variations of water temperatures were due to changes in seasons and water levels of the lake. Reduced depth due to decreased rainfall and increased evaporation led to high water temperatures.

The relatively high dissolved oxygen concentration of 6.8 mg l^{-1} in Lake Baringo showed that the lake is well aerated. Dissolved oxygen in water is greatly influenced by the process of photosynthesis as well as light intensity. This explains why dissolved oxygen values measured in the lake increased with time of sampling with areas sampled early in the morning, when there was low light intensity, having lower dissolved oxygen concentration. Turbidity also indirectly affects the level of dissolved oxygen by limiting photosynthesis through reduction of light penetration in water and this could partly explain the low concentrations of dissolved oxygen at the river mouths where turbidity was highest. Furthermore, decomposition of organic matter would also consume oxygen in such localities, thus lowering its concentration.

In an earlier study, Kiplagat *et al.* (1999) attributed fluctuations in conductivity values in Lake Baringo to the nature of inflowing river waters arising from the high ion loads. Arle (2002) reported that mineral concentrations and dilution affect the value of conductivity. The onset of rains has been observed to signal radical changes in physical and chemical variables in tropical rivers (Lowe-Connell, 1987; Chapman & Kramer, 1991). The high temperatures in Lake Baringo area accompanied by the high evaporation rates, contribute to the increase in conductivity values in the lake due to reduced water volume. During rainy seasons, there is dilution of lake water resulting in decreased ion concentrations while during drought and low water levels there is an increase of salts resulting in high conductivity levels. This is supported by the negative correlation between conductivity values and Lake Depth. The frequent peaks of nutrients realized during the study were probably caused by flushing of ions into the lake after rains in the catchment. River inflow has been observed to shape chemical gradients in other lakes (Swaine *et al*., 2006) through nutrient and organic matter input. On the other hand during dry periods high concentrations of ions observed could be due to reduced water volume in the lake by evaporation. Increased concentrations of ions, due to evaporation, in shallow lakes following dry periods have been reported by Swaine *et al*. (2006).

Chlorophyll *a* is measured frequently to estimate phytoplankton biomass and to predict eutrophication levels of freshwater aquatic ecosystems (Wetzel, 2001; Dodds, 2002). The low Chlorophyll *a* concentrations recorded in Lake Baringo can be attributed to the high turbidity resulting in low light penetration leading to low photosynthetic activity. This is shown by the increase in the Chlorophyll *a* concentration during periods of low water levels in the lake. From the results of the study, increase in depth results in the increase in light transparency which culminates in higher production, thus increasing chlorophyll *a*. However, this was not the case in this study showing that probably the water turbidity arising from the silt brought in by rivers suppressed photosynthesis.

The persistent south-north and east-west trends in most physical and chemical factors observed in this study were due to the effect of the affluent rivers and streams and associated macrophytes in the south and west. Overally, the small differences in most environmental variables between stations in Lake Baringo are not surprising. Studies have shown that it is difficult to establish large scale spatial heterogeneity in small shallow lakes (Sarma *et al*., 2005).

In Lake Baringo, the PCA grouped stations adjacent to river mouths together from the rest based on the relatively high turbidity, Chlorophyll *a,* ammonium, soluble reactive phosphates and conductivity. This is because these are the points in the lake where water with high concentrations of silt, nutrients and ions reach the lake before dilution effect in other parts of the lake. Although grouping of stations was based on similar physico-chemical parameters, interpretation of these results should be taken with care considering that some variations may arise from sampling routines. For example, the same river mouth habitats were always sampled first during the study when temperatures and dissolved oxygen values were low and this could influence the clustering of the stations.

3.5 Conclusion

The study showed that there were significant variations, both spatial and temporal, in physico-chemical parameters. The slight spatial variations are attributed to the lake's small size and shallowness thus reduced heterogeneity of the habitats. Temporal variations are, however, influenced by changes in lake depth resulting from variation in the rainfall pattern in the catchment. The resulting changes in water levels, in turn, influence the levels of the chemical parameters through dilution, during high water levels, or concentration due to water loss and decrease in water levels through water evaporation. Results from the investigations also showed that there were significant variations in phytoplankton biomass, estimated as chlorophyll *a* concentration, spatially and temporally. These findings lead to the rejection of the first hypothesis which stated that there are no significant temporal and spatial variations in physico-chemical parameters and chlorophyll *a* in Lake Baringo.

The present study shows that the incoming water through rivers is the probable source of silt, nutrients and ions which influences the lake's physico-chemical properties. These come from the catchment and are as a result of anthropogenic activities which induce soil erosion arising especially from poor farming methods, deforestation and overgrazing due to keeping of large number of livestock. Increased nutrients in the lake have led to increased primary production with the the algal community being dominated by *Microcystis aeruginosa*, a species known to be inedible for most zooplankton and fish. Such, blooms results in increased lake turbidity and has also been known to be poisonous to some groups of zooplankton (Beenamma & Sadanand, 2011). Increased turbidity, worsened by winds and resuspension of sediments in the lake depress photosynthesis and also reduces feeding efficiency in fish that feed by sight. Indeed the increasing turbidity in the lake water could be one of the reasons for the decreasing catches of the once dominant *O. niloticus*.

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CHAPTER FOUR

4.0 ZOOPLANKTON COMMUNITY CHARACTERISTICS IN LAKE BARINGO

Abstract

The spatial and temporal distribution, composition, diversity, abundance and biomass of zooplankton were studied in Lake Baringo for two years. Samples were collected monthly at five stations from April 2008 to March 2010 using a Nansen net with a 50 µm mesh size. The objectives of the study were to determine the temporal and spatial changes in the composition, diversity, abundance and biomass and to relate these variations with to physico-chemical parameters and phytoplankton biomass. The zooplankton community comprised of 3 copepods, 13 cladocerans and 23 rotifer species. The copepod *Thermocyclops consimilis* dominated the zooplankton community in abundance. Cladocera was dominated by *Diaphanosoma excisum* and *Daphnia barbata* while Rotifera was dominated by *Filinia opoliensis* and *Keratella tropica* but were less abundant in the plankton than copeods. A cladoceran *Ilyocryptus spinifer* was only recorded at one station and on one sampling date. Total zooplankton abundance ranged from 17.7 individuals l^{-1} to 387.8 individuals l^{-1} with a mean of 88.3 ± 5.59 (SE) individuals l^{-1} while total zooplankton biomass ranged from 21.22 to 143.68 µg l^{-1} DW with a mean of 90.08 ±. 6.91 µg l^{-1} DW (SE). Species diversity ranged from 5.42 to 5.48. The study revealed that the lowest species diversity was at the central station C2 probably as a result of water column mixing due to wind action. Temporally higher diversity was observed during higher lake levels probably due to reduced stress caused by dilution of environmental variables. Zooplankton distribution, abundance and biomass were influenced by environmental variables especially conductivity and turbidity. Conductivity probably also influenced the seasonality of the calanoid, *Thermodiaptomus galebi* and the rotifer *Brachionus falcatus*.

Key words: Lake Baringo, Zooplankton, Composition, Abundance, physico-chemical factors

4.1 Introduction

Zooplankton are critical to the functioning of aquatic food webs because of their sheer abundance and vital ecosystem roles that they play (Richardson, 2008; Ka and Hwang, 2011). Among the zooplankton, copepods which are the most dominant zooplankton in tropical lakes, are the most abundant multicellular animals on earth (Schminke, 2007; Ka & Hwang, 2011). Freshwater zooplankton communities are highly diverse and perform a variety of ecosystem functions. Their most important ecosystem function is the provision of a principal pathway for energy flow from primary producers to higher trophic level organisms like fish (Hoxmeier & Wahl, 2004). Furthermore, zooplankton support the microbial community by recycling nitrogen through excretion thereby enhancing bacterial and phytoplankton production. Microbes colonize their feaces and carcasses making them a rich source of organic carbon for detrital feeders. The zooplankton products consistently fall through the water column to the sediments and sustain diverse benthic organisms including, crabs and fish, among others. Large water bodies have the ability of acting as sinks of carbon dioxide, thereby controlling climate change, by deposition of carbon in the deep sediments after consumption of phytoplankton by zooplankton (Richardson, 2008). Some zooplankton associations can be used as indicators of water quality on the basis of the relationship between limnological characteristics of lakes and the structure of such zooplankton communities (Pinto-Coelho *et al.,* 2005).

Numerous studies of zooplankton communities have described seasonal patterns in population dynamics and species succession (Rennella & Quiros, 2002). Spatial and temporal zooplankton composition and abundance variations are the result of many physical and chemical processes interacting with several biological processes. A complex set of related, possibly causal, factors have been implicated in the variations including physical and chemical variables (Sampaio *et al*., 2002; Makode & Charjan, 2010), food (Behn & Boumans, 2001; Abdel-Aziz & Gharib, 2006) and predation (Jeppesen *et al.*, 2005).

Spatially, zooplankton is found in a wide variety of biotopes in aquatic environments ranging from littoral, pelagic and benthic zones of lakes. Their distribution may vary with lake size, depth, water transparency, colour and presence or absence of vertebrate and invertebrate predators (Rajeshekher, 2009). Their horizontal distribution also be influenced by aquatic macrophytes (Cottenie *et al*., 2001). The occurrence of different species of zooplankton in the

Great Lakes of Africa has been reported in many studies (Mavuti, 1990; Mavuti & Litterick, 1991; Ndawula, 1994; Branstrator *et al*., 1996). The dominance of cyclopoid species in zooplankton communities in African lakes has been highlighted (Mavuti & Litterick, 1991; Ndawula, 1994; Branstrator *et al*., 1996).

Numerous studies of temperate lakes have revealed the existence of top-down forces with emphasis on control by fish on the composition and abundance of zooplankton (Lazzaro *et al.*, 2009). The common view of the top-down effect is that the abundance of the uppermost trophic level controls the abundance of the intermediate levels, thus relieving primary producers from grazing control (Scheinin & Mattila, 2010). Accordingly, fluctuations in the top predator populations can cascade through the food web to alter nutrient cycling, algal biomass and primary production in lakes (Carpenter *et al*., 2001).

In tropical lakes, the few studies carried out reveal that bottom-up forces are the main determinants of zooplankton communities (Danger *et al*., 2009). Studies of zooplankton in tropical regions have lagged behind those of the temperate regions because of lack of information on taxonomy. Initial taxonomic studies are prudent before detailed ecological investigations are carried out to ensure organisms are correctly identified. The importance of zooplankton in freshwater ecosystems as indicators of water quality and as components of the diet for fishes especially juveniles, dictate that their studies be integrated in lake management programs. This study aimed at evaluating spatial and temporal distribution, composition, abundance and, biomass of the zooplankton community of Lake Baringo.

4.2 Materials and Methods

4.2.1. Study Area

Lake Baringo is a freshwater lake in the eastern arm of the Great Rift Valley in Kenya (Fig. 4.1). It is located between latitude 0˚30’ N and 0˚45’ N and longitude 36˚ 00’ E and 36˚ 10’ E and lies approximately 60 Km north of the equator at an altitude of 975 m above sea level (Kallqvist, 1987). The lake has a surface area of approximately 130 Km^2 and a catchment of 6,820 Km^2. It has a mean depth of 3 m with the deepest point being about 7 m at high water levels.

The lake is located in an arid area characterized by dry and wet seasons. The dry season usually starts from September to February while wet season occurs between March and August. Rainfall ranges from about 600 mm on the east and south of the lake to 1500 mm on the west. Lake Baringo experiences very high annual evaporation rates of 1650-2300 mm (Odada *et al*., 2006) and its survival depends on the inflows from rivers originating from the hilly basin where rainfall varies from 1100 mm to 2700 mm. The lake is fed by several seasonal rivers including Ol Arabel, Mukutan, Endao and Chemeron while Molo and Perkerra are perennial though with reduced discharges during dry seasons.

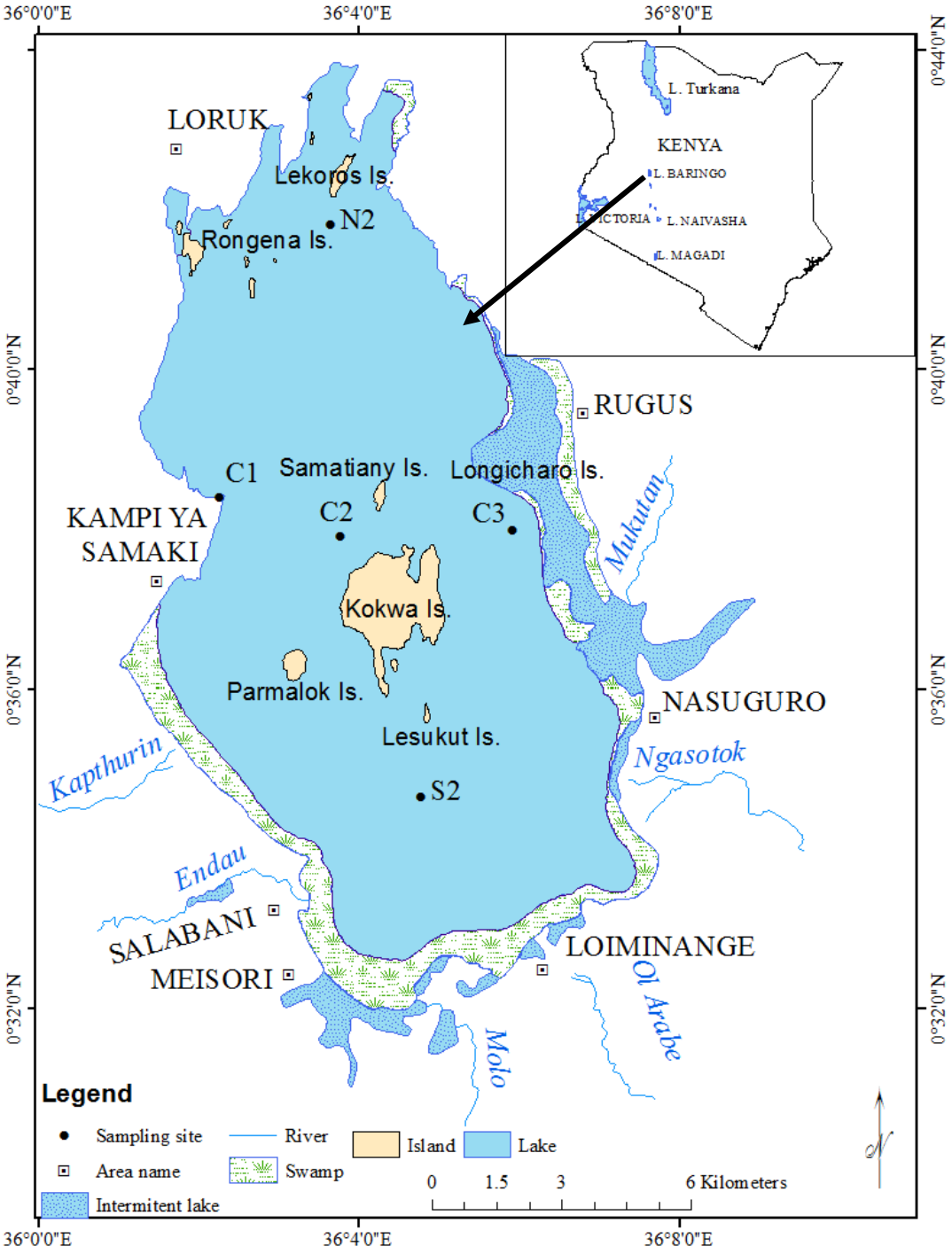

Figure 4.18: A map of Lake Baringo showing the stations, S2, C1, C2, C3 and N2, sampled during the study from April 2008 to March 2010. (Redrawn from Survey of Kenya Map Sheet 91/3)

4.2.2 Sampling protocol

Quantitative triplicate zooplankton samples were collected monthly at each site with a 1.0 m long Nansen type plankton net of 50 μm mesh size and mouth opening measuring 30 cm diameter (Plate 4.1). The net was lowered close to the bottom of the lake without disturbing the sediments and hauled vertically to the surface and the depth noted from the marked rope. The net was rigged with a weight suspended from the receptacle to ensure the hauls were vertical. 100% efficiency of the net was assumed by washing after each sampling and because of the shallow nature of the lake there were no corrections made for loss due to decrease in efficiency of the net.

Plate 4.1: Zooplankton net used for vertical haul sampling during the study.

Besides quantitative samples from the sampling stations, qualitative samples were also collected from a variety of different habitats. The additional habitats included littoral areas and rocky shores. Samples collected were preserved in 4% formaldehyde solution, labeled and transported to the laboratory. In the laboratory, successive aliquots of each sample were examined under a binocular dissecting microscope at X40 magnification. Copepods and cladocerans were

sorted using electronically sharpened tungsten wire fixed on inoculating rods while rotifers were sorted using fine glass capillary tubes into glycerine mixed with distilled water on glass slides.

For observation of copepods, two slides were prepared for each specimen, one with the abdomen and the other with thoracopods, antenna and antennules. Plasticine was placed at each corner of the cover slip to avoid crushing the abdomen. Cladocerans were observed on a slide prepared for each specimen with the various body parts well placed for examination. Mouth parts of rotifers were examined after dissolving the body tissues using sodium hypochlorite. Identification was done under oil immersion lens (X1000) of a compound microscope. Measurements of zooplankton dimensions were made on a calibrated compound microscope.

The zooplankton were identified to genus and where possible to species level using relevant taxonomic literature. For copepods, identification keys by Dussart and Defaye (1995) were used. The keys by Korovchinsky (1992) and Smirnov (1996) were used in Cladocera identification while Koste (1978), Koste and Shiel (1987) and Segers (1995) were used for the identification of rotifers.

In the laboratory each zooplankton sample was made to a known volume and thoroughly shaken for uniform distribution of organisms. A 3 ml plastic dropper was used for sub sampling. 1-3 ml sub-samples were taken, placed in 6 x 6 x 1 cm counting chamber and zooplankton counted under a Leica dissection microscope (X40). The effect of surface tension on the specimens was reduced by addition of a few drops of liquid detergent while visibility was improved by dying with Lugol's solution.

The number of individuals per litre of lake water (D) was determined using the formula:

$D = N/V$

Where

N = number of organisms in sample

= (number in sub-sample x Volume of sample)/sub-sample volume

V = volume of lake water filtered = $\pi r^2 d$, where

r = radius of mouth of net (15 cm)

d = depth of haul

Approximately 20 specimens of each taxon were picked at random and measured under a calibrated inverted microscope. Rotifer volumes were computed from linear dimensions assuming

they approximated simple geometric shapes such as cylinder, sphere e. t.c (Bottrell *et al*., 1976). The volumes of crustaceans were estimated using the formula:

$$V = {}^{4}/_{3}\pi ab^{2}$$

Where $a = ½ L$ and

$b = ½ W$

Biomass was then estimated by multiplying the number of animals per litre by the average dry weight of the animal. By assuming density of 1.0, volumes, in μm^3, were converted to wet weight, in µg, by dividing by 10^6. Finally dry weights were obtained by dividing wet weight by 10, assuming that wet weight to dry weight ratio is 1: 0.1 (Smith, 1999).

4.2.3 Data analysis

The abundance data were expressed as number of individuals per litre of lake water (individuals l^{-1}). To compare the zooplankton abundance and environmental parameters, Kolmogorov-Smirnov and Lilliefors tests were first applied to check the normality of distribution and the homogeneity of variances. Due to the heteroscedasticity of the zooplankton data (K-S $P < 0.05$; Lilliefors $P < 0.05$), it was transformed using log (x + 1) transformations to avoid violations of linearity assumptions and one way ANOVA was then applied to determine significant differences between spatial (over all stations) and temporal (over all months) distribution of zooplankton abundance using the statistical computing language and environment R 2.15.0 (R Development Core Team, 2012). In addition, the most dominant and the rarest zooplankton species according to sampling sites and periods were determined using the relative abundances (in percentages) of the taxon. Taxa richness, which is the total number of species at a specific station, was determined at all taxa levels. Shannon-Wiener index (*H*') was used to determine the species diversity both spatially and temporally. This is the most widely used diversity index because it is stable in any spatial distribution and insensitive to rare species (Ludwig & Reynolds 1988).

Principle Components Analysis (PCA) was performed using Past version 1.94b (Hammer *et al*., 2001) to examine the variation of zooplankton abundance and biomass among the stations and months. PCA also was carried out to elucidate the relationships between species abundance and biomass and the environmental variables. This multivariate analysis allowed ordination between species and environmental variables, and was carried out for both the total sampling

period and in all the stations sampled. Environmental variables influencing the distribution and abundance of different zooplankton species were identified by carrying out stepwise regression (MINITAB) while Community Analysis Package (CAP) was used to group stations with similar distribution of zooplankton species.

4.3 Results

4.3.1 Species composition and distribution

A total of 39 species of zooplankton were recorded in Lake Baringo during the study between April 2008 and March 2010 (Table 4.1). Only three species of Copepods were recorded, one calanoid *Thermodiaptomus galebi* (Diaptomidae) and two cyclopoids, *Thermocyclops consimilis* and *Mesocyclops* sp. The latter could, however, not be identified to species level because the few specimens encountered were immature. Cladocerans were represented by six families which included Chydoridae, Daphnidae, Sididae, Macrothricidae, Moinidae and Ilyocryptidae. Of these Chydoridae was the most dominant with six species. Rotifera, which was the highest number of species, comprised the families Brachionidae, Euchlanidae, Filinidae, Lecanidae, Mytilinidae and Trichocercidae. Lecanidae family was the largest with twelve species followed by Brachionidae with 6 species. During the study period, the zooplankton groups consisted mainly of euplanktonic organisms. However, littoral and periphytic zooplankton species occurred such as the rotifers *Lecane* spp and *Mytilina ventralis* and the cladoceran species *Macrothrix spinosa, Alona* spp and *Chydorus* spp, which occurred in the lake pelagic zone in low numbers. The latter were, in fact, common in the qualitative samples from the swampy areas in the southern and eastern parts of the lake.

Table 4.1: A checklist of zooplankton species recorded in Lake Baringo between April 2008 and March 2010. Numbers in parenthesis indicate number of species which could not conclusively be identified.

COPEPODA	*B. patulus* Muller, 1786
Cyclopidae	*Keratella tropica* (Apstein, 1907)
Thermocyclops consimilis Kiefer, 1934	*Platyias quadricornis* Ehrenberg, 1832
Mesocyclops sp	**Euchlanidae**
Diaptomidae	*Euchlanis* sp
Thermodiaptomus galebi Verheye & Dumont, 1984	**Filinidae**
CLADOCERA	*Filinia opoliensis* Zacharias, 1898
Daphnidae	**Hexarthridae**
Ceriodaphnia cornuta Sars, 1885	*Hexarthra* sp
Daphnia barbata Weltner, 1898	**Lecanidae**
Sididae	*Lecane aspasia* Myers, 1917
Diaphanosoma excisum Sars, 1885	*L. curvicornis* (Murray, 1913)
Moinidae	*L. lateralis* Sharma, 1978
Moina micrura Kurz, 1874	*L. leontina* (Turner, 1892)
Macrothricidae	*L. ludwigii* (Eckstein, 1883)
Macrothrix spinosa King 1853	*L. mira* (Murray, 1913)
Chydoridae	*L. unguitata* (Fadeev, 1925)
Alona spp (3)	*Lecane* spp (4)
Chydorus spp (2)	*Monostyla bulla* Gosse1886
Tretocephala sp	**Mytilinidae**
Ilyocryptidae	*Mytilina ventralis* (Ehrenberg, 1832)
Ilyocryptus spinifer Herrick, 1882	**Synchaetidae**
ROTIFERA	*Polyarthra* sp
Brachionidae	**Trichorcercidae**
Brachionus angularis Gosse, 1851	*Trichorcerca* sp
B. calyciflorus Pallas, 1776	
B. falcatus Zacharias, 1898	

4.3.2 Species diversity

The highest species diversity of the zooplankton community was recorded at S2 while the lowest was found at C2 with indices of 5.48 and 5.42, respectively (Fig. 4.2). There was a significant difference ($P < 0.05$) in species diversity between station C2 and the rest of the stations.

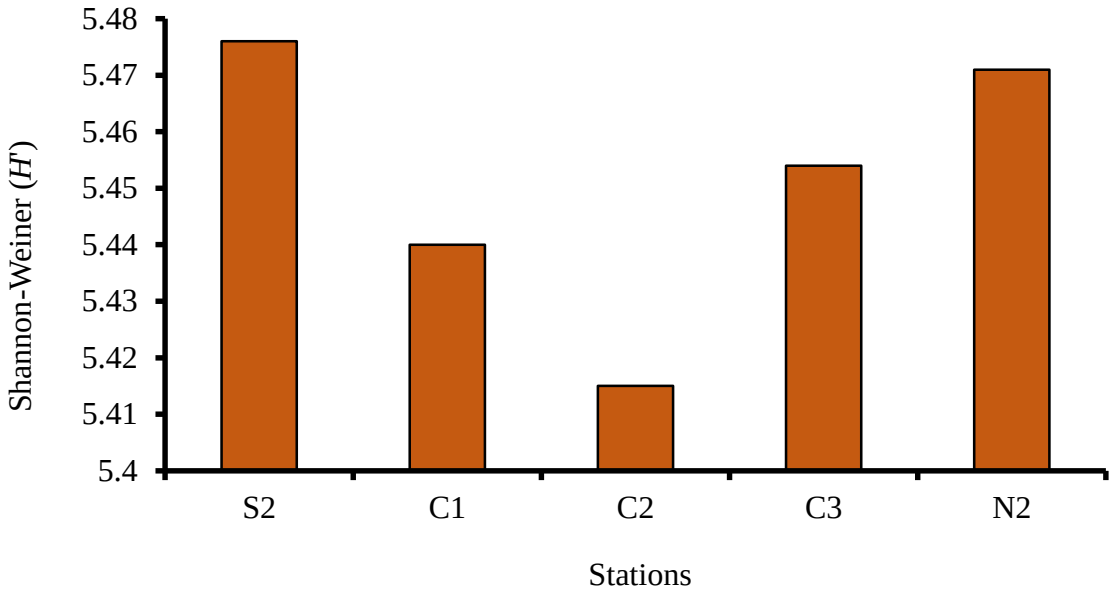

Figure 4.2: Zooplankton species diversity (Shannon- Weiner Index, *H*') at the stations sampled in Lake Baringo from April 2008 to March 2010.

Temporally, zooplankton community displayed marked seasonal fluctuation in diversity. The highest diversity was recorded in June 2008 with an index value of 2.02 followed by 1.99 in April 2008 while the lowest (0.82) was in September 2009 (Fig. 4.3). There was fluctuations in species diversity from the start of the study in April 2008 to March 2009 after which there was an increase followed by a decrease down to September 2009 after which there was another increase till December 2009.

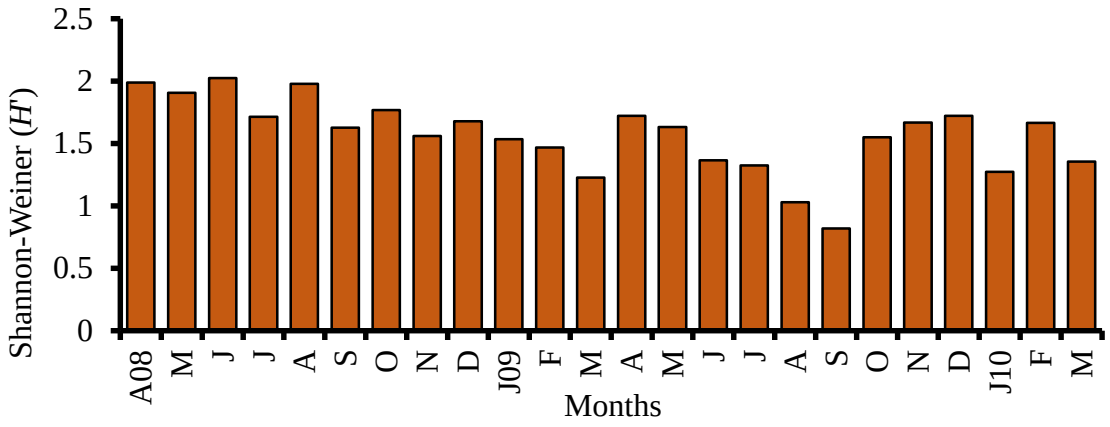

Figure 4.3: Zooplankton species diversity (Shannon- Weiner Index, *H*'), by month, recorded during the study period between April 2008 and March 2010.

4.3.3 Zooplankton Distribution, Abundance and Biomass

Spatially, zooplankton abundance showed a clear variation between different sampling stations (Fig.4.4). The highest zooplankton abundance of 101.7 ind l^{-1} was recorded at S2 while the lowest (76.4 ± 12.44 ind l^{-1}) was recorded at C1. The mean abundance among the sampling stations was 88.32 ± 4.93 ind l^{-1}.

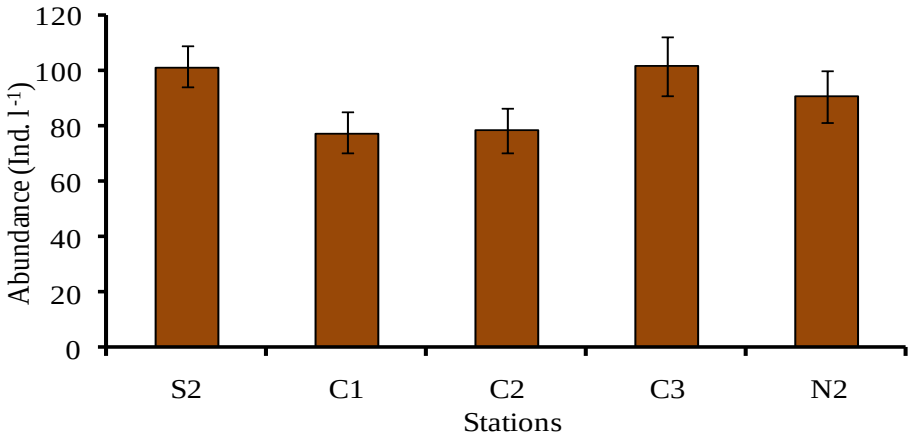

Figure 19: Zooplankton abundance (mean ±SE) at the stations sampled from April 2008 to March 2010.

One way ANOVA showed that there was significant difference in zooplankton abundance ($F = 2.47$, $P < 0.05$) among the stations. Further analysis, by Tukey (HSD) test showed that two homogenous groups of stations existed with respect to the abundance of zooplankton. The first

group consisted of S2, C3 and N2 while stations C1 and C2 were in the second group with the first group having significantly higher abundance than the second group.

Cluster analysis identified three primary clusters of stations based on similarities in zooplankton community structure. Stations S2 and C3 were in the first group, C2 and N2 in the second while C1 formed its own group (Fig. 4.5). It further showed that stations S2 and C3 were the most similar, with a Euclidean distance of 4.71, followed by C2 and N2 (Euclidean distance 7.35) while C1 was closer to the C2 and N2 cluster than to the S2 and C3 cluster.

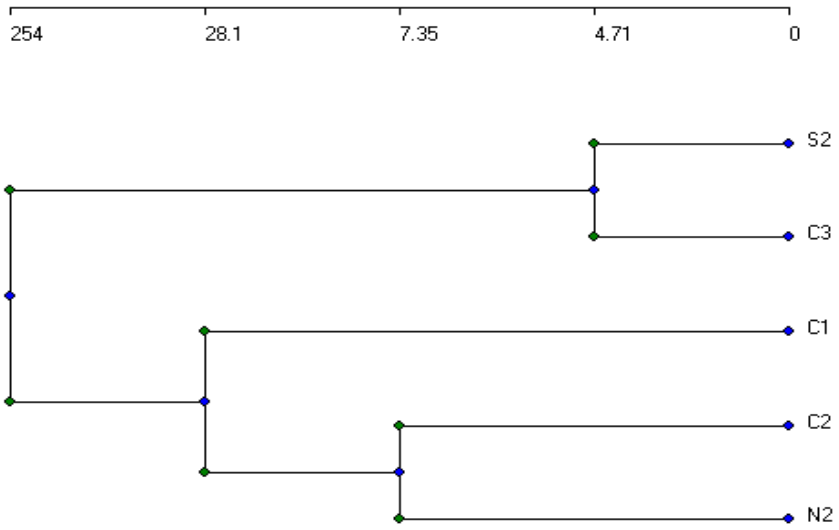

Figure 4.5: Hierarchical agglomerative clustering (Ward's method) of sampling stations using Euclidean distance of the zooplankton abundance in Lake Baringo from April 2008 to March 2010.

Temporally, the total zooplankton abundance ranged from 27.5 ind l^{-1} in December 2008 to 270.8 ind l^{-1} in January 2010 (Fig. 4.6) with a mean of 90.3 ± 11.75. The abundance tended to fluctuate at a fairly constant level from the start up to August 2009 after which there was a steady rise towards the end of the study period. There were fluctuations in the abundance of zooplankton exhibiting four obvious pulses during the study period.

One way ANOVA showed that there was significant difference in zooplankton abundance between months ($P < 0.05$; $F = 18.53$).

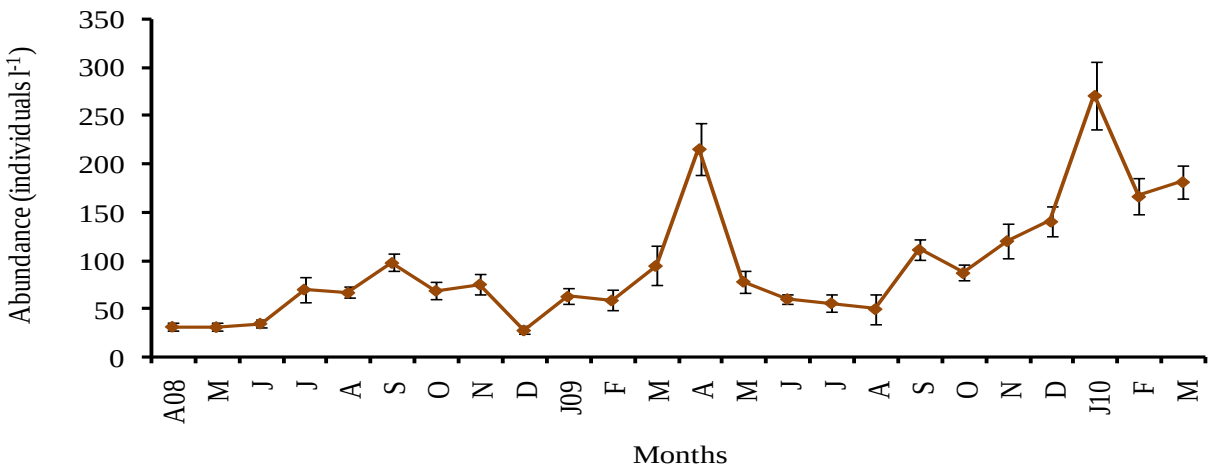

Figure 4.620: Temporal variations in zooplankton abundance (mean ± SE), in individuals l^{-1}, in Lake Baringo from April 2008 to March 2010.

Copepoda dominated zooplankton in abundance at all the study sites with relative composition ranging from 60% in S2 to 66% in N2 (Fig. 4.7). Cladocera contribution to total zooplankton abundance ranged from 9 to 13% in sampling stations C3 and C1, respectively. Contribution of Rotifera among the sampling stations varied from 23% in N2 to 29% in both S2 and C3.

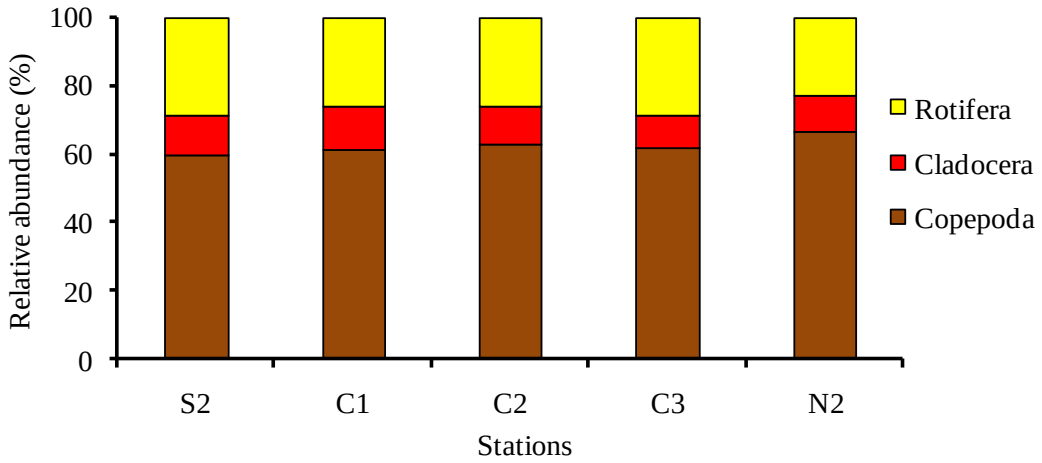

Figure4.7 Relative abundance of the major zooplankton groups at the stations sampled from April 2008 to March 2010.

Copepoda also dominated zooplankton abundance throughout the study period (Fig. 4.8) accounting for 43 to 86% of the total zooplankton abundance in June 2008 and September 2009,

respectively. The composition of Cladocera ranged from 3% in March 2010 to 28% in June 2008 while that of Rotifera fluctuated from 4% to 30% in September 2009 and April 2009, respectively.

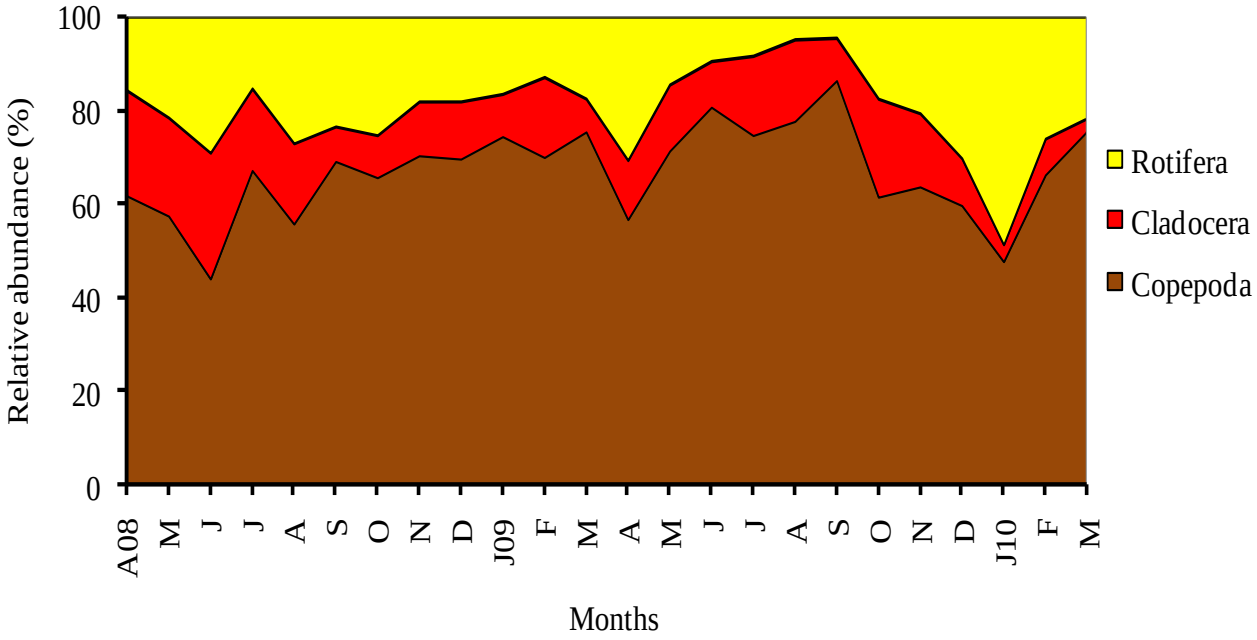

Figure: 4.8 Relative abundance of the major groups of zooplankton in Lake Baringo from April 2008 to March 2010.

Among Copepoda, the nauplii stage were the most abundant in all the sampled stations with a proportion ranging from 54.7% in N2 to 67.0% in C2 (Fig. 4.9). This was followed by adult Cyclopoida with a relative composition varying from 32.7 to 44.9% in stations C2 and N2, respectively. The adult calanoids occurred in very low abundances with < 0.1% in all the stations.

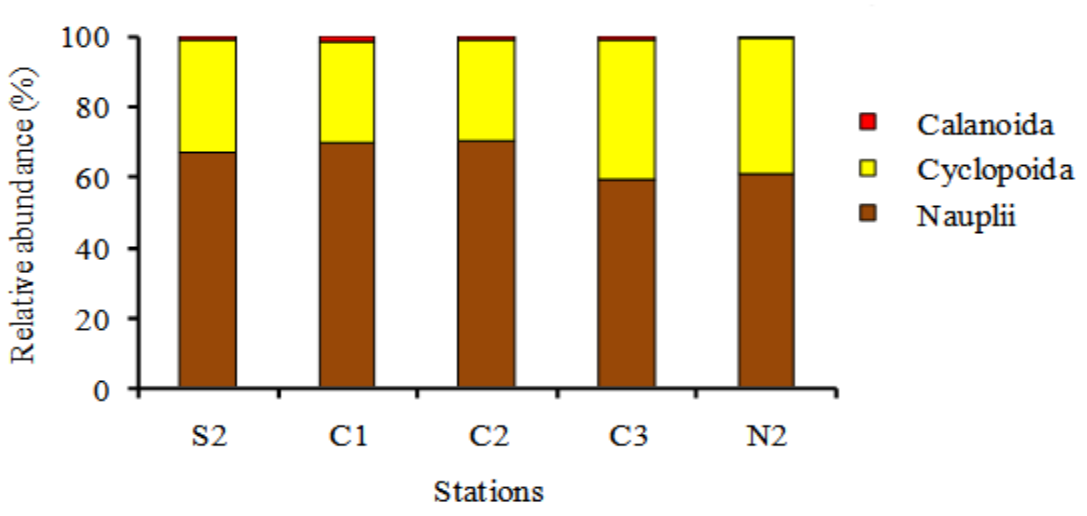

Figure 4.9 Relative abundance of nauplii and mature Cyclopoida and calanoida in the sampled stations in Lake Baringo between April 2008 and March 2010.

Temporally, nauplii stage composition ranged from 38% in August 2008 to 90% in September 2009 (Fig. 4.10) while mature Cyclopoida contributed between 10% and 62% in September 2009 and August 2008, respectively. Mature Calanoida contributed only 7% in April 2008, decreased to 0.1% in October 2008 after which none was recorded in the lake up to the end of the study (Fig. 4.10). The nauplii to mature copepod ratio ranged from 0.6 in April 2008 to 9.4 in September 2009.

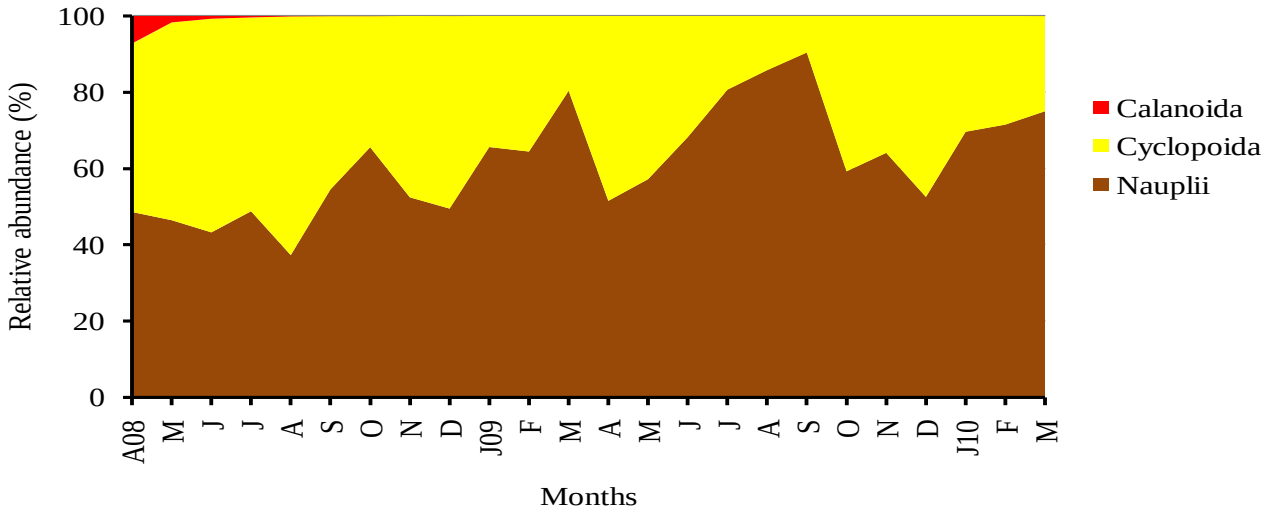

Figure 4.10: Relative abundance of Cyclopoida, Calanoida and nauplii, in Lake Baringo from April 2008 to March 2010.

Cladoceran abundance was dominated by *D. excisum* in all the stations with relative abundance ranging from 42.6 to 54.5% in stations C1 and S2, respectively (Fig. 4.11). Other important cladoceran species found in stations sampled included *M. micrura*, *C. cornuta* and *D. barbata*. *M. spinosa*, however, occurred in low proportions in all the stations. The highest composition attained by *M. spinosa* was 3.0% in station C3.

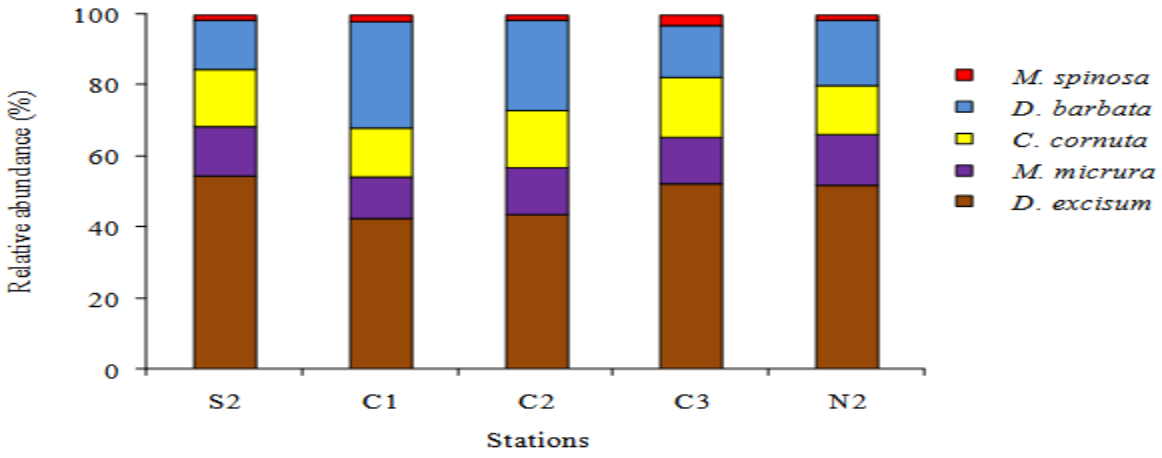

Figure 4.11: Relative abundance of cladoceran species in the sampled stations in Lake Baringo from April 2008 to March 2010.

Cladoceran abundance was dominated by *D. excisum* throughout the study period (Fig. 4.12). The species composition ranged between 26% and 96% in the months of November 2008

and August 2009 respectively (Fig. 12). On a number of occasions during the study, a reverse relationship between *D. excisum* and *D. barbata* was observed. In November 2008 and January 2010 there was a decrease in the proportion of *D. excisum* and an increase in proportion of *D. barbata*. A similar observation was made during April and July in 2008 and during February and April in 2009.

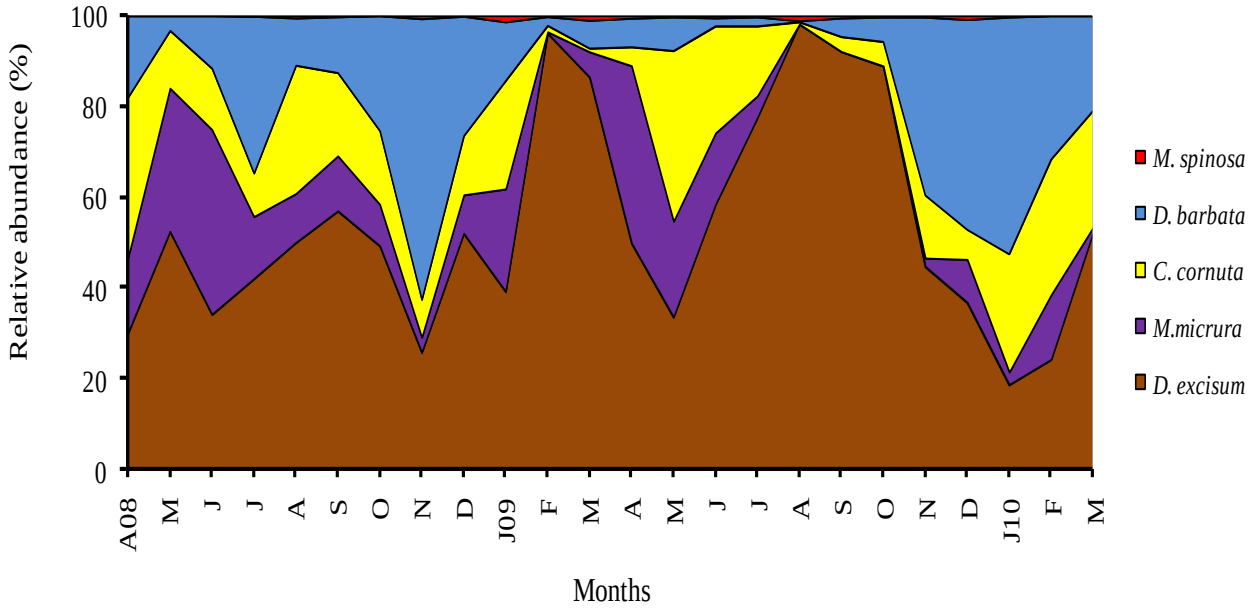

Figure 4.12: Relative abundance of cladoceran species in Lake Baringo from April 2008 to March 2010.

Rotifera were dominated in abundance by *F. opoliensis* and *K. tropica* at all the stations sampled followed by *Polyarthra* sp (Fig. 4.13). Composition of *F. opoliensis* ranged between 28.7 and 47.3% in stations C3 and C2, respectively while that of *K. tropica* ranged from 25.6% in N2 to 40.4% in S2. Other species recorded during the study period included *B. angularis, B. calyciflorus, B. falcatus, B. patulus, Hexarthra* sp and *Lecane* spp.

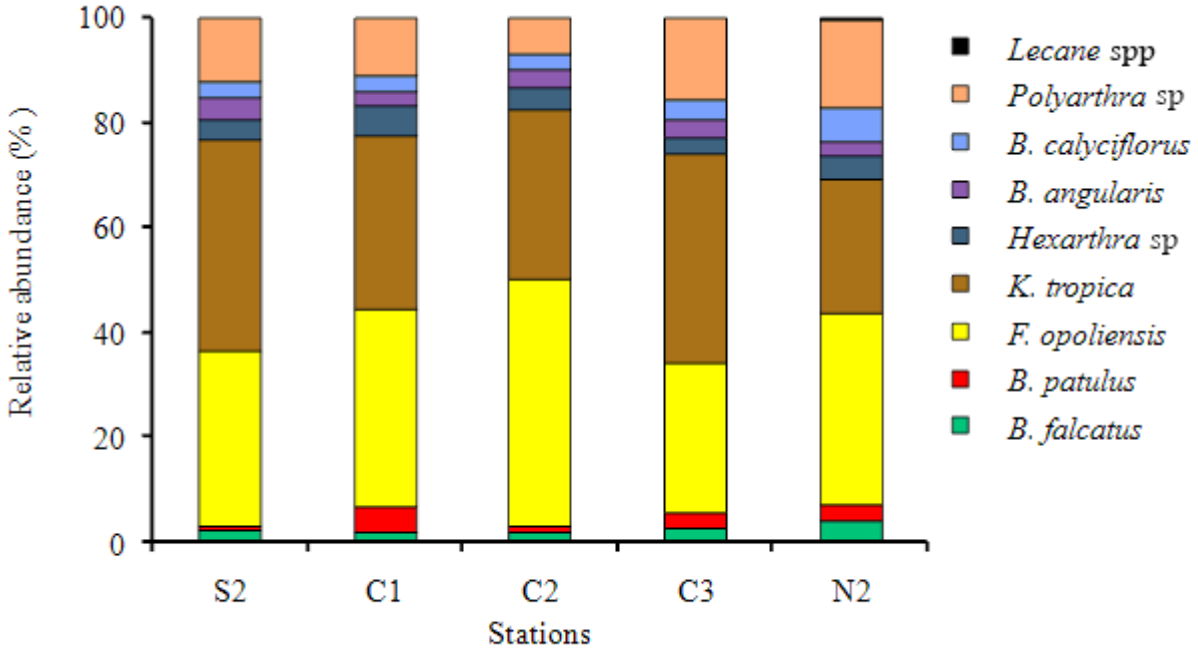

Figure 4.13: Relative abundance of Rotifera species at the sampled stations in Lake Baringo from April 2008 to March 2010.

F. opoliensis dominated the abundance in most of the months sampled except in May 2008 and January 2010 when *K. tropica* dominated (Fig. 4.14). Proportion of *F. opoliensis* was highest in March 2009 when it accounted for 85% of total rotifer abundance. The species, however, had the lowest proportion of 6% in May 2008 when *K. tropica* had the highest proportion of 44%. These two could be considered perennial species, occurring in all the months during the study period while *Lecane* spp, *B. falcatus* and *B. patulus* may be considered seasonal species. Strikingly, *B. patulus* appeared in samples from April 2008 to September 2008 after which the species was not recorded until January 2010 (Fig. 4.14). Although hardly abundant in the zooplankton community for most of the study period, rotifers showed one marked increase in abundance from September 2009 to a peak in January 2010 (Fig. 4.8). This was almost entirely due to the explosion in the population of *K. tropica* which accounted for 96% of total rotifer abundance (Fig. 4.14).

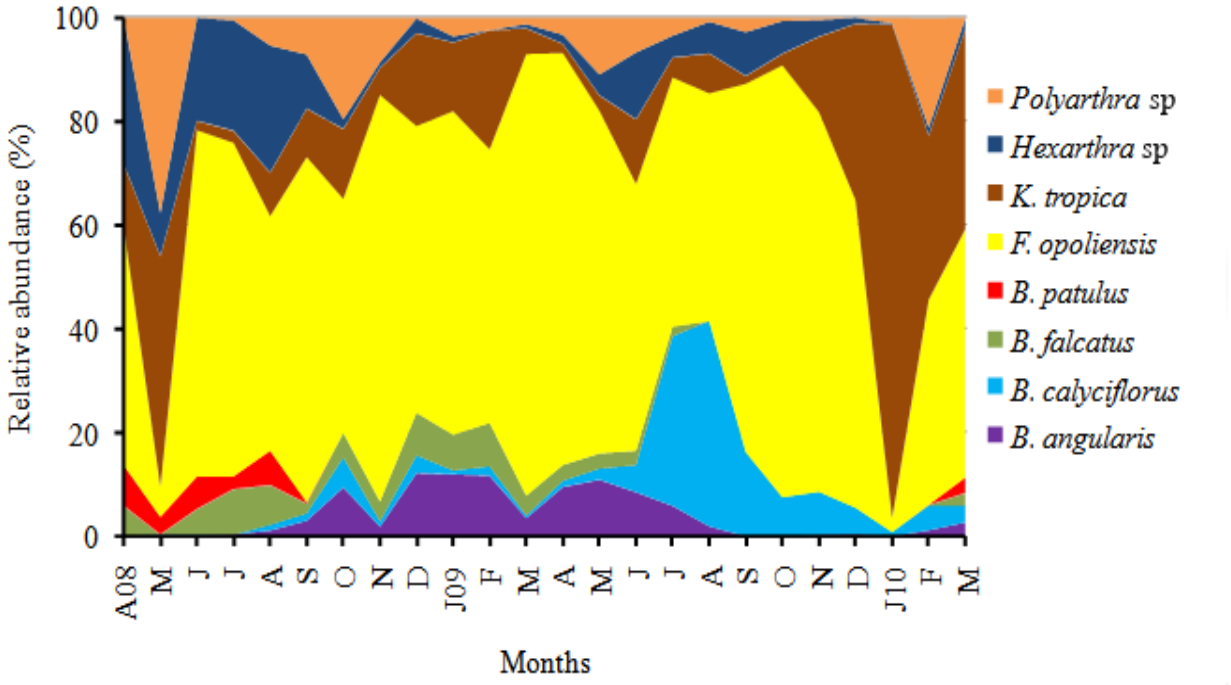

Figure: 4.14 Relative abundance of Rotifera species in Lake Baringo from April 2008 to March 2010.

The spatial distribution of zooplankton biomass showed clear variations between different sampling stations (Fig. 4.15). The highest biomass value of 89.94 µg l^{-1} was recorded at C3 followed by S2 with a value of 84.90 µg l^{-1} while the lowest value of 62.24 µg $l^{-1}$was obtained at C1. The mean biomass among the stations was 76.09 ± 5.40 µg l^{-1}. Statistically, there was no significant difference in zooplankton biomass between sampling stations ($P > 0.125$).

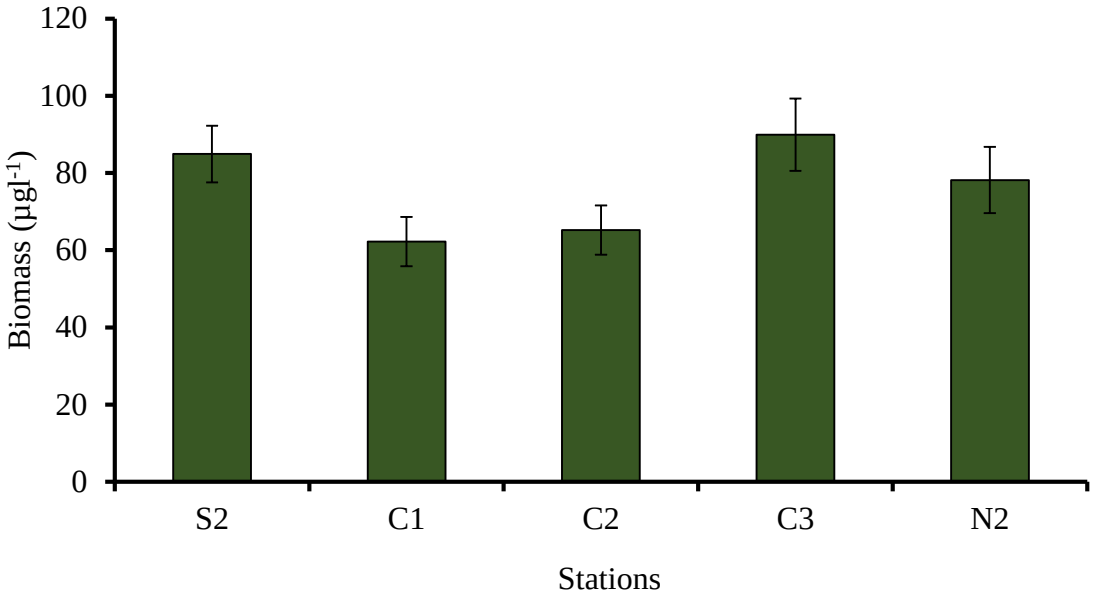

Figure 21: Spatial variations of zooplankton biomass (µg l^{-1} ± SE) at the different stations sampled in Lake Baringo from April 2008 to March 2010.

Throughout the study period, zooplankton biomass was characterized by relatively low values ranging from 32.29 µg l^{-1} at C1 in December 2008 to 133.79 µg l^{-1} recorded at C3 in December 2009 with a mean of 76.09 ± 6.19 µg l^{-1} (Fig. 4.16). Results of ANOVA test showed a significant variation in zooplankton biomass between the months sampled ($P < 0.05$).

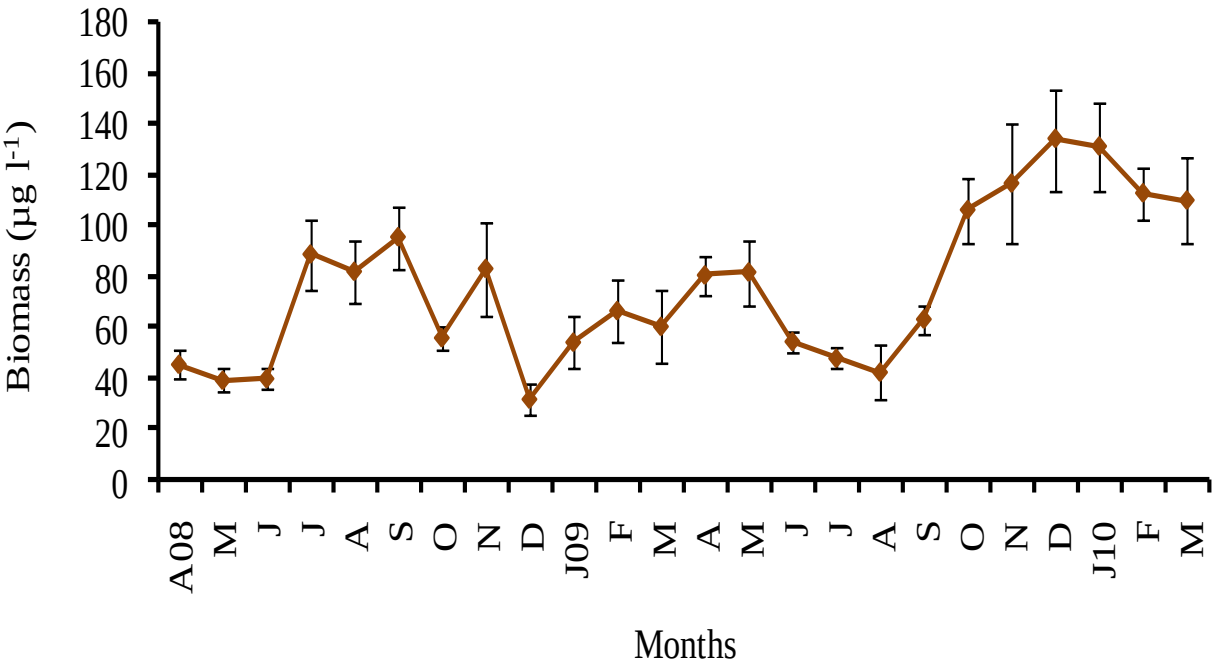

Figure 4.16: Temporal variations in zooplankton biomass (µg l^{-1} ± SE) from April 2008 to March 2010.

Spatially, Copepoda dominated the biomass at all sampled stations with relative proportion ranging from 65.64% at C1 to 76.44% at C3 (Fig. 4.17). Cladocera biomass contribution to total zooplankton biomass was highest (33.13%) at C1 and lowest (22.29%) at C3. At all the stations sampled, rotifer contribution was extremely low with the highest (1.35%) being realized at stations S2 and lowest (1.06%) at N2.

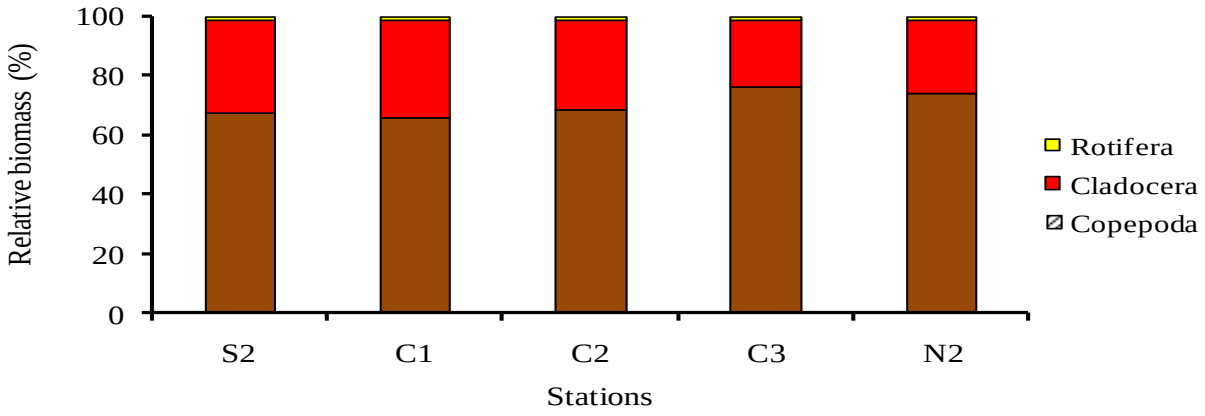

Figure 4.17: Relative biomass of major zooplankton groups at the stations sampled from April 2008 to March 2010.

Temporally zooplankton biomass was dominated by Copepoda with biomass ranging from 42% in August 2009 to 88.4% in March 2010 (Fig. 4.18). Cladocera biomass accounted for between 9.6% in March 2010 and 56.4% in August 2009 of the total zooplankton biomass. Rotifera on the other hand contributed less biomass than the two other groups with a proportion ranging from 0.4% in April 2008 to 4.0% of total zooplankton in January 2010.

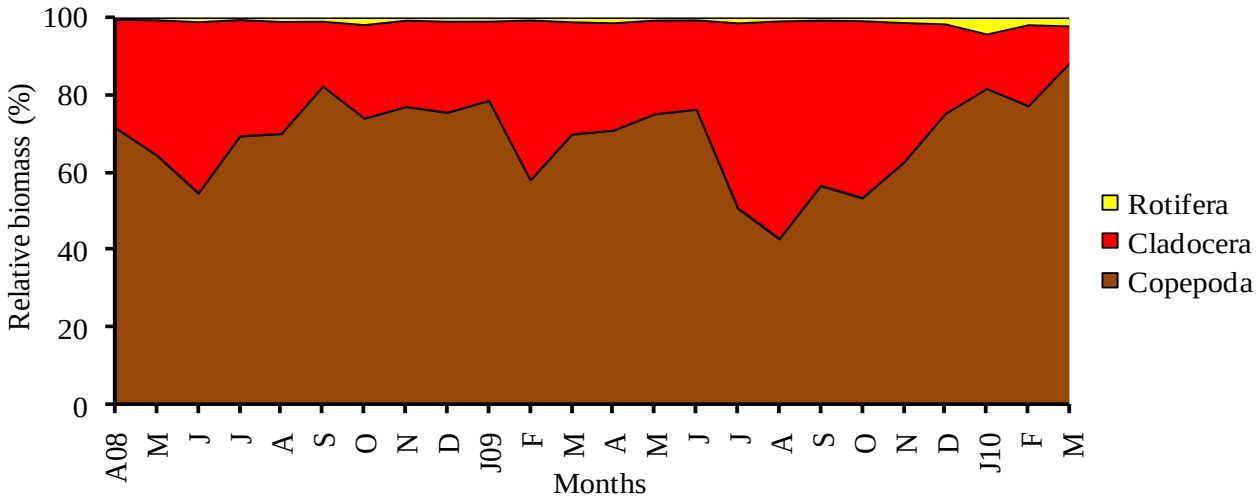

Figure 4.18: Relative biomass of major zooplankton groups in Lake Baringo between April 2008 and March 2010.

Mature Cyclopoida dominated copepod biomass in the sampled stations with a contribution of between 83.86% and 89.74% (Fig. 4.19). The highest proportion of 89.74% was recorded at

station C3 while the lowest of 83.34% was found at Station C1. Nauplii contributed between 9.2% at C3 and 14.12% at C2 of the Copepod biomass while adult Calanoida had low proportions of between 0.86% and 2.39 at N2 and C1, respectively.

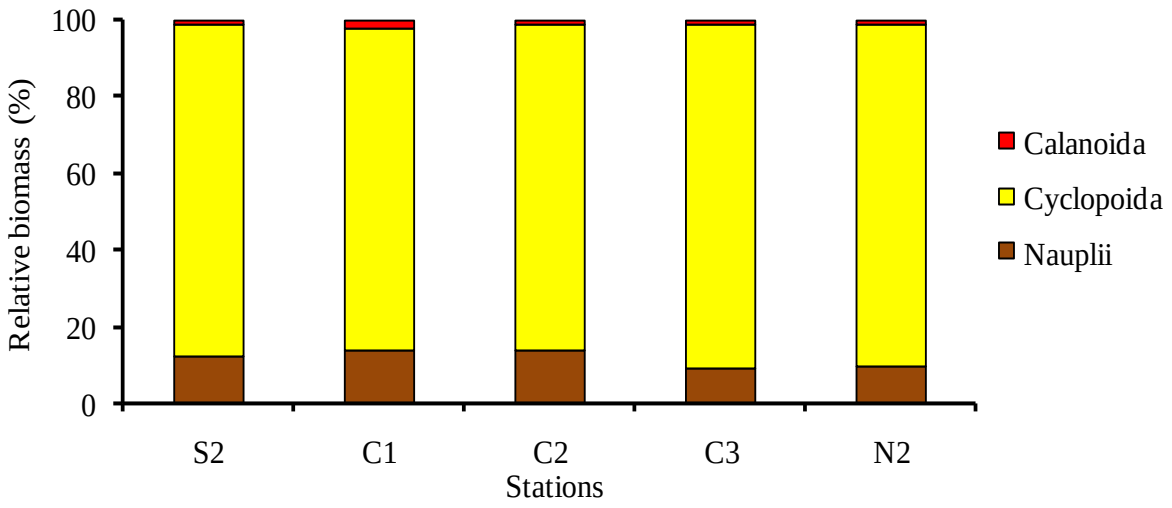

Figure 4.19: Relative biomass of nauplii and Cyclopoida and Calanoida adults in the sampled stations in Lake Baringo between April 2008 and March 2010.

As in spatial contribution, adult Cyclopoida dominated the biomass of copepods throughout the sampling period with a proportion of between 60.78% in September 2009 and 95.52% in August 2008 (Fig. 4.20). Contribution of adult Calanoida to copepod biomass was only significant in the first two sampling months with 34% and 9.4% after which the biomass steadily decreased up to December 2008 after which there were no calanoids in the samples until the last month of the study period (March 2010) when the organisms emerged accounting for 0.23% contribution. Unlike in abundance, nauplii biomass was lower than that of adult Cyclopoida throughout the study period. Nauplii contributed between 3.9% and 39.22% of total copepod biomass in August 2008 and September 2009, respectively.

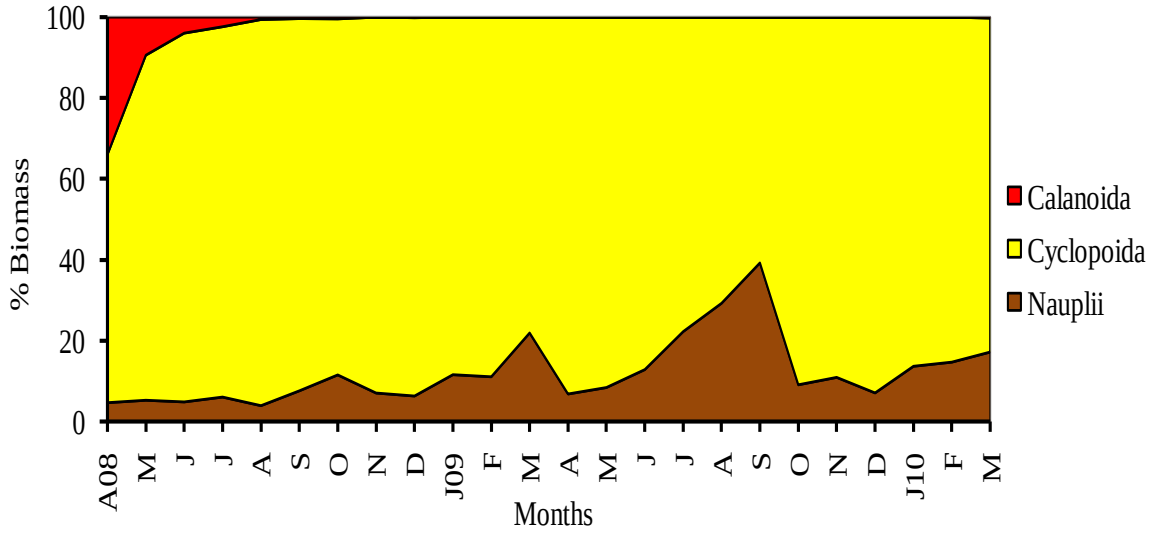

Figure 4.20: Relative biomass of nauplii and Cyclopoida and Calanoida adults in Lake Baringo between April 2008 and March 2010.

Cladoceran biomass ranged from 19.54 µg l^{-1} at C2 to 26.6 µg l^{-1} at S2. *D. excisum* biomass dominated in all the stations with proportion of 51% at C1 to 73.4% at S2 and 11.8% in S2 to 28% at C1, respectively (Fig. 4.21).

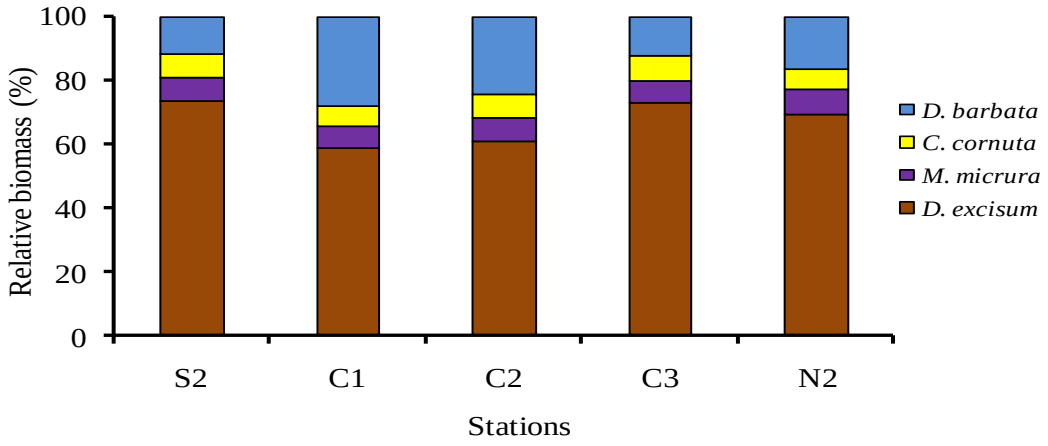

Figure 4.21: Relative biomass of four cladoceran species in the sampled stations between April 2008 and March 2010.

The other cladoceran species which occurred in all the stations, albeit in low proportions, were *M. micrura* and *C. cornuta*. Temporally, the two dominant species constituted 60% and above of total

cladoceran biomass throughout the study period (Fig. 4.22). *D. excisum* biomass dominated in all the months except in November 2008 and January 2010 when *D. barbata* dominated.

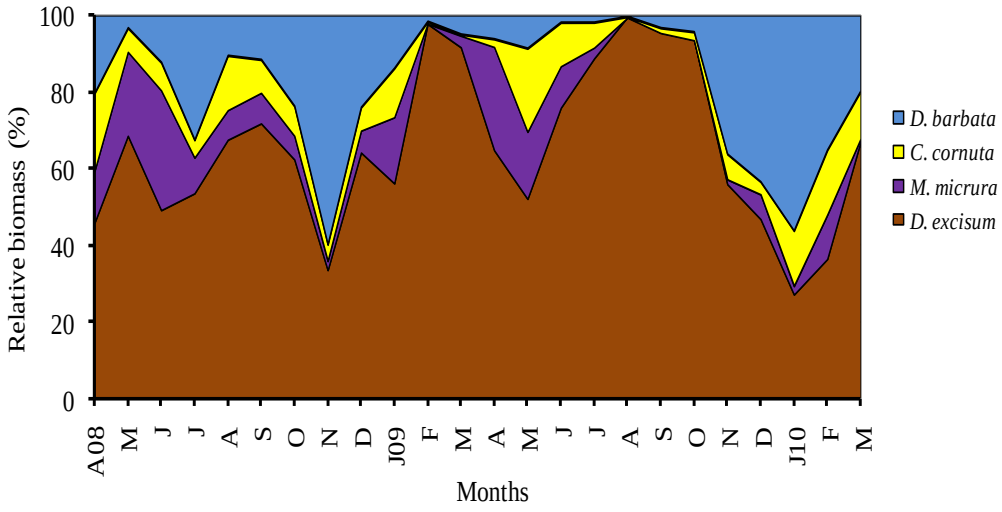

Figure 4.22: Relative biomass of Cladocera species in Lake Baringo between April 2008 and March 2010.

The biomass of Rotifera in Lake Baringo was generally very low with the highest biomass of 1.15 µg l^{-1} being recorded in station C3 followed by 1.14 µg l^{-1} in S2 while the lowest biomass of 0.77 µg l^{-1} was recorded in C1. Rotifer biomass in the sampling stations was dominated by *K. tropica*, *F. opoliensis* and *B. calyciflorus* (Fig. 4.23).

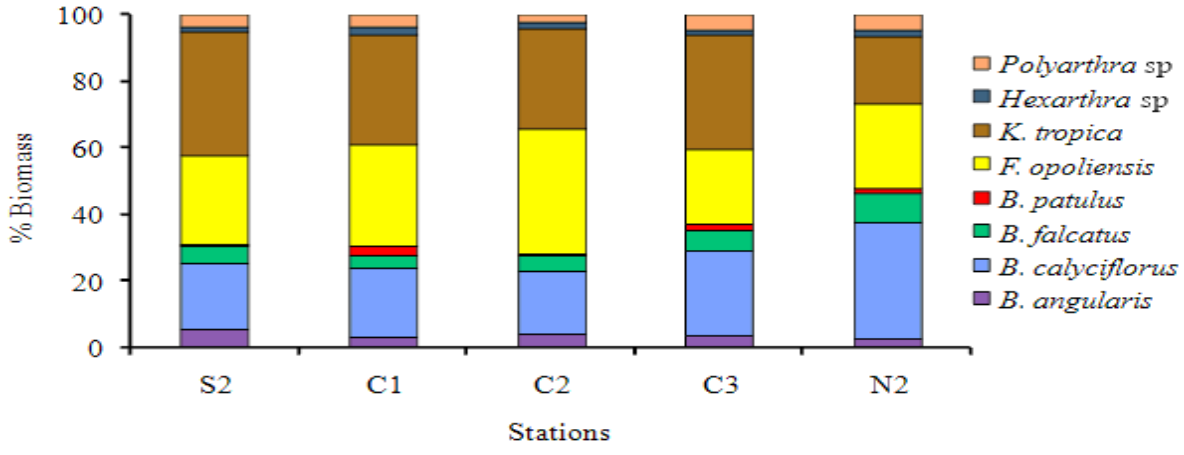

Figure 4.23: Relative biomass of rotifer species in the sampled stations between April 2008 and March 2010.

Rotifera biomass, during the study, was dominated by *F. opoliensis* with a proportion ranging from 2% in January 2010 to 67% in March 2009 (Fig. 4.24). Other rotifer species with significant biomass contribution were *B. calyciflorus* and *K. tropica*. Biomass of *B. patulus* was recorded in the first year of study up to September 2008 after which there was none until February 2010 when biomass was again recorded. Other species whose biomasses were important during the study included *Hexarthra* sp, *B. angularis* and *Polyarthra* sp.

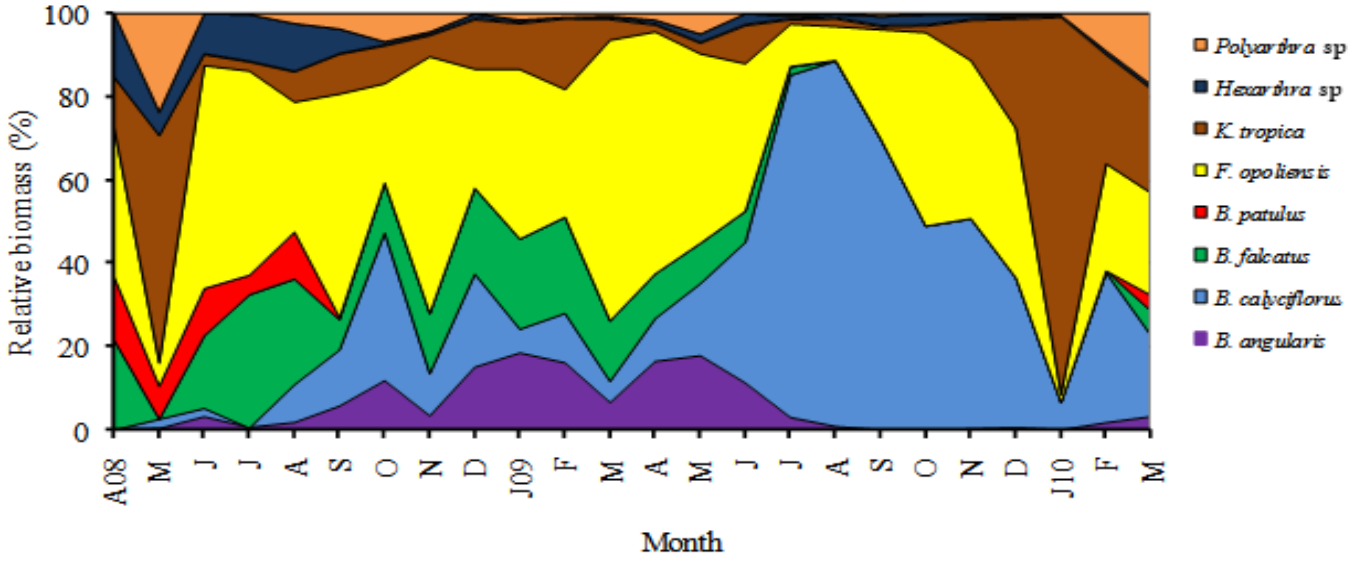

Figure 4.24: Relative biomass of rotifer species in Lake Baringo between April 2008 and March 2010.

4.3.4 Relationships between physico-chemical factors and zooplankton abundance

Pearson correlation coefficients showed that there were significant positive correlations between the abundance nauplii and turbidity (r = 0.62) and conductivity (r = 0.68) while mature cyclopoids were positively correlated with turbidity (r = 0.55). Among the rotifers, *B. calyciflorus* was negatively correlated with depth (r = -0.5) and positively correlated with conductivity (r = 0.62) while *K. tropica* was positively correlated with turbidity (r = 0.61) (Table 4.2). Calanoida had an insignificant negative relationship with conductivity (r = -0.43).

Table 4.2: Correlation matrix between physico-chemical parameters and zooplankton species abundance in Lake Baringo between April 2008 and March 2010. Nau = Nauplii, Cycl = Cyclopoida, Cal = Calanoida, *De = D. excisum*, *Mm =M. micrura*, *Cc = C. cornuta*, *Db = D. barbata*, *Ms = M. spinosa*, *Ba = B. angularis*, *Bc = B. calyciflorus*, *Bf = B. falcatus*, *Bp = B. patulus*, *Fo = F. opoliensis*, *Kt = K. tropica*, *Hex = Hexarthra* sp, *Poly = Polyarthra* sp, *Lec = Lecane* spp.

	Depth	Turb	Temp	pH	Cond	Hard	Alkal	DO	Chl *a*	SRP	NH_4	NO_3
Nau	-0.47	0.65*	-0.03	0.42	0.68*	0.35	0.28	0.01	-0.09	0.18	-0.13	0.26
Cycl	-0.32	0.55*	-0.05	0.08	0.45	0.19	-0.09	-0.08	0.13	0.18	-0.02	0.36
Cal	0.16	-0.11	-0.04	0.15	-0.43	-0.29	-0.38	-0.09	0.11	-0.08	0.02	-0.05
De	-0.34	-0.15	-0.05	-0.06	0.21	0.18	0.21	-0.03	0.16	-0.07	0.28	-0.01
Mm	0.12	-0.18	-0.12	-0.24	-0.23	-0.24	-0.13	-0.11	-0.03	0.08	-0.04	-0.16
Cc	-0.20	0.25	-0.19	0.12	0.12	0.15	-0.19	-0.20	0.16	0.09	0.12	0.01
Db	-0.12	0.39	0.02	-0.07	0.33	0.09	0.08	-0.03	0.29	0.13	-0.01	0.39
Ms	-0.27	0.03	0.04	0.03	0.16	0.14	0.09	0.08	0.22	-0.06	0.06	0.11
Ba	0.02	-0.01	0.03	0.08	-0.05	0.04	-0.14	-0.01	-0.26	-0.04	-0.22	-0.09
Bc	-0.50*	0.39	0.01	0.17	0.62*	0.40	0.15	-0.13	0.11	0.12	-0.04	0.48
Bf	0.34	-0.10	0.12	-0.05	-0.38	-0.31	-0.21	0.001	0.05	-0.02	0.09	-0.25
Bp	0.09	0.09	0.21	0.20	-0.13	-0.18	-0.10	-0.01	0.05	0.03	0.01	-0.05
Fo	-0.25	0.33	0.03	0.13	0.43	0.12	-0.09	0.03	0.18	0.15	-0.02	0.48
Kt	-0.27	0.61*	-0.05	0.13	0.40	0.22	0.08	-0.02	0.03	0.18	-0.13	0.20
Hex	0.15	-0.17	-0.05	-0.14	-0.28	-0.34	-0.23	-0.17	0.29	0.09	0.43	-0.14
Poly	-0.06	0.33	-0.29	-0.08	0.15	0.03	-0.08	-0.26	-0.14	0.05	-0.11	-0.01
Lec	-0.12	0.17	-0.13	0.04	0.14	0.06	-0.01	-0.09	-0.03	0.16	-0.04	0.09

- *Significant at $P< 0.05$

Although chlorophyll *a* was only significantly correlated with the abundance of few species of zooplankton, comparison between zooplankton abundance and Chl *a* concentrations revealed that zooplankton abundance peaks always followed those of Chl *a* (Fig. 4.25).

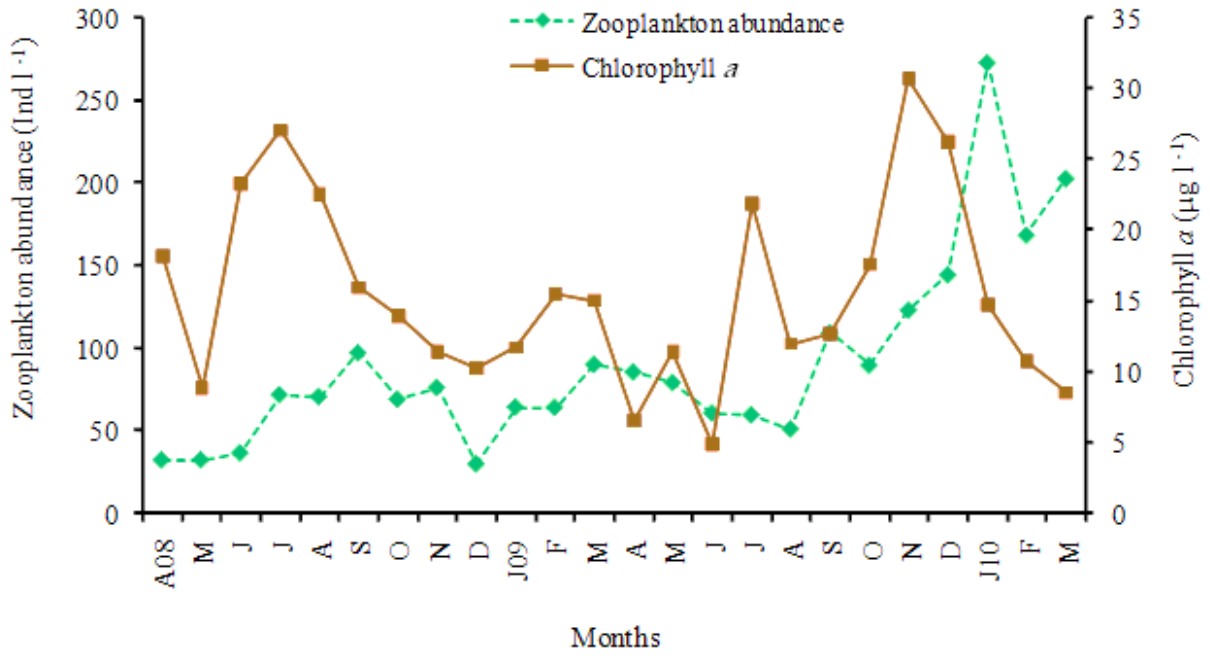

Figure 4.25: Relationship between total zooplankton abundance and chlorophyll a between April 2008 and March 2010.

Computation of stepwise multiple regression between the physico-chemical parameters and zooplankton species abundance identified parameters that influence zooplankton dynamics in the lake (Table 4.3). The influences were, however, weak with R^2 being less than 0.5 with most variables. Conductivity and turbidity appeared to be the main parameters influencing the distribution and abundance of zooplankton in the lake.

Table 4.3: Results of stepwise multiple regression analysis between physico-chemical factors and zooplankton species abundance in Lake Baringo from April 2008 to March 2010.

Zooplankton species	**Parameters (*P*, R^2)**	
Nauplii	Conductivity (< 0.05; 0.465)	Turbidity (< 0.05; 0.549)
Cyclopoida	Turbidity (0.05; 0.298)	Alkalinity (<0.05; 0.333)
Calanoida	Conductivity (< 0.05; 0.186)	Secchi (< 0.05; 0.422)
D. excisum	Depth (< 0.05; 0.118)	Turbidity (< 0.05; 0.211)
M. micrura	Hardness (<0.05; 0.056)	Silicates (<0.05; 0.010)
C. cornuta	Secchi (0.05; 0.070)	Alkalinity (<0.05; 0.130)
D. barbata	Secchi (< 0.05; 0.189)	
M. spinosa	Depth (<0.05; 0.007)	
B. angularis	Chl *at* (<0.05; 0.080)	
B. calyciflorus	Conductivity (<0.05; 0.384)	Nitrates (<0.05; 0.406)
B. falcatus	Conductivity (<0.05; 0.146)	Turbidity <0.05; 0.179)
B. patulus	Temperature (<0.05; 0.448)	Hardness (<0.05; 0.091)
F. opoliensis	Nitrates (<0.05; 0.227)	Conductivity (<0.05; 0.261)
K. tropica	Turbidity (< 0.05; 0.360)	
Hexarthra sp	Ammonium (< 0.05; 0.183)	Hardness (<0.05; 0.258)

Principal Component Analysis (PCA) was carried out between the abundance of major zooplankton groups, stations and physico-chemical parameters. It separated zooplankton groups based the physico-chemical parameters associated with this distinction. Axis 1 grouped Stations N2, C1 and C2, characterized with high abundance of Cladocera while C3 and S2 were characterized with high abumndance of Copepoda and Rotifera (Fig. 4.26). Axis 2 further separated N2 and C2 from C1 based on secchi and alkalinity, respectively and Station S2 from C3 based on ammonium and turbidity, respectively.

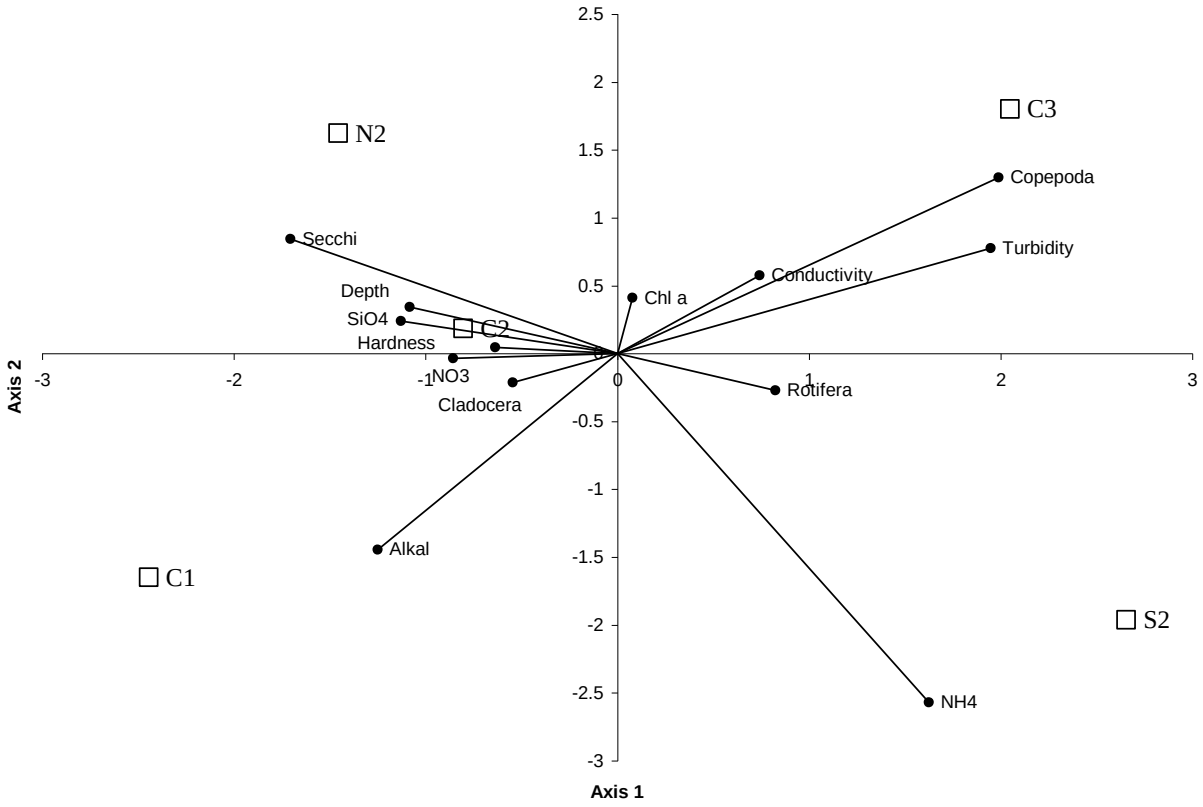

Figure 4.26: Principal Component Analysis (PCA) between abundance of major zooplankton groups and physico-chemical parameters in Lake Baringo between April 2008 and March 2010.

4.3.5 Relationships between physico-chemical factors and zooplankton biomass

Pearson correlation coefficients analysis between the biomass of different species of zooplankton and physico-chemical factors showed the same outcome as that with abundance. Although there was insignificant correlation between the biomass of the various zooplankton species and Chlorophyll *a*, the temporal variation between the two showed that zooplankton biomass and Chl *a* concentration coincided (Fig. 4.27).

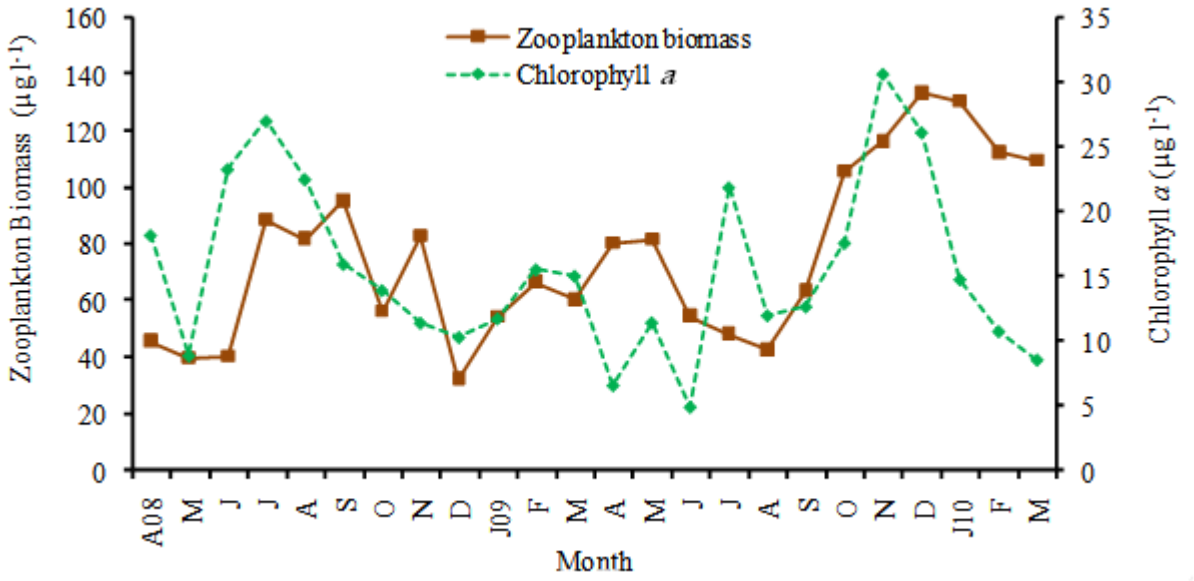

Figure 4.27: Relationship between total zooplankton biomass and chlorophyll *a* concentration between April 2008 and March 2010.

A significant and positive relationship was found between zooplankton biomass and turbidity (r = 0.54) and conductivity (r = 0.55) showing that these variables have influence on the zooplankton biomass in the lake. Zooplankton biomass had a positive but insignificant correlation with nitrates (r = 0.38) and negative with depth (r = -0.45).

Principle Component Analysis (PCA) carried out between the biomass of major zooplankton groups and physico-chemical parameters showed Station S2 to be influenced by ammonium and turbidity but was characterized by elevated Cladocera biomass (Fig. 4.28). Stations C1 and C2 were both influenced by alkalinity and hardness and characterized by high Rotifera biomass. Stations C3 and N2 were both characterized by high biomass of Copepoda. However, while C3 was influenced by turbidity and conductivity, N2 was influenced by Secchi and depth.

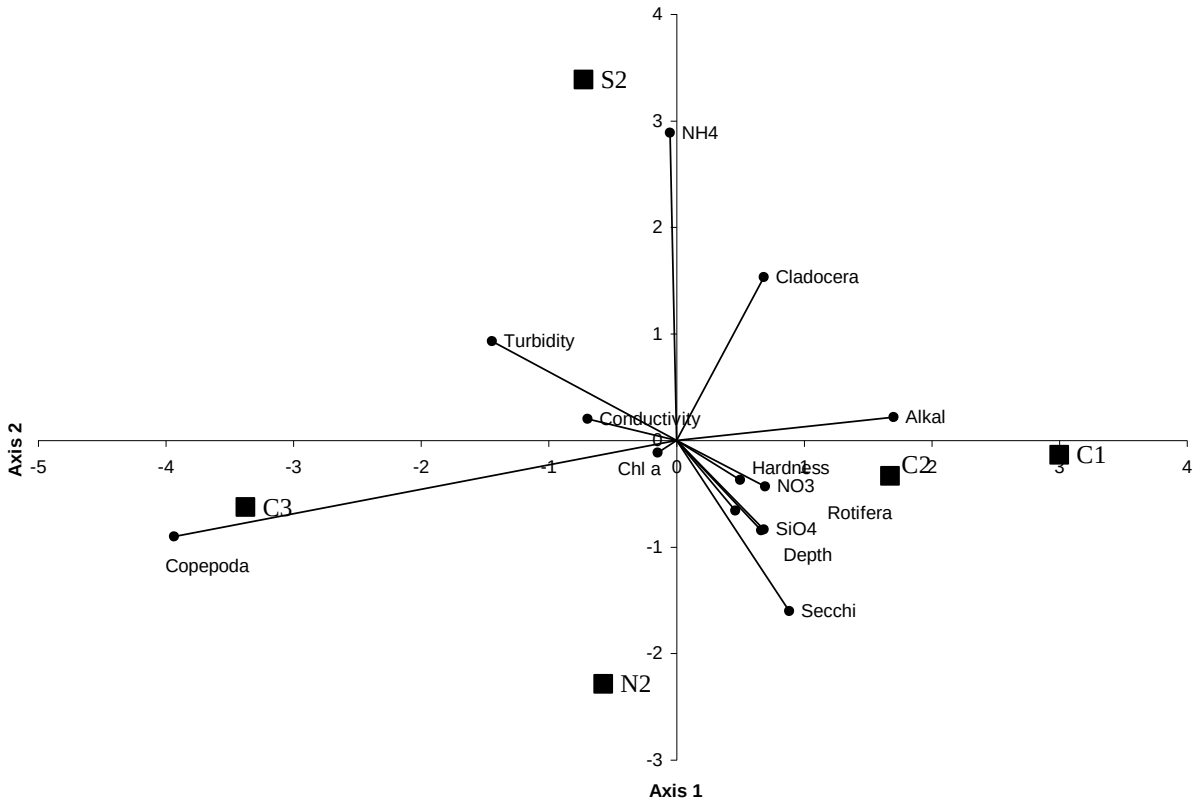

Figure 4.28: Principal Component Analysis (PCA) between biomass of major zooplankton groups and physico-chemical parameters in Lake Baringo between April 2008 and March 2010.

4.4. Discussion

The zooplankton community in Lake Baringo is characterized by typical freshwater species comparable to those found in other Rift Valley freshwater lakes (Wodajo & Belay, 1984; Mavuti, 1990; Uku & Mavuti, 1994; Sarmento *et al.*, 2009). Copepods from the most abundant zooplankton group in the lake corroborating previous observations that this group dominates the community in tropical freshwater ecosystems (Mavuti & Litterick, 1991). Whereas Busienei (2003) reported that zooplankton community in Lake Baringo was dominated by *Mesocyclops* sp, results of this study showed that the community was dominated by *Thermocyclops consimilis*. *Mesocyclops* found were very few and no mature female was found that could be used for detailed identification to species level. Busienei (2003) identified the only calanoid in the lake as *Diaptomus* sp while in this study this species was identified as *Thermodiaptomus galebi* from the shape and armature of the second ornamentation of the second exopodite segment of the left male P5**.**

The generally low species diversity found in this study has also been reported in other Rift Valley freshwater lakes (Burgis, 1973; Mavuti, 1990; Uku & Mavuti, 1994). A large number of studies covering a wide variety of ecosystems and organisms suggest that species richness tends to vary strongly with ecosystem production and habitat heterogeneity (Rosenzweig, 1995). Connectivity of habitats has also been reported to influence diversity through passive dispersal (Doi *et al*., 2010). The high species diversity reported in the southern and eastern parts of the lake are due to connectivity with rivers whose water velocity could dislodge some zooplankton species from the estuarine swamps into the lake. The unusually high diversity in the northern zone could be attributed to calm water sheltered by rocky cliffs. The central zone of the lake, which had the lowest diversity, on the other hand is exposed to regular wind mixing. These results agree with those of Tiwari and Vijayyalakshimi (1993) who attributed high zooplankton diversity to calmer and more stable waters. Temporal variations in diversity of zooplankton could be attributed to the changes in the abiotic and biotic components in the lake. Reduction in water volume in the lake results in higher concentration of ions in the water thus stressing the organisms. Increase in water volume, on the other hand, due to rainfall results in dilution of the lake water solutes ion concentrations.

The variability of zooplankton species composition, abundance and biomass indicates that the lake is dynamic and changes with time. Spatial variation was influenced mainly by

morphometric characteristics of the lake while temporal variations were influenced by weather changes during the sampling period especially rainfall. Tropical lakes are generally small, shallow and it is difficult to establish a large scale spatial heterogeneity (Sarma *et al.*, 2005).

The low occurrence and seasonality of Calanoida was a striking feature of zooplankton community in the lake. The decline after October 2008 and later collapse in their population may be attributed to the increase in conductivity observed in the same period. This is supported by the high negative and significant correlation between conductivity and calanoids also reported in Lake Nakuru (Chepkiyeng *et al*., 2010) and in some Ethiopian lakes by Wodajo and Bailey (1984). Among the copepods, the order Calanoida is more representative in oligotrophic environments, while the order Cyclopoida is abundant in eutrophic systems (Wetzel, 2001). The low abundance of calanoids in Lake Baringo may therefore be an indication of a eutrophic environment. Moreover, Beenamma and Sadanand (2011) reported that cyanobacterium *M. aeruginosa*, which is dominant in this lake (Owili *et al*., 2008), is probably poisonous to calanoids.

The dominance of Cladocera by *D. excisum* can be attributed to its adaptation to the prevailing turbid conditions in the lake. Hart (1988) showed that *D. brachyrum* is better adapted to mineral turbidity. Rajeshekher *et al*. (2009) reported that *D. excisum* thrives in high organic content water bodies and can be considered as an indicator of eutrophication. The prominence of *D. barbata* in Lake Baringo is not surprising as the species is a typical turbid water species (Hart, 1988). In Lake Victoria, the species is reported to occur only in the turbid river mouth localities in the Nyanza Gulf (Omondi, 2003).

The low abundance and diversity of copepods and cladocerans in Lake Baringo may be explained by the unfavourable conditions in the lake such as high turbidity and presence of planktivorous fish. Visual predation by fish on large zooplankton is considered a major factor structuring the zooplankton community of lakes through top-down control (Rachman & Fitriya, 2012). However, the presence of the large bodied *D. barbata* in Lake Baringo can be attributed to the turbidity of the lake water which reduces its visibility. The species have been found to dominate the zooplankton of Lake Chilwa in Malawi despite the high densities of cichlid fishes (Kalk, 1979). In high turbid lakes, fish predators may be non-selective, allowing the persistence of large species (Geddes, 1984). A positive relationship between turbidity and occurrence of large zooplankton when fish are present has also been reported by Timms in New South Wales (1970).

Rotifers are rare in the pelagic environments of the African Great lakes but have high abundances in the littoral areas and shallow lakes like Lake George and Lake Kyoga (Green, 1967). In this study, 23 species of rotifers were recorded of which 17 were littoral species. The high number of species of the macrophyte loving genus *Lecane*, despite limited population of water plants in the lake is probably because of its shallow depth. This conforms earlier findings (Cronin *et al*., 2006) that such species may be found in the plankton when the populations become dense or when swept by currents after rainfall. Rainfall has been reported to be a major factor that influences zooplankton abundance and population dynamics (Kizito & Nauwerck, 1995; Osore *et al*., 1997). The near daily wind mixing in the lake could also have aided in dislodging these organisms from macrophytes in littoral areas into the pelagic areas. These results are similar to those of earlier studies in Ethiopian lakes by Wodajo and Belay (1984). The high abundance of some rotifer species could also be due to the fact that they are r-strategists, with short life-cycles and a wide tolerance to fluctuations of environmental factors (Wetzel, 2001; Neves *et al*., 2003). The population explosion of *K. tropica* and *F. opoliensis* in Lake Baringo towards the end of the study was probably due to increased availability of suitable food. Rotifers are able to outcompete other groups of zooplankton because they have less specialized feeding habits, parthenogenic reproduction and high fecundity (Sampaio *et al*., 2002).

The generally low biomass of zooplankton in the lake (76 µg l^{-1}) can be associated with the low diversity and density of the organisms, especially the large sized ones. Burgis (1973) reported a mean crustacean biomass of 326 µg l^{-1} in Lake George. Mavuti (1990) on the other hand reported mean total zooplankton abundance in range of 120 to 650 individuals l^{-1} and mean total zooplankton biomass that ranged from 80 to 480 µg l^{-1} for Lake Naivasha. The low biomass in the lake could be attributed the low primary production due to low transparency. Although copepods dominated the zooplankton community biomass in Lake Baringo, this was to a lesser extent than they did in abundance. This was due to the relatively greater individual weights of the less numerous cladocerans, especially *D. excisum* and *D. barbata*. Rotifers on the other hand, while contributing substantially to zooplankton abundance, accounted for a small portion of the biomass due their small size.

Results of the study showed that among the environmental factors, lake depth, water transparency, temperature and dissolved oxygen content were negatively correlated to both abundance and biomass of the major groups of zooplankton in Lake Baringo. Lake depth and

transparency in the lake were positively correlated and both increase with increase in precipitation. Increased water volume in the lake results in the dilution of suspended solids allowing deeper penetration of light and also dilution of organisms in the water. Decrease in both depth and water transparency have been shown, in chapter 3, to result from the increase in nutrients with possibly increase in primary production. Indeed PCA results showed that abundance of Cladocera is influenced positively with depth and water transparency. However, this may not favour copepods and rotifers because of their mode of feeding. While cladocerans are able to feed on large sized phytoplankton, rotifers feed on small particles usually less than 12 µm in diameter, which include bacteria, small algae and detrital particulate matter (Claps *et al*., 2011).

In contrast to the impact of water depth on Chlorophyll *a*, zooplankton abundance seem not to be favoured by reduced depth. This could explain the seasonality observed in some species such as calanoids and the rotifer species *B. falcatus* when conductivity values changed in the lake. While higher conductivity favoured nauplii and *B. calyciflorus*, such conditions resulted in the decrease or total disappearance of calanoids and some rotifers such as *B. falcatus*.

The study showed that there was a weak correlation between phytoplankton biomass (Chlorophyll *a*) and zooplankton communities hence an imbalance in the ecosystem. This could be a pointer that zooplankton were also relying on other food sources other than phytoplankton, probably microzooplankton and detritus as reported by Pinto-Coelho *et al*., (2005) and Morgado *et al*., (2007; Friedrich & Pohlmann, 2009; Mitra, 2009).

4.5 Conclusion

The study showed that the lake has low diversity of zooplankton especially Copepoda where only two species of Cyclopoida and one species of Calanoida were recorded. The two species of cyclopoids were *Thermocyclops consimilis* and an unidentified species of *Mesocyclops*. The important cladoceran species were *D. excisum, M. micrura, D. barbata* and *C. cornuta* while important rotifer species included *F. opoliensis, K. tropica* and *B. calyciflorus.* While some species had low abundances, their importance with respect to their relative biomass was noteworthy.

Although there was little variation in composition, abundance and biomass spatially, results showed that there were significant temporal variations in the lake, hence hypothesis 2, which stated

that there are no significant temporal and spatial changes in the composition, diversity, abundance and biomass of zooplankton in the lake was rejected.

The study further showed that variations in zooplankton abundance and biomass were significantly influenced by physico-chemical factors, especially depth, conductivity and turbidity. Therefore hypothesis 3, which stated that there are no significant relationships between diversity, abundance and biomass of zooplankton and physico-chemical factors and phytoplankton biomass was also rejected. Notable factors that significantly influence zooplankton abundance and biomass are changes in water volume, turbidity and conductivity.

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CHAPTER FIVE

5.0 DIEL VERTICAL MIGRATION OF ZOOPLANKTON IN LAKE BARINGO

Abstract

Zooplankton diel vertical migration was studied in Lake Baringo to determine the diel vertical distribution of zooplankters. Samples were obtained at the 4 m deep central station (C2) on two sampling occasions in January 2010 and February 2010 in Lake Baringo. Sampling was done at 1 m interval every four hours for 24 hours from 8 am to 4 am. Ten litres of lake water was collected by a Van Dorn sampler and sieved through a 50 µm mesh sieve and organisms in the entire sample counted. Concurrently, physico-chemical factors including temperature, pH, and conductivity and dissolved oxygen were measured at the same depths *insitu*. In both sampling months, the temperatures were higher during the day when stratification was observed just below the 1 m depth. This was, however, broken by diurnal winds in the evenings. pH and dissolved oxygen values followed the same trend but conductivity was generally uniform. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of dissolved oxygen ($F = 0.72$, $P = 0.40$) between the two months sampled. There were, however, significant differences in the mean temperature ($F = 4.86$, $P < 0.05$) and conductivity ($F = 148.0$, $P < 0.05$) between the two months. With reference to different depths, there were no significant differences in temperature ($F = 1.5$, $P < 0.05$), and conductivity ($F = 0.24$, $P < 0.05$). There was a significant difference in the values of dissolved oxygen concentrations between the different depths. ANOVA further showed that there were significant differences in the mean values of temperature ($F = 28.9$, $P < 0.05$) and dissolved oxygen ($F = 10.06$, $P < 0.05$) between different times of sampling. There was, however, no significant difference in conductivity ($F = 2.37$, $P < 0.05$). In contrast to what has been observed in clear water lakes, Lake Baringo zooplankton densities were generally higher at the surface waters during the day while during the night the organisms were distributed throughout the lake column, a phenomenon which could be attributed to the high water turbidity. Proximity of zooplankton to the euphotic zone during the day provides them with feeding opportunities on phytoplankton.

Key words: Lake Baringo, zooplankton, migration, turbid lake.

5.1 Introduction

Diel vertical migration (DVM) of zooplankton is a well studied phenomenon in lentic ecosystems which is believed to be a strategy to reduce risk of predation (Perticarrari *et al*., 2004; Record & Young, 2006). A majority of zooplankton species in deep lakes undergo diel vertical migration in response to changes in various abiotic and biotic factors. The migration has been related to efficient utilization of resources or avoidance of mortality due to predation (Lampert *et al*., 2003). Usually, the organisms congregate near the water surface at night and migrate to lower depths during the day (Morgado *et al*., 2007). Ascension enables more abundant food of high quality resources in the upper strata to be exploited at night, while predators can be avoided during the day by descent to depths where the light intensity is too low for planktivorous fishes to spot them. The daily migrations vary from lake to lake and from season to season.

Numerous studies on the vertical migration of zooplankton have shown that diel migration in the water column is driven largely by responses to light (Ashjian *et al*., 2002). The presence of a thermocline or an oxycline (Dawidowicz, 1994), food concentration (Beklioglu *et al*., 2008), and chemical stimuli (Bezerra-Neto *et al*., 2009) also influence vertical distribution of zooplankton. The adaptive significance of this migration is believed to be related to the reduction of predation pressure by the visually hunting vertebrate predators (Bezerra-Neto *et al*., 2009). The zooplankton undergo more extensive diurnal vertical migration in clear lakes, where they move to the surface waters at night and remain lower in the water column during the day (Record & Young, 2006). In contrast, in turbid lakes, reduced light penetration impairs prey perception by planktivorous fish thereby releasing large zooplankton species from predation pressure resulting in less extensive migration due to reduced predation threats (Claps *et al*., 2011).

Some investigations into zooplankton migration in Kenyan clear lakes include those by Worthington & Riccardo (1936) and Mavuti (1992) in Lake Naivasha and Worthington (1931) and Omondi (2003) in Lake Victoria. These studies showed that most of the zooplankters tended to concentrate in the upper zones during the night and moved to the lower depths during the day. However, some organisms don't seem to respond to these changes and remain at all depths from surface to the bottom throughout the 24 hour regime (Worthington, 1931; Omondi, 2003). No studies on the vertical migration of zooplankton have been carried out in Lake Baringo which is different from the above studied lakes because of its highly turbid waters. Therefore in this study,

the migration patterns of the zooplankton community in Lake Baringo was determined. Results of the study can be used as a basis for future ecological investigations in the lake.

5.2 Materials and Methods

5.2.1 Study area

Lake Baringo is a freshwater lake in the eastern arm of the Great Rift Valley in Kenya (Fig. 5.1). It is located between latitude 0˚30' N and 0˚45' N and longitude 36˚ 00' E and 36˚ 10' E and lies approximately 60 Km north of the equator at an altitude of 975 m above sea level (Kallqvist, 1987). The lake has a surface area of approximately 130 Km^2 and a catchment of 6,820 Km^2. It has a mean depth of 3 m with the deepest point being about 7 m at high water levels. The lake is located in an arid area characterized by dry and wet seasons. The dry season usually starts from September to February while wet season occurs between March and August. Rainfall ranges from about 600 mm on the east and south of the lake to 1500 mm on the west. Lake Baringo experiences very high annual evaporation rates of 1650-2300 mm (Odada *et al*., 2006) and its survival depends on the inflows from rivers originating from the hilly basin where rainfall varies from 1100 mm to 2700 mm. The lake is fed by several seasonal rivers including Ol Arabel, Mukutan, Endao and Chemeron while Molo and Perkerra are perennial though with reduced discharges during dry seasons.

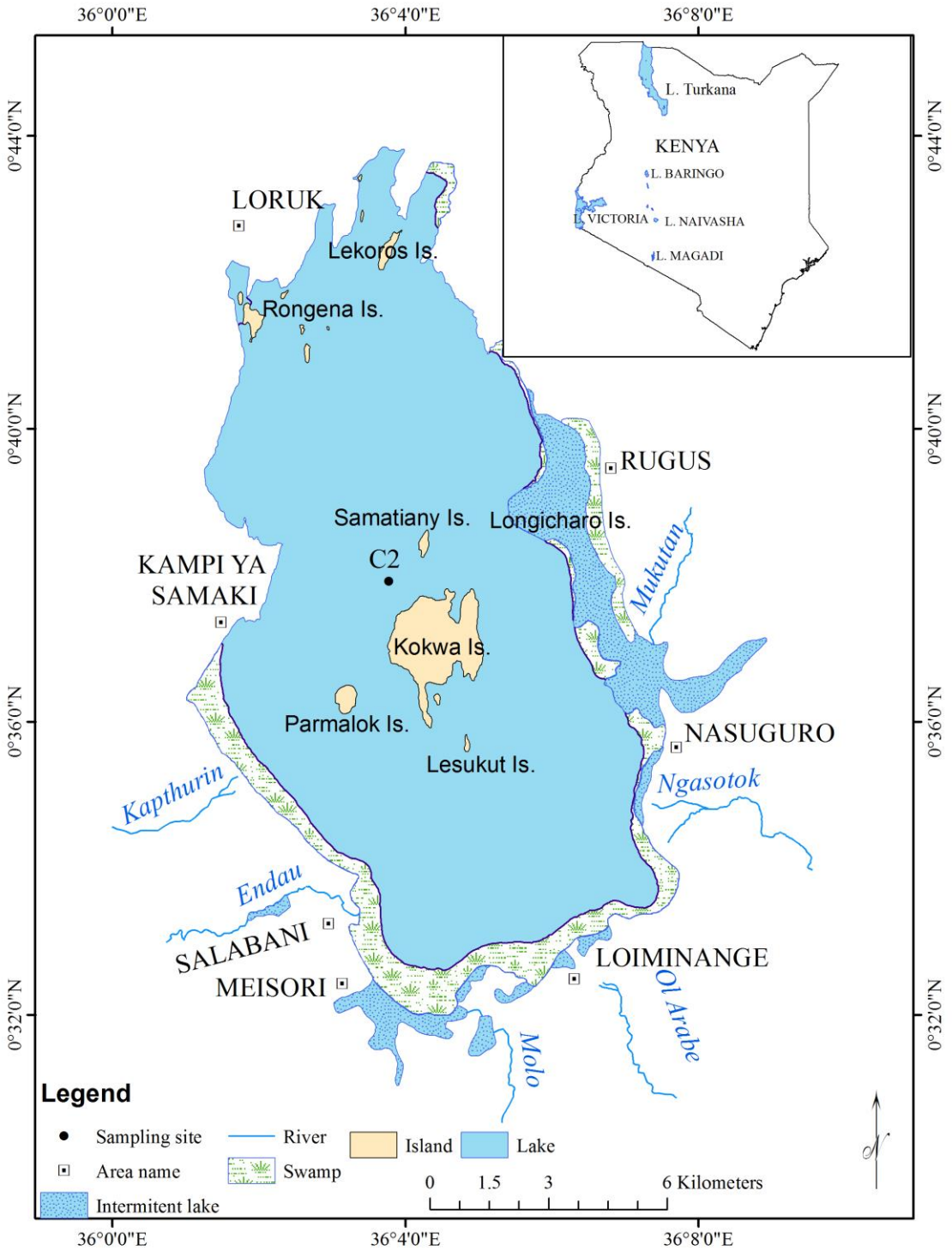

Figure 5.1: A map of Lake Baringo showing the sampling station (C2).

5.2.2 Sampling

Diel sampling was carried out twice in January and February 2010 at the central station (C2). Physico-chemical parameters including conductivity, temperature, dissolved oxygen and pH were measured *in situ* using a Surveyor II model hydrolab at each depth before zooplankton samples were taken. The samples were collected from the surface to the bottom at an interval of 1 m every four hours for 24 hours using a 5L Van Dorn water sampler. Ten litre samples from each depth were filtered through a 50 µm sieve and zooplankton preserved in 4% formalin. In the laboratory all the organisms were counted without sub sampling under a binocular dissecting microscope at magnification X40. Copepods and cladocerans were sorted using electronically sharpened tungsten wire fixed on inoculating rods while rotifers were sorted using fine glass capillary tubes into glycerine mixed with distilled water on glass slides.

The zooplankton were identified to genus and where possible to species level using relevant taxonomic literature. For copepods, identification keys by Dussart and Defaye (1995) were used. The keys by Korovchinsky (1992) and Smirnov (1996) were used in Cladocera identification while Koste (1978), Koste and Shiel (1987) and Segers (1995) were used for the identification of rotifers.

The number of individuals per litre of lake water (D) was determined using the formula:

$D = N/V$

Where

N = number of organisms in sample

= (number in sub-sample x Volume of sample)/sub-sample volume

V = volume of lake water filtered = $\pi r^2 d$, where

r = radius of mouth of net (15 cm)

d = depth of haul

5.2.3 Data Analysis

Parametric One-way Analysis of Variance (ANOVA) (MINITAB) was used to test the differences among the physico-chemical factors and zooplankton abundances on spatial and temporal (months and time) scales. Zooplankton data were Log (x+1) transformed. Pearson correlation analysis was carried out using PAST version 1.94b (Hammer *et al*., 2001) to determine the relationship between the environmental variables and species abundance.

5.3. Results

5.3.1 Physico-chemical factors

In the January 2010 sampling exercise, the variations in physico-chemical factors are shown in Figure 5.2. Water temperature was uniform in the whole water column from 4 pm to 12 noon. It increased steadily from 23 ºC to 25 ºC between 8 am and 12 noon. In the afternoon there was stratification with the surface waters reaching 29 ºC between noon and 4 pm. At around 6 pm there was a breakdown of the stratification and temperatures were again uniform in the whole water column with decreasing temperatures from 25 ºC at 6 pm to 22 ºC at 4 am. Between 8 am and about 10 am the pH of the surface waters, above 1 m depth, were higher than the bottom waters. pH of the lake water remained fairly constant at around 9. Generally, the pH of the surface waters were slightly higher than those at the lower depths.

Conductivity of Lake Baringo water during the January 2010 sampling was more or less uniform in the water column throughout the 24-hour regime. There was, however, a steady decrease in conductivity from 860 µS cm^{-1} at 8 am at the surface to 825 µS cm^{-1} at 4 am at the 0 m and 1 m depths. Dissolved oxygen concentrations were on the other hand higher at the surface waters compared to the bottom. The highest concentration of 8 mg l^{-1} was attained between 12 noon and 2 pm. The stratification was broken after 8.00 pm but was followed by another after 12 mid night.

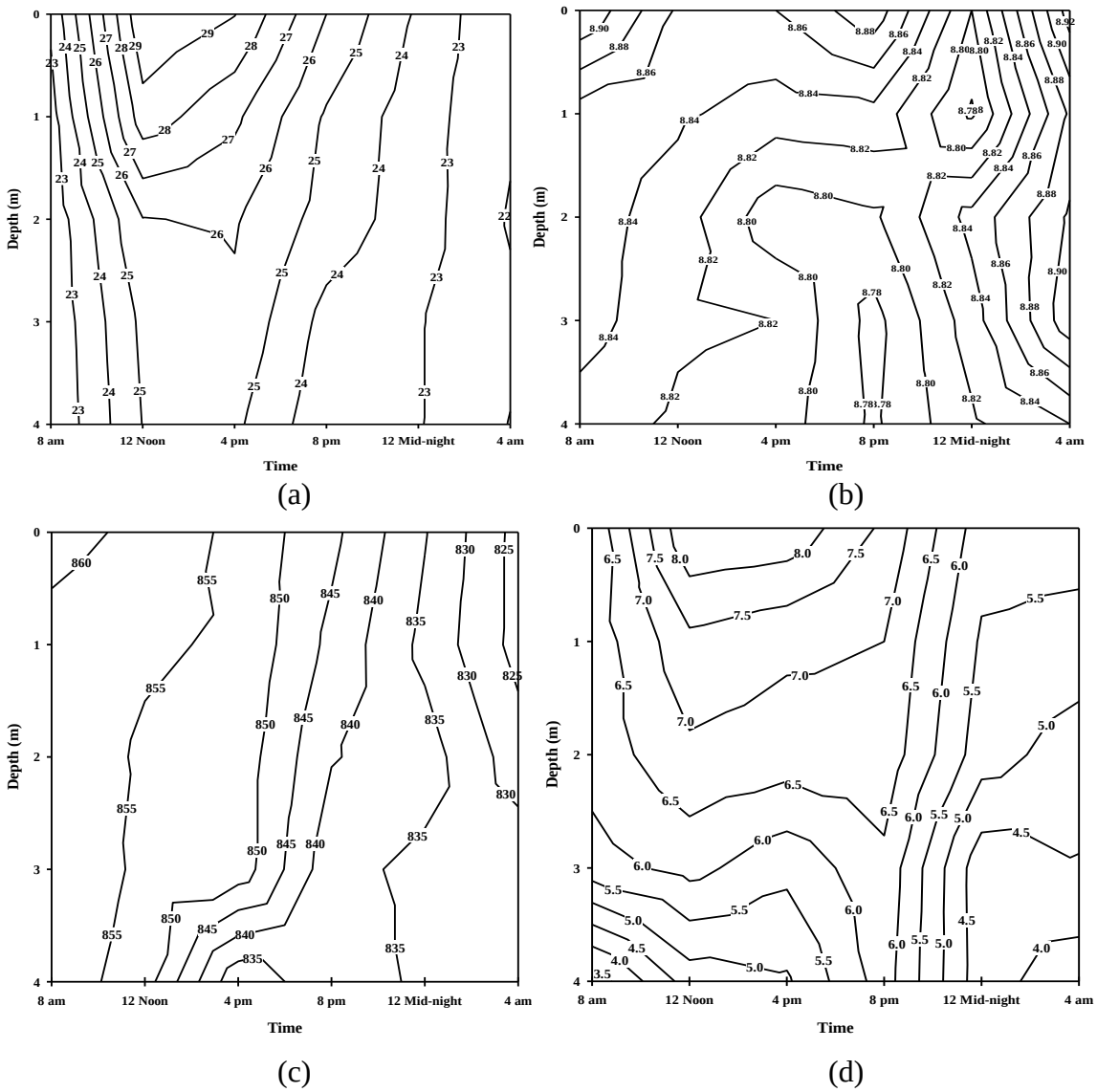

Figure 5.2: Diel variation in (a) temperature, (b) pH (c) conductivity and (d) dissolved oxygen in Lake Baringo in January 2010.

Values of the physical and chemical variables during the February 2010 sampling are shown in Figure 5.3. Between 8 am and 12 noon there was an increase in water temperature from 25 ºC to 28 ºC uniformly distributed throughout the water column. In the afternoon there was stratification with surface waters reaching 32 ºC while the bottom temperatures were 27 ºC. After 4 pm there was, however, breakdown of stratification with a decrease in temperature from 26 ºC to 23 ºC at 4 am.

The values of pH were generally higher during the day with discrete pH variations within 1 m of surface. The lowest pH of 8.2 was attained at noon in the surface waters. Conductivity

values were higher at the surface waters than bottom waters and the values decreased from 8 am to the end of sampling time. Dissolved oxygen values were higher in surface waters with an increase from 5.0 mg l^{-1} at 8 am to 9 mg l^{-1} at 4 pm followed by a gradual decrease to 5.0 mg l^{-1} at 3 am. At 12 noon dissolved oxygen was evenly distributed in the water column after which there was a clear oxycline between 12 noon and 8 pm followed by uniform levels of dissolved oxygen at all depths. The highest value of dissolved oxygen (9.0 mg l^{-1}) was recorded at 4 pm at the surface waters while the lowest (3.5 mg l^{-1}) was found at the bottom of the lake from 10 pm to about 5 am.

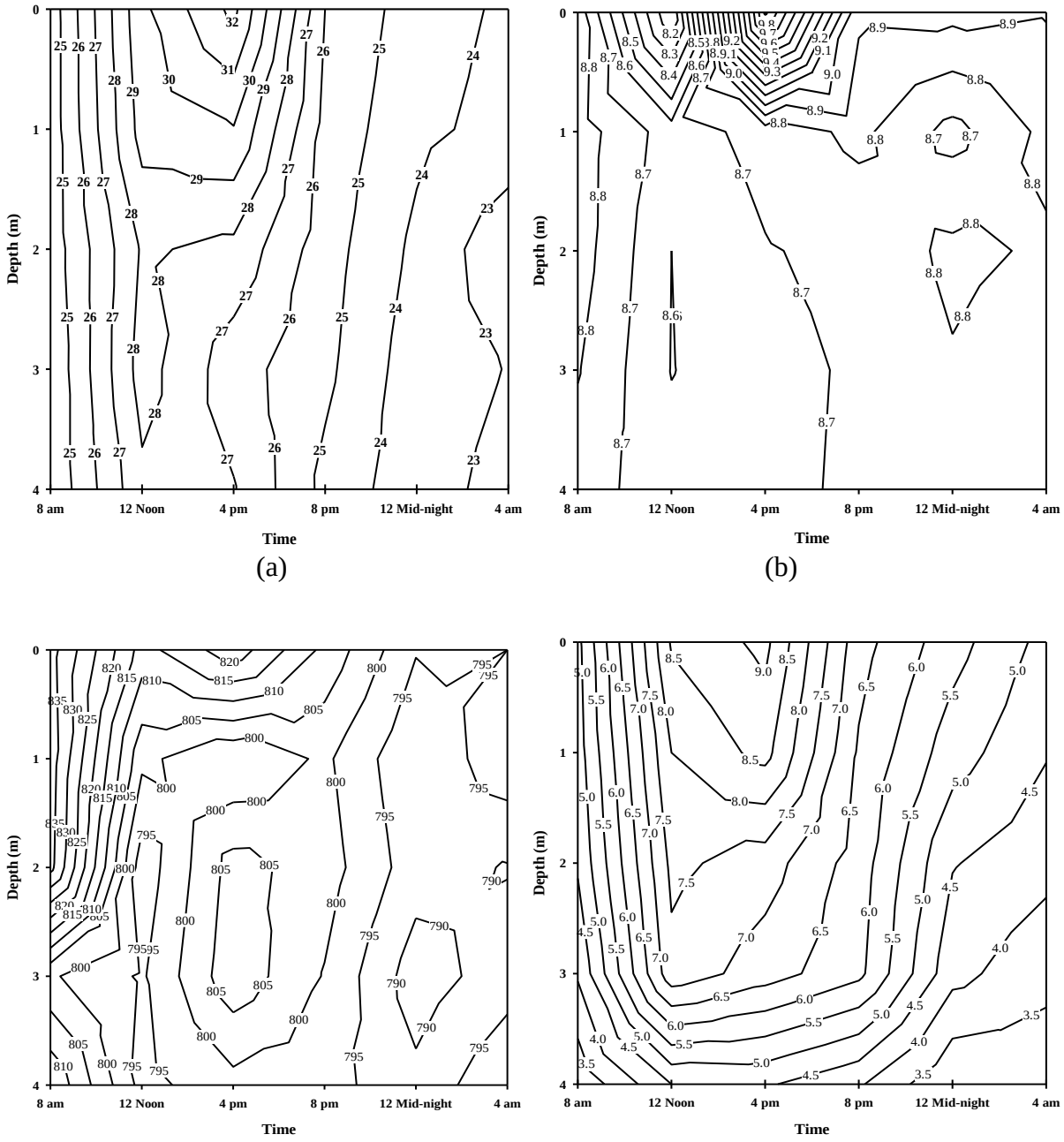

Figure 5.3: Diel variation in (a) temperature, (b) pH (c) conductivity and (d) dissolved oxygen in Lake Baringo in February 2010.

Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of dissolved oxygen ($F = 0.72$; $P > 0.05$) between the two months sampled. There were, however, significant differences in the mean temperature ($F = 4.86$; $P < 0.05$) and conductivity ($F = 148.0$; $P < 0.05$) between the two months (Table 5.1). With reference to depth,

there were no significant differences in the mean values of temperature (F = 1.5; $P < 0.05$), and conductivity (F = 0.24; $P < 0.05$). There was a significant difference in the mean values of dissolved oxygen concentrations between the different depths (F = 8.01; $P < 0.05$). Further analysis using Tukey test revealed that three groups of depths with similar mean dissolved oxygen concentration were depths 0 and 1 m, 2 and 3 m and 4 m. ANOVA further showed that there were significant differences in temperature (F = 28.9; $P < 0.05$) and dissolved oxygen (F = 10.06; $P < 0.05$) between different times of sampling. There was, however, no significant difference in the mean conductivity values (F = 2.37; $P < 0.05$). The three groups of sampling times with similar temperatures were 12 noon and 4 pm, 8 pm and 12 midnight, 4 am and 8 am while groups of sampling times with similar dissolved oxygen were 12 mid night, 4 am and 8 am and 12 noon, 4 pm and 8 pm.

Table 5.1: Statistics (F, *P*) of variation of physico-chemical parameters in relation to month, depth and time of sampling.

	Month	Depth	Time
Temperature	4.86, 0.03	1.50, 0.22	28.9, < 0.05
Conductivity	148.0, < 0.05	0.24, 0.91	2.37, 0.052
Dissolved oxygen	0.72, 0.40	8.01, <0.05	10.06, < 0.05

5.3.2 Zooplankton vertical distribution

The zooplankton species encountered in the study included the three major groups Copepoda, Cladocera and Rotifera (Table 5.2). Rotifera was the most speciose group with 8 species while Cladocera had 5 species. The same species of zooplankton were recorded in both months, except the rotifer *Asplanchna* sp which was not found in January 2010 samples. During the period of sampling no calanoids were recorded in the samples. In both months, Copepoda was dominated by nauplii while Cladocera was dominated by *D. barbata*. Rotifera was, however, dominated by *K. tropica* and *F. opoliensis* in January and February 2010, respectively. While more copepods were recorded in January 2010 sampling, abundances for cladocerans and rotifers were higher in February 2010 sampling except for the rotifer *K. tropica* which occurred in higher numbers in January 2010.

Table 5.2: Mean abundance (ind. l^{-1}) and percentage contribution to total density of the different species of zooplankton recorded in the two sampling dates, January and February 2010.

	January 2010			**February 2010**		
	Mean	**SE**	**%**	**Mean**	**SE**	**%**
Copepoda						
Cyclopoida	63.57	7.22	13.16	39.08	5.79	17.45
Nauplii	160.97	16.13	33.33	111.89	9.95	49.95
Cladocera						
D. excisum	3.30	0.52	0.68	4.94	0.53	2.20
M. micrura	0.52	0.14	0.11	1.81	0.29	0.81
C. cornuta	2.98	0.33	0.62	5.90	0.38	2.63
D. barbata	6.51	0.52	1.35	7.95	0.55	3.55
M. spinosa	0.36	0.18	0.08	0.60	0.23	0.27
Rotifera						
B. angularis	0.08	0.03	0.02	0.27	0.07	0.12
B. calyciflorus	1.47	0.29	0.30	1.81	0.49	0.81
F. opoliensis	8.22	0.88	1.70	22.87	3.28	10.21
K. tropica	234.11	29.83	48.47	17.04	2.37	7.61
Hexarthra sp	0.16	0.06	0.03	7.53	4.65	3.36
Polyarthra sp	0.74	0.27	0.15	1.81	0.33	0.81
Lecane spp	0.01	0.01	0.00	0.50	0.43	0.22
Asplanchna sp				0.01	0.01	0.01

In January 2010 DVM sampling, the major groups of zooplankton found were Copepoda, Cladocera and Rotifera. They showed similar distribution patterns in the water column with higher

proportions of the organisms occurring in the upper 2 m of the column (Fig. 5.4). The highest proportions of copepods were at the surface at 8.00 am and 12 noon with a proportion of 27% and 32%, respectively. After 4 pm the organisms tended to move downwards with a peak of 27% at 3 m depth at 4 am afterwards followed by upward migration towards the surface.

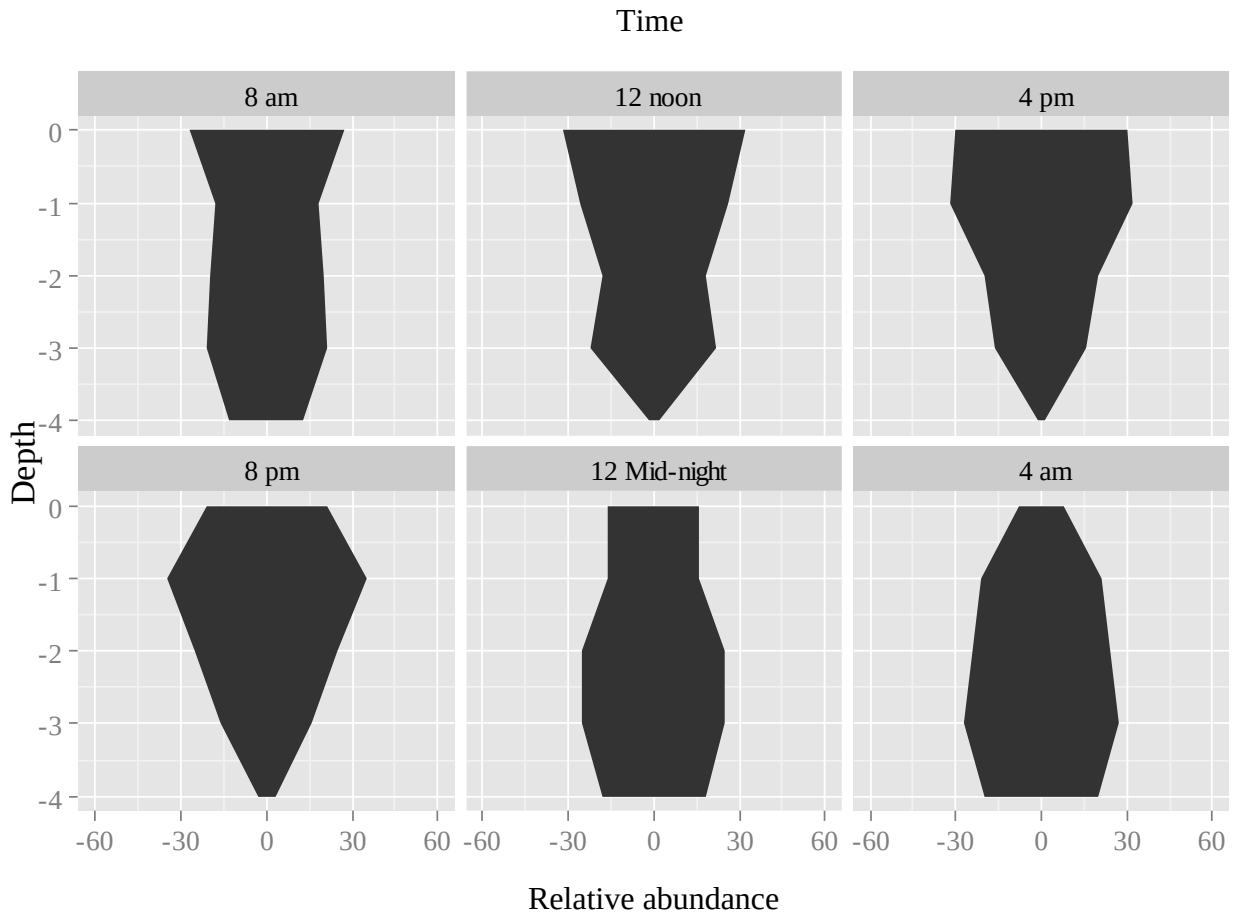

Figure 5.4: Vertical distribution (in relative abundance) from surface to 4 m depth of Copepoda in Lake Baringo in January 2010. Each kite represents 100%.

Unlike Copepoda, Cladocera was fairly well distributed in the water column but with relatively high proportion in the surface waters during the day. The highest proportion (28%) at the surface was recorded at 12 noon while the highest proportion at the bottom (28%) was recorded at 4 am (Fig. 5.5). A considerable proportion of the cladocerans were found at the bottom of the lake throughout the sampling regime with the least proportion of 13% at 4 pm.

Time

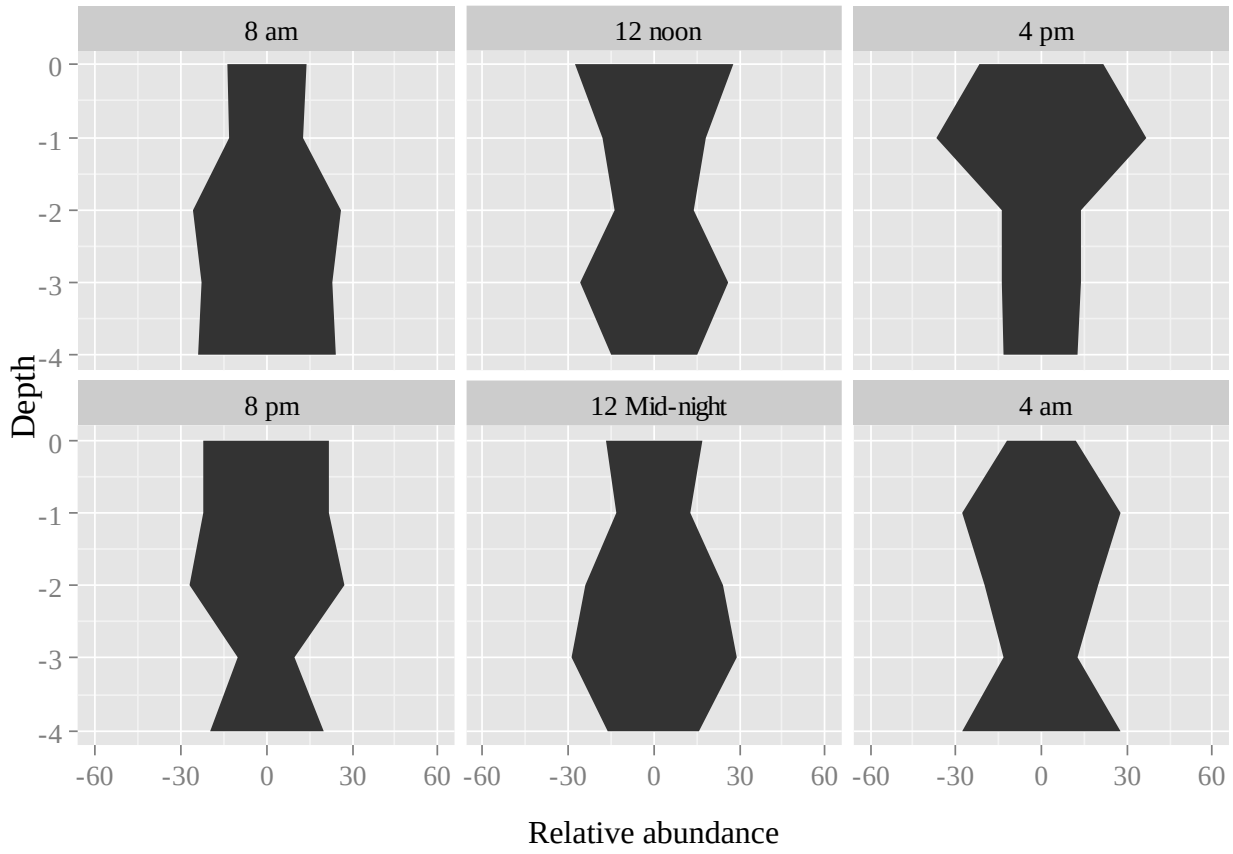

Figure 5.5: Vertical distribution (in relative abundance) from surface to 4 m depth of Cladocera in Lake Baringo in January 2010. Each kite represents 100%.

Rotifers presented the most discrete pattern of distribution along the water column in Lake Baringo. On day break at 8 am up to 4 pm the highest proportions of rotifers were found at the surface water with proportions of 37%, 36% and 34%, respectively (Fig. 5.6). From 8 pm there was a steady movement of the organism towards the bottom. The highest proportion (35%) of organisms at 4 am was at the 3 m depth. Between 4 pm and 8 pm there were no rotifers recorded at the bottom of the lake.

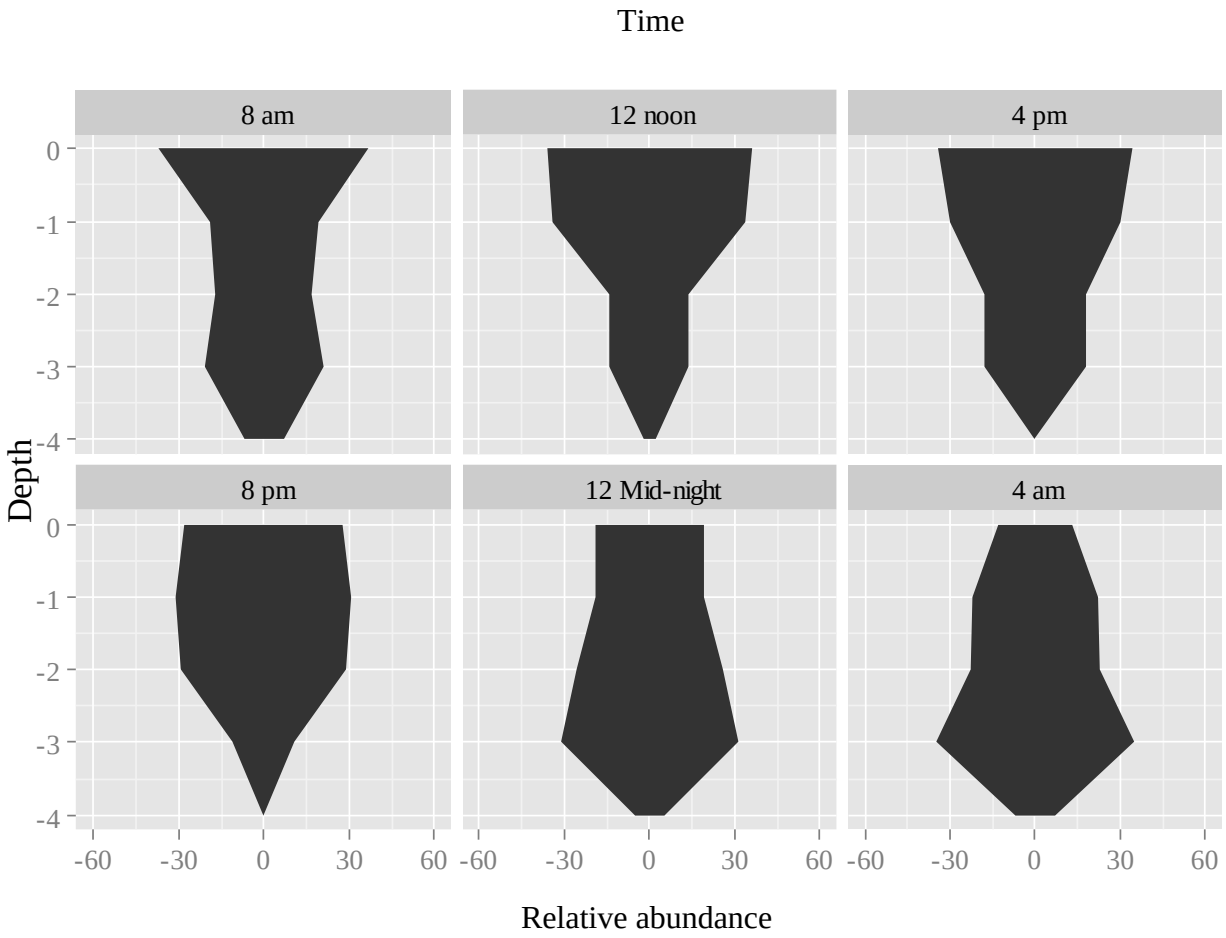

Figure 5.6: Vertical distribution (in relative abundance) from surface to 4 m depth of Rotifera in Lake Baringo in January 2010. Each kite represents 100%.

The three major groups of zooplankton, Copepod and Rotifer had a similar vertical distribution pattern over a 24-hour period. At 8 am most copepods (31%) were found at 1m depth after which there seemed to be an upward movement of the organisms (Fig. 5.7). At noon and 4 pm the organisms were concentrated in the two upper layers of the water (66% and 72%, respectively) after which the organisms moved downward forming a relatively homogenous distribution at all depths. During day light between 8 am and 4 pm more copepods were found at the surface waters than the bottom waters while during the night most of the organisms occurred at the mid waters. The highest (50%) proportion of copepods was found at the surface waters at 12 noon.

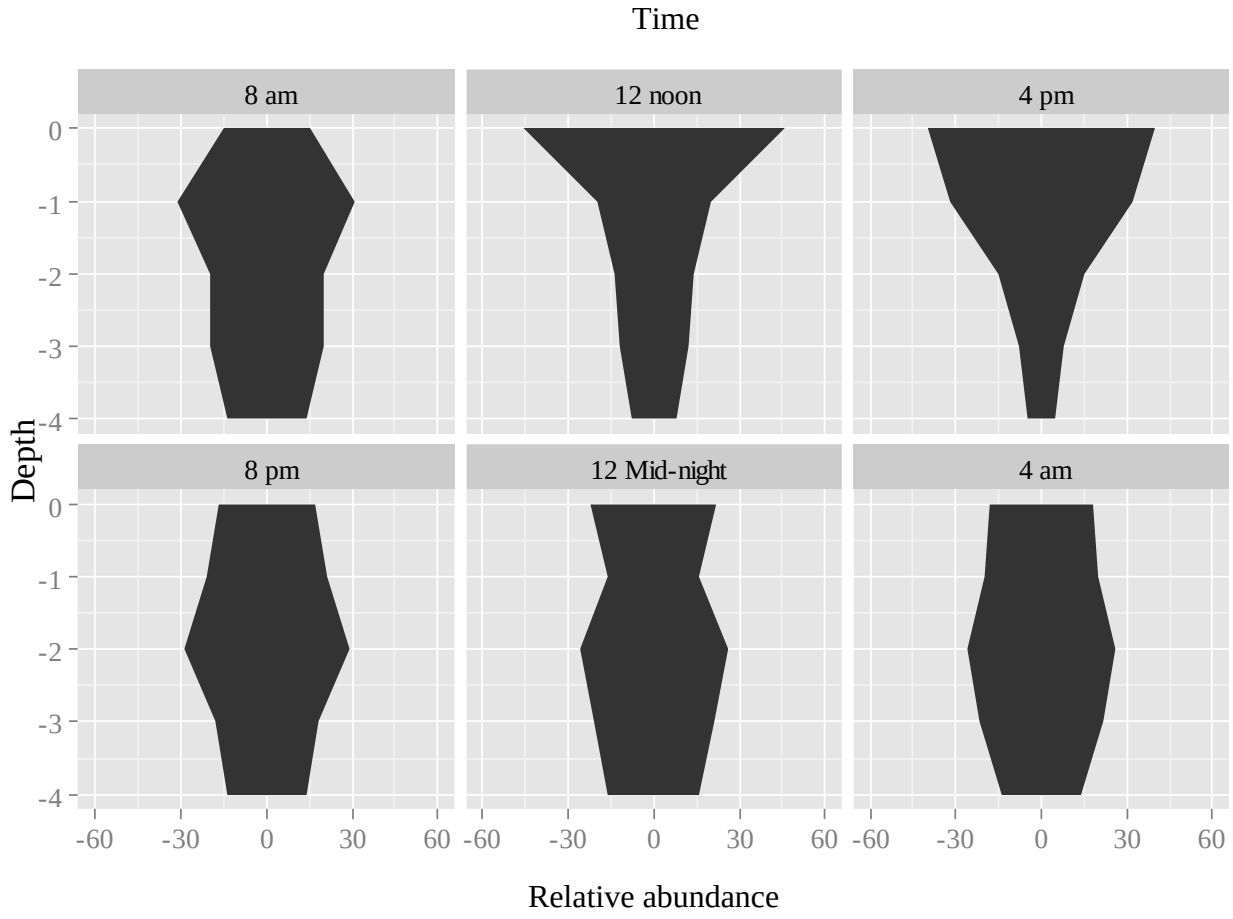

Figure 5.7: Vertical distribution (in relative abundance) from surface to 4 m depth of Copepoda in Lake Baringo in February 2010. Each kite represents 100%.

Cladocerans were fairly distributed at all depths with considerable proportion (>18%) at the bottom of the lake throughout the 24-hour sampling period (Fig. 5.8). At 8 am the highest proportion (27%) of cladocerans was found at 1m depth followed by 4 m depth with 20% while the least (13%) was recorded at the surface. At 12 noon some organisms moved to the surface (28%) while others descended to the bottom of the lake (27%). At 4 pm, there was a general movement of the cladocerans towards the bottom where the highest proportion of 32% was attained at 4 am.

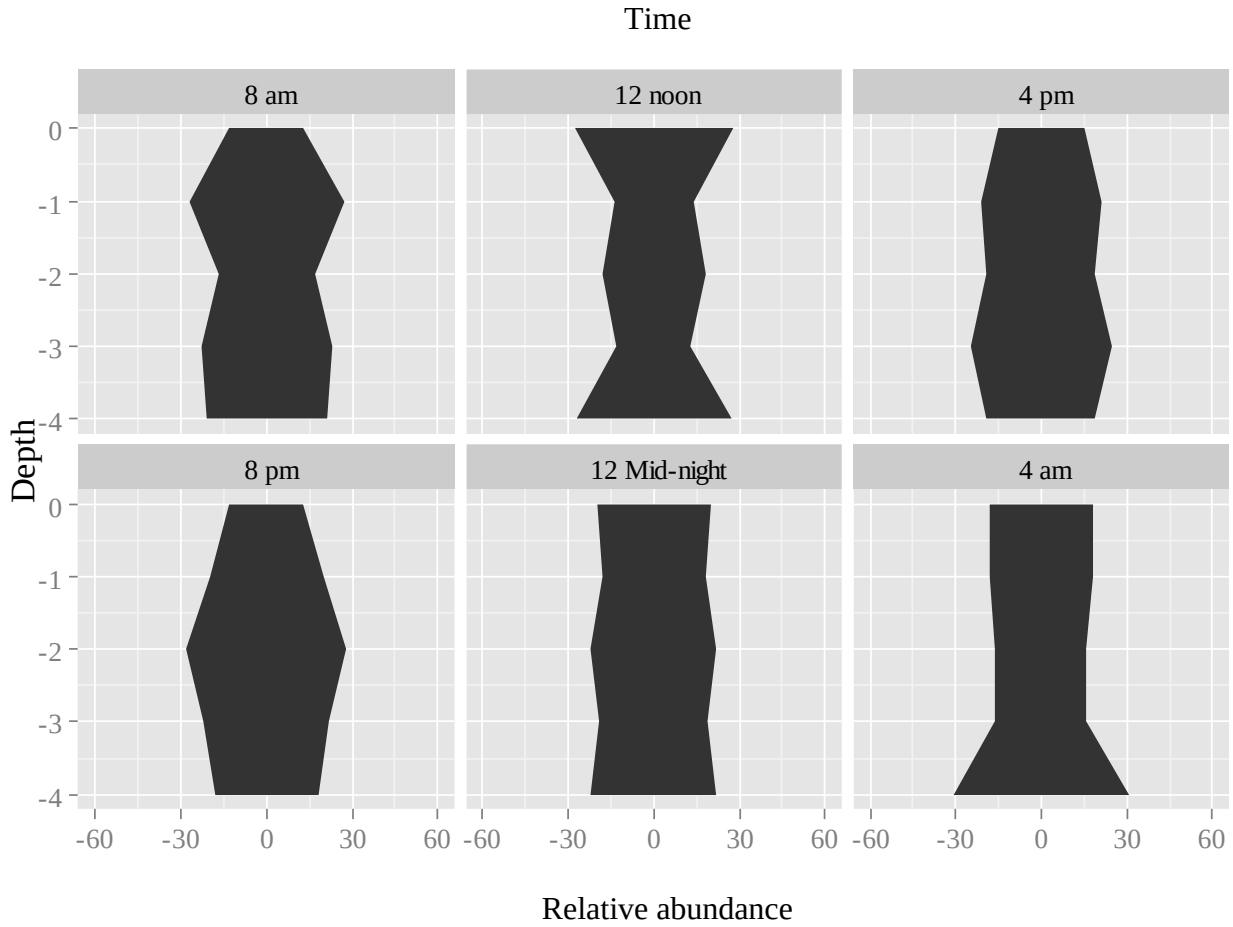

Figure 5.8: Vertical distribution (in relative abundance) from surface to 4 m depth of Cladocera in Lake Baringo in February 2010. Each kite represents 100%.

Rotifers showed a relatively similar pattern of vertical distribution to that of copepods (Fig. 5.9). After day break there was a clear migration of rotifers towards the surface waters of the lake where a maximum proportion of 50% was reached at noon. After 12 noon there was downward migration to the lower depths. The highest proportion (28%) of rotifers at the bottom was recorded at 4 am.

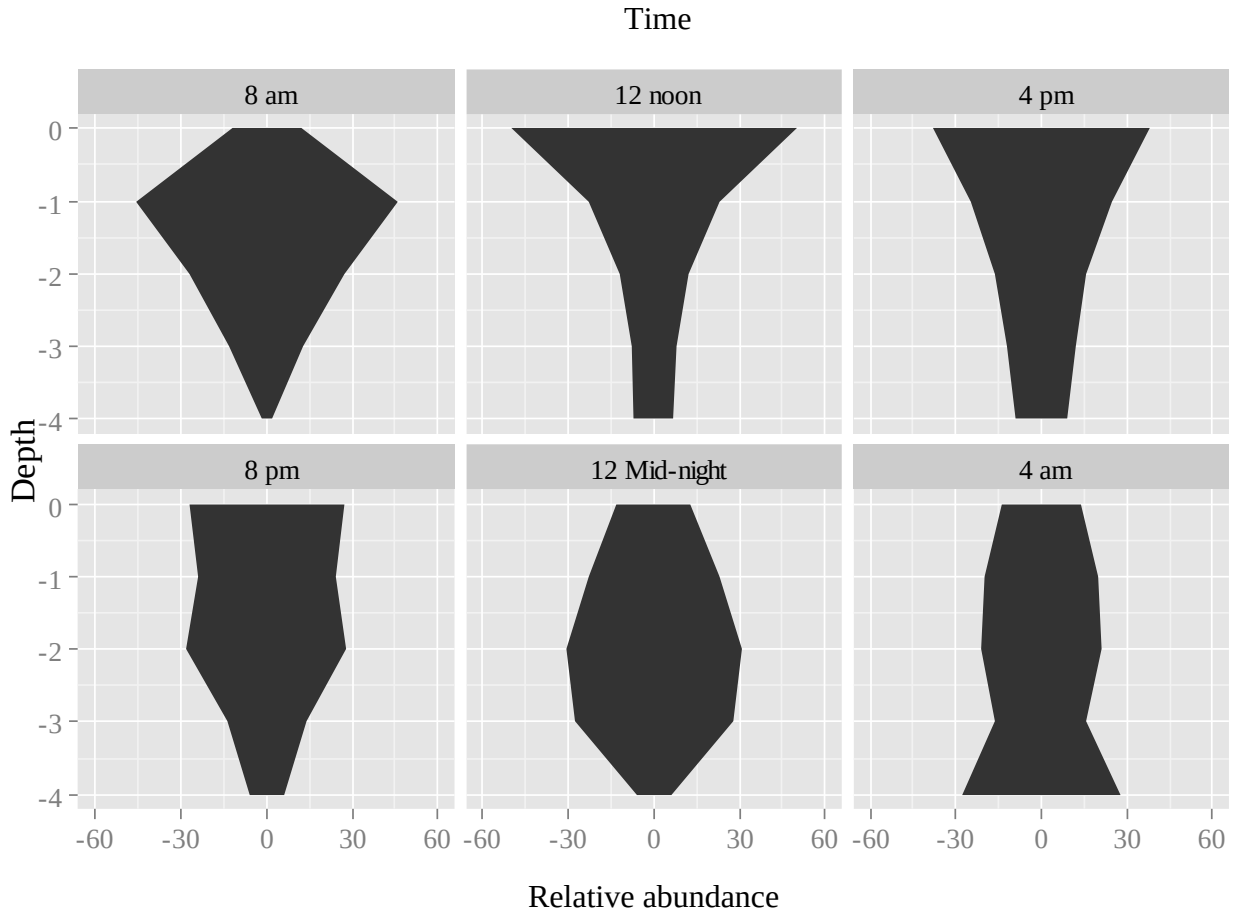

Figure 5.9: Vertical distribution (in relative abundance) from surface to 4 m depth of Rotifera in Lake Baringo in February 2010. Each kite represents 100%.

Analysis of Variance (ANOVA) showed that total zooplankton abundance had significant differences between the two months sampled ($F = 13.13$; $P < 0.05$) and depth ($F = 8.0$; $P < 0.05$) but not between the different sampling times ($F = 0.31$; $P > 0.05$). Tukey test further showed that depths 0, 1, 2 and 3 m did not vary significantly from one another in terms of zooplankton abundance but depth 4 m varied significantly from all the other depths.

Data on total zooplankton densities indicated that during the day most of the organisms occurred in the surface waters while during the dark the organisms were more or less distributed uniformly in the water column. Further, merging of zooplankton densities during day (8 am to 4 pm) and night (8 pm to 4 am) phases revealed that zooplankton densities were, generally, higher at the surface waters during the day than during the night when the organisms occurred at higher densities towards the bottom of the lake (Fig. 5.10).

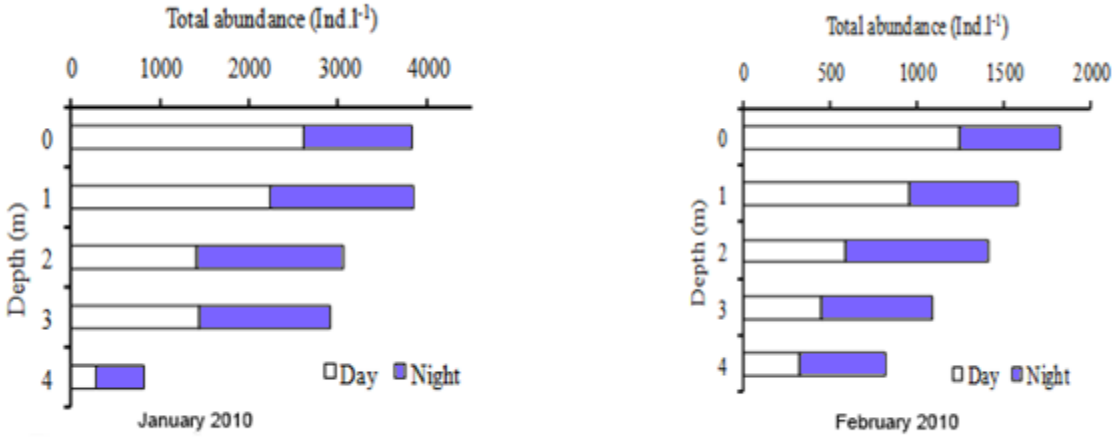

Figure 5.10: Abundance of zooplankton in the day and night periods of sampling in January and February 2010

5.3.3. Correlation between environmental variables and zooplankton distribution

The correlation relationships between some environmental variables and the distribution of major zooplankton groups Copepoda, Cladocera and Rotifera are shown in Table 5.3. Temperature was positively correlated with Copepoda (r = 0.48) and Rotifera (r = 0.016) but negatively correlated with Cladocera (r = -0.159). pH was negatively correlated with all the three groups of zooplankton but only significantly with Cladocera. Conductivity had a significant correlation with all the groups of zooplankton, positively with Copepoda (r = 0.124) and Rotifera (r = 0.259) but was negatively correlated with Cladocera (r = -0.189). Dissolved oxygen was also positively significantly correlated with Copepoda (r = 0.563) and Rotifera (r = 0.331) but was negatively, and insignificantly, correlated with Cladocera (r = -0.189).

Table 5.3: Correlation matrix between environmental variables temperature, pH, conductivity and dissolved oxygen (DO) and groups of zooplankton Copepoda, Cladocera and Rotifera.

	Copepoda	Cladocera	Rotifera
Temperature	0.480*	-0.159	0.016
pH	-0.001	-0.370*	-0.248
Conductivity	0.124*	-0.314*	0.259*
DO	0.563*	-0.189	0.331*

- *Significant at $P < 0.05$

5.4 Discussion

The temporary thermal stratification exhibited in the lake may have been caused by the absorbance of solar energy by suspended particles in the lake which accentuated the increase in temperature of the surface waters during the day between noon and 4 am. This was broken down in the evenings with the surface cooling and wind mixing. This phenomenon of thermal stratification during the day and mixing at night had earlier been reported in the lake by Beadle (1932). High pH values at the surface waters during the day were attributed to use of carbon dioxide during photosynthesis process. The opposite was realized during the night, more so, at the bottom of the lake due to respiration process.

Dissolved oxygen concentration distribution in the lake can be explained in terms of the dominant phytoplankton, *Microcystis aeruginosa*, in the lake (Oduor *et al*., 2003; Busienei, 2003). Ganf (1974) found that the buoyant colonies of the phytoplankton moved to the surface during the day after a period of dark incubation in Lake George, a similar lake to Lake Baringo. This explains the rise in the concentration of dissolved oxygen towards mid- day, however, this is limited by the high turbid water. From this study, the relatively homogenous environmental variables could not be used to explain the distribution of zooplankton in Lake Baringo.

The difference in the mean abundance of zooplankton in the two sampling dates could have been occasioned by differences in environmental factors between the two dates. This was supported by statistics that showed that there were significant correlations in temperature and conductivity in relation to months. One notable change between the two months was realized in conductivity values which decreased from a mean of 844.5 to 830.1 µS cm^{-1}, in January and February 2010, respectively. These changes could explain population explosion of rotifer *K. tropica* in January, with 48% of total zooplankton. The relatively higher densities of littoral cladoceran species *Lecane* spp in February could be attributed to development of a cyanobacterial bloom.

Contrary to the expected maximum zooplankton concentration near the surface at night and daytime migration to the lower depths (Record and Young, 2006), the results of this study indicate the complete opposite of the same. In my study, zooplankton generally migrated to the surface water during the day and descended to the mid and bottom water during the night. Light, modified by other physical and biological factors, seems to be important in initiating, controlling

and orientating zooplankton migration in this lake. The organisms move to the surface for food and migrate to colder temperatures where metabolism rates are reduced. The higher densities at the surface during the day could be due to behavioral changes coinciding with decrease in predation pressures from planktivorous fish due to turbidity. There is presumably no advantage to strong migration during the day since the selective forces of predation are practically absent. This is the way cladocerans avoid predation despite their large size in the lake. Similar observations were made in a shallow, polymictic and eutrophic Lake Vela where most taxa were homogenously distributed in the water column in the turbid phase (Castro *et al*., 2007). Dumont *et al*. (1985) stressed that in the absence of factors like visual predators and light damage, it would be advantageous to zooplankton not to descend to the lower depths as this would allow them to feed continuously in the euphotic zone. Indeed this seems to be the case in Lake Baringo where visual predation and light damage could have been reduced by the turbid waters.

In my study, migration behavior was different between the different zooplankton groups with the tendency to assemble at the surface water being shown more by copepods and rotifers than in cladocerans. This can be attributed to the different response to stimuli by the different species within the groups. Sekino and Yamamura (1999) demonstrated that individual zooplankton changed their migrating behavior depending on the amount of accumulated energy. Fiksen and Giske (1995) further showed that the internal condition affected vertical distribution of zooplankton, which explains variation between individuals of same species. Convergence of organisms in the surface waters, in my study, during the day puts the organisms in a habitat with high oxygen concentration and available food arising from photosynthesis. The choice of optimal habitat by different groups of zooplankton was, however, a function of other factors such as food availability and response to environmental factors. The low proportion of rotifers at the bottom at most of the times of the day was probably due presence of invertebrate predators in the lower depths. Moreover, because of their small size rotifers are not the preferred prey by fish predation limited to the surface waters. Despite the turbid waters of the lake, at the surface water there could have been some visibility which made cladocerans avoid being predated on by fish by staying at lower, darker habitats.

Most samples had significantly fewer organisms at the bottom probably due to low dissolved oxygen concentration which was always below 4 mg l^{-1} except during the day between noon and 4 pm. Incidentally this is the period when most organisms moved to the upper euphotic

zone to feed. This study, however, showed that *M. spinosa* remained at the bottom of the lake throughout the sampling period. This corroborates the findings of Cronin *et al.* (2006) that the organism is a bottom and weed dwelling species.

5.5 Conclusion

This study showed that diel vertical migration is an important phenomenon in shallow environments with homogenous distribution of environmental variables like Lake Baringo. This leads to the rejection of hypothesis 4 of the study which predicted that there was no significant difference in diel vertical migration of zooplankton in the lake. The study supports the idea that vertical distribution of zooplankton in Lake Baringo is controlled by light and feeding strategies. During the day the organisms remain at surface where they feed on phytoplankton with reduced risk of predation by sight feeding predators because of the high turbidity.

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CHAPTER SIX

6.0 FOOD AND FEEDING HABITS OF THREE MAIN FISH SPECIES IN LAKE BARINGO

Abstract

The food and feeding habits of three fish species of commercial importance in Lake Baringo, *Protopterus aethiopicus*, *Clarias gariepinus* and *Oreochromis niloticus* were studied with an aim of determining ther diet. Fish was caught by seine and gillnets and preserved in 10% formalin for gut analyses in the laboratory. The contents of every stomach was scrutinized under X40 magnification of a binocular microscope. Prey were identified to the lowest possible taxonomic levels and counted. The diet of the fish were determined using frequency of occurrence and volumetric methods between April 2008 and March 2010. Seine and gill nets were used to catch a total of 430 fish specimens. The diet of *P. aethiopicus* was found to be 94.3% molluscs with a frequency of occurrence of 98.6% of stomachs with food. Adult *C. gariepinus* fed mainly on small fish with 75% of the gut contents being fish remains and a mean of 49.2% contribution by volume. *C. gariepinus* fed on zooplankton, especially the cladoceran *Daphnia barbata*. The food items in the gut contents of *O. niloticus* consisted mainly of algae, detritus and zooplankton. Algae was consumed by *O. niloticus* of all length classes in proportions ranging from 26.5% to 88.1%. The importance of zooplankton as food for *O. niloticus* decreased with size of fish. The study revealed the importance of zooplankton as food for *O. niloticus* and *C. gariepinus* in Lake Baringo. Because of their position in the food web in aquatic ecosystems, it is important to maintain good water quality for the growth of plankton in the lake. One way of doing this is to improve the clarity of the lake water by reducing siltation and this can be achieved through rehabilitation of the catchment of Lake Baringo so as to improve the water quality thus improve productivity.

Key words: Lake Baringo, diet, omnivorous, zooplankton, food web

6.1 Introduction

Aquatic ecosystem productivity is governed primarily by the inputs of light and nutrients, both in absolute and relative terms. Fishery production in freshwater lakes depends on the productivity and health of the system. Turbidity is one of the main environmental stressors threatening aquatic productivity globally (Donohue & Molinos, 2009) by lowering light availability for photosynthesis. It usually arises from siltation of the lake that is brought about by deforestation and near-shore development and increased algal growth from eutrophication. In addition to the detrimental physiological effects imposed on fish and other aquatic taxa by turbidity, the visual environment of fishes is severely altered as the intensity of underwater light decreases and the spectral content of light changes (Utne-Palm, 2002). Changes to the visual environment from increased turbidity have impacts on the ecology and evolution of fishes (Maan *et al*., 2010). Specifically, the altered visual environment impair visually mediated behaviours in fish, such as foraging (Utne-Palm, 2002; Schulze, 2010), avoiding predators (Abrahams & Kattenfeld, 1997) and selecting mates (Candolin *et al.*, 2007; Maan *et al*., 2010; Gray *et al*., 2011).

The fish community of Lake Baringo comprises seven species which are *Aplocheliches* sp, *Barbus intermedius australis, B. lineomaculatus, Clarias gariepinus, Labeo cylindricus, Oreochromis niloticus baringoensis* and *Protopterus aethiopicus* (Britton *et al*., 2006). Of these, three species, namely *C. gariepinus, O. niloticus baringoensis* and *P. aethiopicus,* are economically exploited. The fishery of the lake was once dominated by the endemic *O. niloticus baringoensis* but is presently dominated by *P. aethiopicus,* which was introduced in 1975. Annual catches of *O. niloticus baringoensis* exceeded 600 t in the 1960s but this decreased to below 12 t in 2006 despite a prolonged period of fishery closure (Britton *et al*., 2006). Sedimentation into Lake Baringo is considered to be the main threat to the lake. Besides reducing the depth of the lake, it also results in the increased turbidity of the lake water.

Lungfishes, *Protopterus* spp have been classified as omnivores feeding mainly on smaller fishes besides other items like insects, crustaceans, annelids, mollusks, detritus and plant material (Corbet, 1961; Mlewa & Green, 2004; Oniye *et al.*, 2006; Adeyemi *et al*., 2009). *C. gariepinus* is a benthopelagic fish which is known to be voracious with a wide range of diet (Yalcin *et al*., 2002). Fish has been reported to be the most important food item among other materials like insects, shrimps, snails, detritus and macrophytes (Skelton, 1993; Dadebo, 2000, 2009; Yalcin *et al.*, 2001;

El Gamal & Ismail 2005; Potts *et al*., 2008; David *et al*., 2010). Earlier studies in various lakes showed that *O. niloticus* is capable of using a wide range of food resources including algae, detritus, higher plant material, chironomids, zooplankton and fish (Getabu, 1994; Njiru *et al*., 2004; Shalloof & Khalifa, 2009).

Studies on natural feeding of fish could provide useful information on the trophic relationships in aquatic ecosystems (Abdel-Aziz and Gharib, 2006), which could be used in formulating management strategies in a multi species fishery. Pius and Benedicta (2002) reported the use of stomach content in reducing intra and inter specific competition for ecological niche. Apart from studies on the feeding biology of the marble fish, *P. aethiopicus* and *O. niloticus* by Mlewa and Green (2004) and Busienei (2003), respectively, there has been no comprehensive investigation on the diet of fish species of commercial importance in Lake Baringo. This study investigated the diet and the trophic inter-relationships of *P. aethiopicus, C. gariepinus* and *O. niloticus* in Lake Baringo.

6.2 Materials and Methods

6.2.1 Study area

Lake Baringo is a freshwater lake in the eastern arm of the Great Rift Valley in Kenya (Fig. 6.1). The lake is located between latitude 0˚30’ N and 0˚45’ N and longitude 36˚ 00’ E and 36˚ 10’ E and lies approximately 60 Km north of the equator at an altitude of 975 m above sea level (Kallqvist, 1987). The lake has a surface area of approximately 130 Km^2 and a catchment of 6,820 Km^2. It has a mean depth of 3 m with the deepest point being about 7 m at high water levels. The lake is located in an arid area characterized by dry and wet seasons. The dry season usually starts from September to February while wet season occurs between March and August. Rainfall ranges from about 600 mm on the east and south of the lake to 1500 mm on the west. Lake Baringo experiences very high annual evaporation rates of 1650-2300 mm (Odada *et al*., 2006). The lake is fed by several seasonal rivers including Ol Arabel, Mukutan, Endao and Chemeron while Molo and Perkerra are perennial though with reduced discharges during dry seasons.

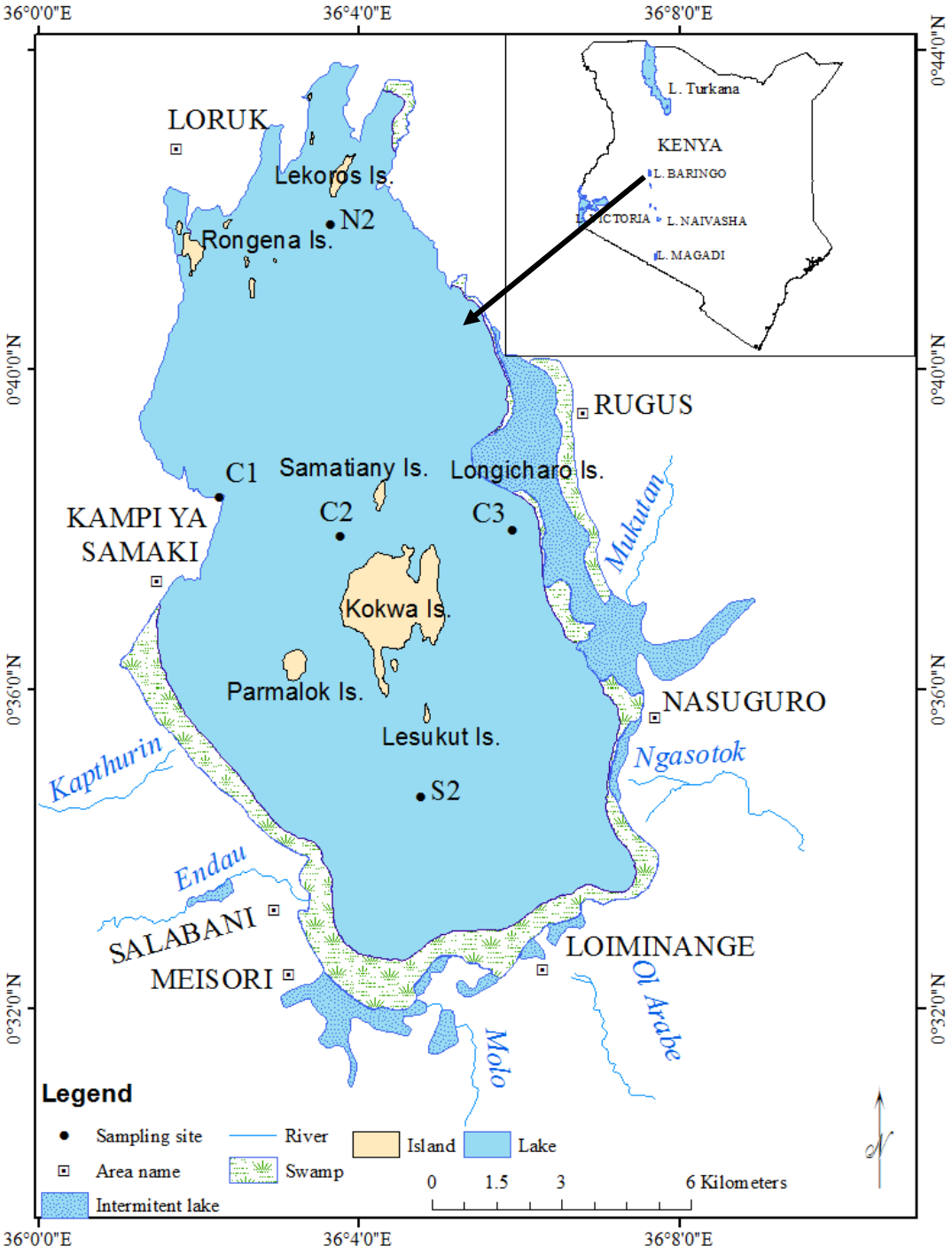

Figure 6.22: A map of Lake Baringo showing the stations, S2, C1, C2, C3 and N2, sampled during the study from April 2008 to March 2010.

6.2.2 Fish sampling and stomach content analysis

Fish was caught quarterly by seining in the lake using a 5 mm mesh size seine net whose size was 30 m in length and 2 m depth. Gillnets of various mesh sizes 2" to 6" were also used especially for larger fish specimens. The fish were sorted into different species and their total length recorded before they were preserved in 10% formaldehyde solution for gut analyses in the laboratory. The contents of every stomach were scrutinized under 50X magnification of a binocular microscope. Prey were identified to the lowest possible taxonomic levels and counted. Most prey items in the stomachs were intact although occasionally prey fragments were easily identified.

The relative importance of food items was investigated using frequency of occurrence and volumetric analysis. In frequency of occurrence method, the number of stomachs in which a given category of food item occurs is expressed as a percentage of the total number of stomachs with food. This method provides information on the proportion of the population that fed on that particular food item. In volumetric analysis, food items that were found in the stomachs were sorted into different taxonomic categories and the volume of the items in each category was then expressed as a percentage of all the categories of food items present in the samples.

Prey preference by *C. gariepinus* and *O. niloticus* were determined using Ivlev's index (1961) using the formula:

$$E = (ri - pi)/ (ri + pi)$$

Where ri was the proportion of prey in the fish stomach and pi the proportion of the prey in the environment. This was not carried out for *P. aethiopicus* due to insignificance of zooplankton as food for the species.

The index varies from -1 to +1. Negative values indicate rejection of a food item while positive values mean prey preference. An E–value of 0 indicates that food is being ingested in the same proportion as is present in the environment. E values between -0.3 and +0.3 are generally considered not significantly different from 0 and thus indicate non-selective feeding (Lazzaro 1987).

6.2.3 Zooplankton sampling

Quantitative triplicate zooplankton samples were collected monthly at each site with a 1.0 m long Nansen type plankton net of 50 μm mesh size and mouth opening measuring 30 cm diameter. The net was lowered close to the bottom of the lake without disturbing the sediments and hauled vertically to the surface and the depth noted from the marked rope. The net was rigged with a weight suspended from the receptacle to ensure the hauls were vertical. 100% efficiency of the net was assumed by washing after each sampling and because of the shallow nature of the lake there were no corrections made for loss due to decrease in efficiency of the net. Samples collected were preserved in 4% formaldehyde solution, labeled and transported to the laboratory. In the laboratory, successive aliquots of each sample were examined under a binocular dissecting microscope at X40 magnification. Copepods and cladocerans were sorted using electronically sharpened tungsten wire fixed on inoculating rods while rotifers were sorted using fine glass capillary tubes into glycerine mixed with distilled water on glass slides.

The zooplankton were identified to genus and where possible to species level using relevant taxonomic literature. For copepods, identification keys by Dussart and Defaye (1995) were used. The keys by Korovchinsky (1992) and Smirnov (1996) were used in Cladocera identification while Koste (1978), Koste and Shiel (1987) and Segers (1995) were used for the identification of rotifers.

In the laboratory each zooplankton sample was made to a known volume and thoroughly shaken for uniform distribution of organisms. A 3 ml plastic dropper was used for sub sampling. 1-3 ml sub-samples were taken, placed in 6 x 6 x 1 cm counting chamber and zooplankton counted under a Leica dissection microscope (X40). The effect of surface tension on the specimens was reduced by addition of a few drops of liquid detergent while visibility was improved by dying with Lugol's solution.

The number of individuals per litre of lake water (D) was determined using the formula:

$D = N/V$, Where

N = number of organisms in sample

= (number in sub-sample x Volume of sample)/sub-sample volume

V = volume of lake water filtered = $\pi r^2 d$, where

r = radius of mouth of net (15 cm)

d = depth of haul

6.3 Results

Gut contents of a total of 430 fishes were analysed. These included 142, 72 and 216 for *P. aethiopicus, C. gariepinus* and *O. niloticus,* respectively. The total length for the three fish species were in the ranges of 17.3-97.5 cm, 19.6-63.0 cm and 2.4-28.0 cm, respectively. Smaller size classes of *P. aethiopicus* and *C. gariepinus* were not obtained from the lake during the study.

The results shows that*P. aethiopicus* in Lake Baringo feeds on different kinds of food items such as molluscs, fish, detritus, higher plants and insects. Gut content was dominated by molluscs with a mean composition of 94.3% (Fig. 6.2) with a frequency of occurrence of 98.6% of stomachs with food. Fish was also an important component of the gut contents with a mean contribution of 4.9% and a frequency of occurrence of 39.4% of the stomachs with food. Other food items recorded included detritus (0.6%), insects (0.1%) and higher plant materials (0.1%). Insects found in the stomachs were of the order Odonata while the higher plant materials belonged to the families Ceratophyllaceae and Poaceae.

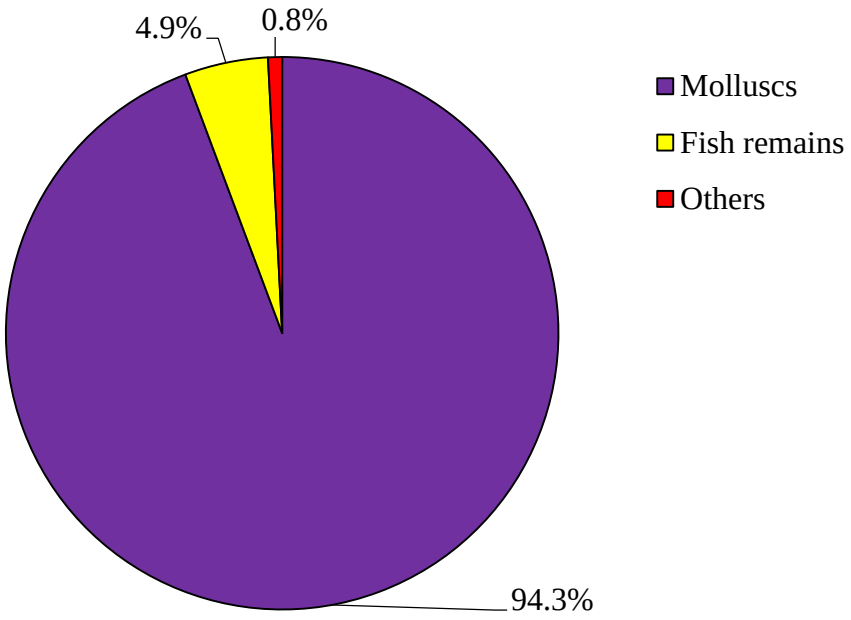

Figure 6.2: Percentage contribution of different prey items in the diet of *P. aethiopicus* in Lake Baringo during the study period.

The diet of *C. gariepinus* consisted mainly of fish, detritus and zooplankton (Fig. 6.3) with fish as the dominant prey item. The frequency of occurrence for the prey was 75% with a mean contribution of 49.2% by volume. The other important components of the diet of the species were detritus and zooplankton which contributed 28.3% and 19.6%, of the gut contents respectively. The numbers of zooplankton recorded in the stomach were, however, high with the highest being 85,300 organisms in a stomach of a 43.5 cm fish. Higher plant materials were also recorded in the stomach, albeit in small proportions.

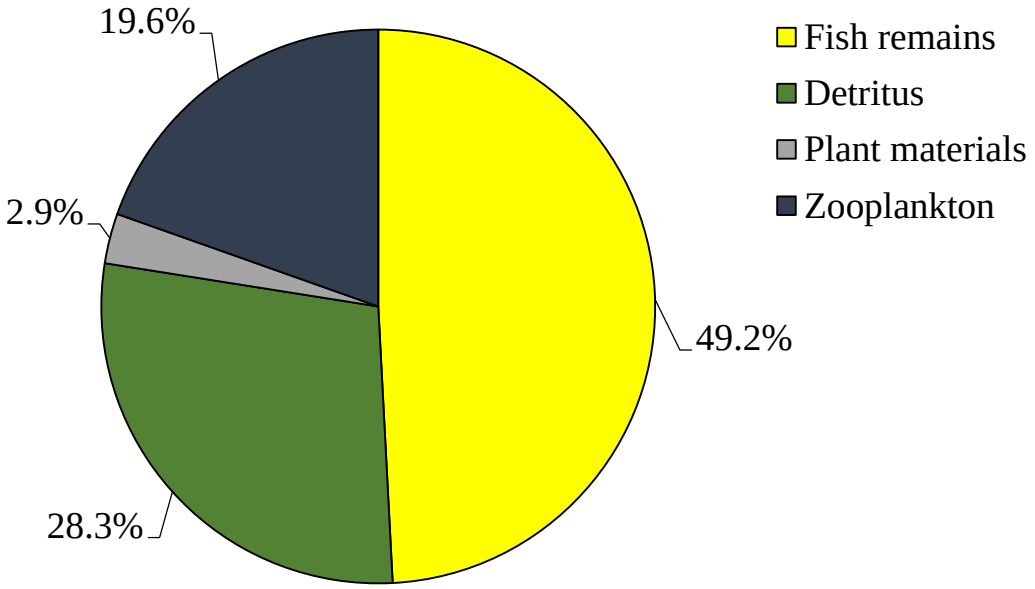

Figure 6.3: Percentage contribution of different prey items in the diet of *C. gariepinus* in Lake Baringo during the study period.

Among the zooplankton prey, *C. gariepinus* preferred the cladoceran *D. barbata* as its prey. The percentage contribution of the item in the *C. gariepinus* stomachs ranged from 33% to 94% while the Ivlev's index (E) ranged from 0.5 to 0.8 showing that the zooplankton species was highly selected for by the fish. Other zooplankton taxa in the diet of *C. gariepinus* included copepods (nauplii, cyclopoids and calanoids), cladocerans *D. excisum*, and *C. cornuta* while *F. opoliensis* was the only rotifer recorded in the stomachs. Among the zooplankton, the proportion of *D. barbata* in the diet of *C. gariepinus* above 40 cm in length was higher (96.1%) compared to those fishes below 40 cm with a proportion of 30.5% (Fig. 6.4).

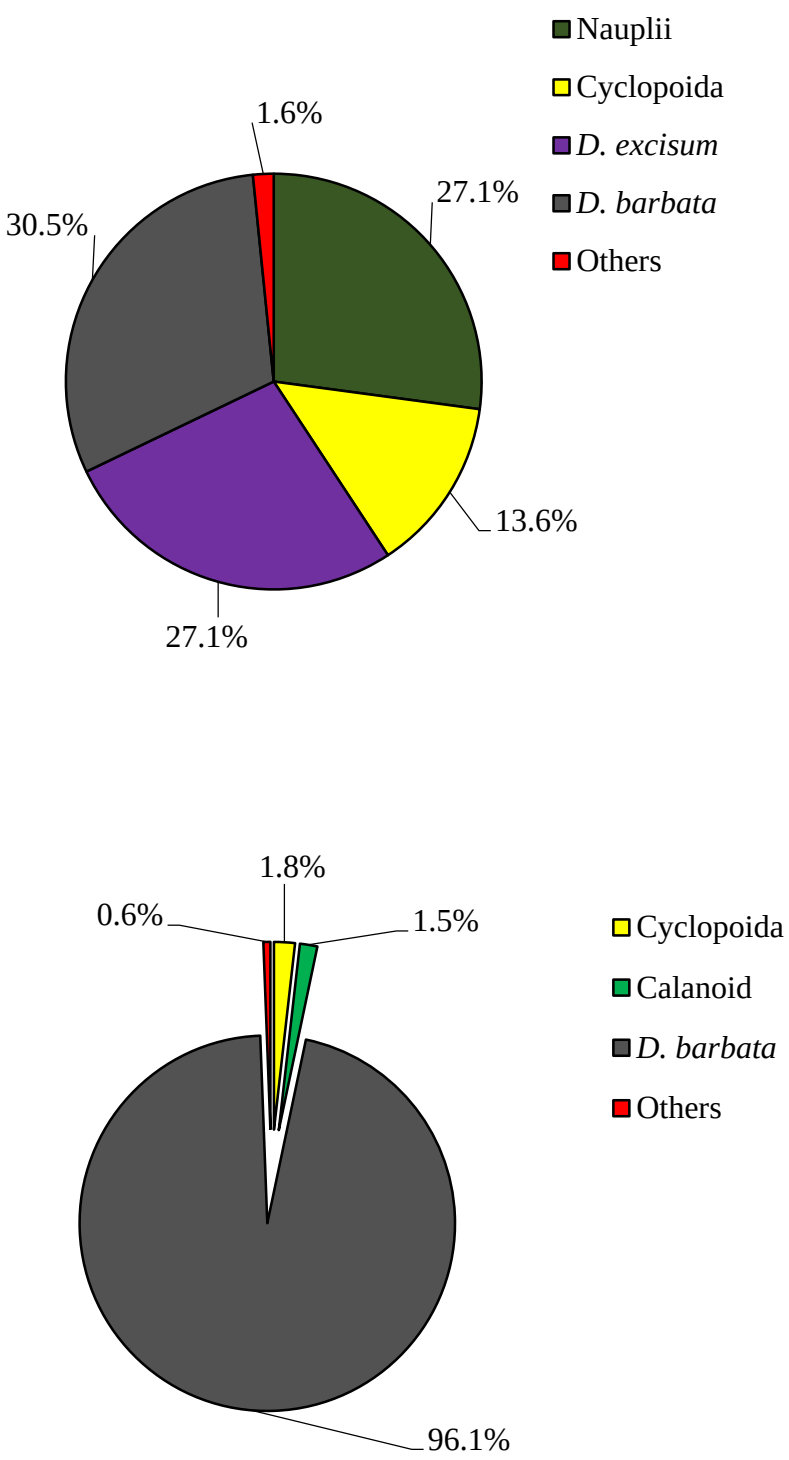

Figure 6.4: Percentage contribution of different prey items in the diet of different size classes of *C. gariepinus* (Top) 10.0-39.9 cm size class and (Bottom) 40.0-69.9 cm, size class in Lake Baringo during the study period.

The food items in the stomachs of *O. niloticus* consisted mainly of algae, detritus and zooplankton (Fig. 6.5). Other components consumed were higher plant materials, fish and insects. Algae was predominantly consumed by all size classes of this fish in high proportions of between 26.5% and 88.1%. While the importance of zooplankton as amajor food item decreased with size of fish, the reverse trend occurred for detritus with the proportion ingested increasing with size. Insects, fish and higher plant materials on the other hand were hardly utilized by *O. niloticus* over 15 cm in length. The fish found in some guts were probably accidentally swallowed by the mouth brooding females as all the stomachs where they occurred were females. Insects were found only in the stomachs of fishes in the size class of 5.0-9.9 cm with a proportion of 1.9% and these were terrestrial insects which could have been taken from the water surface.

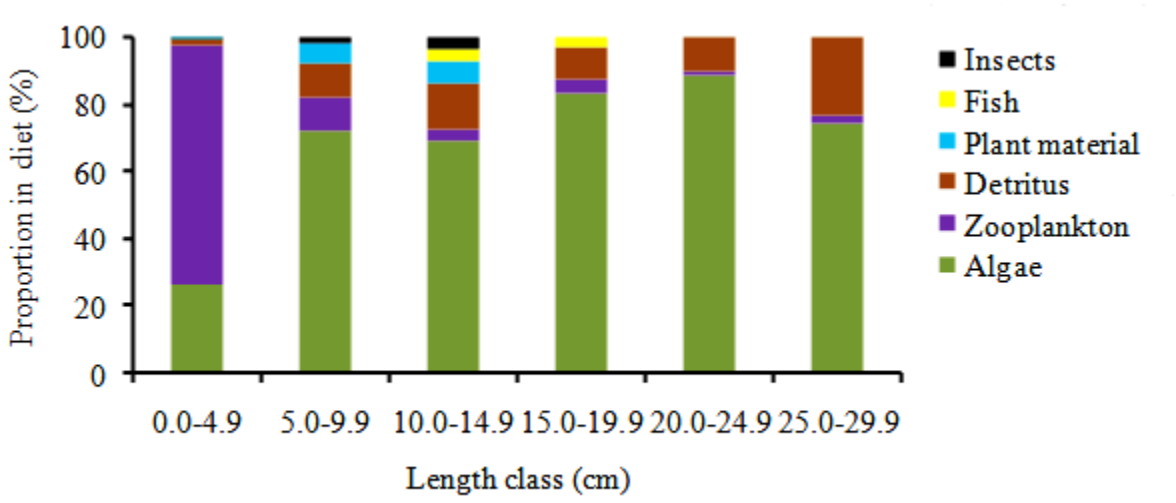

Figure 6.5: Diet composition of different length classes, by volume, of *O. niloticus* in Lake Baringo.

Among the zooplankton species forming the main diet of *O. niloticus* are the cladocerans *D. excisum*, *M. micrura* and *D. barbata*. Important rotifer species were *B. patulus* and *K. tropica*. The importance of copepods as food for the species was negligible as only nauplii were recorded in a few stomachs in low proportions. *M. micrura* and *D. excisum* were the dominant prey items ingested by all length classes occurring in proportion ranging from 13.8% to 66.5% in the stomachs of fishes below 10.0 cm (Table 6.1). The two species were also found in the largest length group, 25.0-29.9 cm, in the proportions of 72% and 16% respectively.

Table 6.1: Proportions, as %, of various zooplankton species in the diet of *O. niloticus* in Lake Baringo.

	Length classes (cm)					
	2.4-4.9	5.0-9.9	10.0-14.9	15.0-19.9	20.0-24.9	25.0-29.9
M. micrura	66.5	45.4			2.7	72
D. excisum	33.2	13.8		11.5	2.4	16
D. barbata	0.3		74.6	40.5	81.3	12
B. patulus		13.8	4.5	15.7	2.7	
K. tropica		13.1	5.4	19.9	6.2	
F. opoliensis			10.5		2.1	
Nauplii		8.5				
Others		5.4	5.0	12.4	2.4	

The results exhibited a clear ontogenic shift with lower length groups feeding predominantly on *M. micrura* and *D. excisum* while larger classes feeding mainly on *D. barbata*. 56% of the lowest length class fed on the smallest prey, *M. micrura* which averaged 627 µm in length while 23.4% of the class fed on medium sized *D. excisum* with a mean length of 790 µm. These proportions decreased with increase in size of *O. niloticus* juveniles and at 10.0-19.9 cm and 20.0-29.9 cm length classes the fishes were predominantly feeding on *D. barbata* which is a bigger prey. The mean length of *D. barbata* in the lake was found to be 1347 µm.

Electivity tests carried out in *O. niloticus* for zooplankton prey showed that copepods (nauplii, cyclopoids and calanoids) and *F. opoliensis* were generally not selected for by this fish (Table 6.2). It was also evident from the results that the smallest size group of *O. niloticus* had the narrowest spectrum of diet with *M. micrura* being the only selected zooplankton in the diet while Calanoida and Cyclopoida were completely avoided. The latter phenomenon was also observed in all the rotifers.

Table 6.2: Electivity indices for zooplankton prey of *O. niloticus* in Lake Baringo.

	Length class (cm)				
Zooplankton species	0 - 4.9	5.0 - 9.9	10.0 - 14.9	15.0 - 19.9	20.0 - 24.9
Nauplii		-0.43	-0.91	-0.63	-0.72
Cyclopoida	-1.00	-0.87	-0.71	-0.72	-0.77
Calanoida	-1.00	-1.00	0.00	-0.62	-1.00
D. excisum	0.00	0.07	0.17	-0.03	0.13
M. micrura	0.96	0.69	0.28	0.74	0.78
D. barbata			0.14		
C. cornuta			-0.30		
B. falcatus	0.00	0.93	0.32	0.82	0.29
B. patulus	-1.00	0.99	0.87	0.97	0.89
K. tropica	-1.00	0.57	0.28	0.70	0.47
F. opoliensis	-1.00	-0.61	0.36	-0.83	-0.15

As the fishes increased in size (5.0 cm - 9.9 cm), there was a slight decrease in preference for *M. micrura* while *D. excisum* was introduced into the diet.

6.4 Discussion

The absence of juveniles of *P. aethiopicus* in the fish catches of Lake Baringo is not unique. Earlier studies in Lake Victoria basin revealed that small sizes of this species are rarely encountered in the open waters (Mosille & Mainoya, 1988; Goudswaard *et al*., 2002). The juveniles of the fish are believed to be found in matted roots of papyrus and may be limited to these habitats (Graham, 1929; Greenwood, 1966). While an earlier investigation in the lake had reported that *P. aethiopicus* show selective preference for fishes as food (Mlewa and Green, 2004), this study shows that *P. aethiopicus* show preference for feeding on molluscan diet. This corroborates the findings of studies on this species from other lakes (Worthington, 1932; Corbet, 1961). The fish, which was introduced into Lake Baringo in 1975 and presently dominates the fish community, is mostly a benthic feeder and probably has no competitor. Moreover, while *O. niloticus* feeds by sight in the pelagic zonesand is affected by the lake's high turbidity, *P. aethiopicus* feeds by groping at the bottom of the lake which molluscs inhabit. Success of *P. aethiopicus* is probably as a result of the widespread distribution, albeit in low abundance, of molluscs in the lake. Busienei (2003) and Muli *et al.* (2007) reported that Molluscs and Insects were the most widely distributed and abundant macroinvertebrates in this lake.

Although *C. gariepinus* feed by sight, it is also ram feeder, ingests by keeping the mouth open while swimming, and as such would be expected not be affected much by the turbidity of Lake Baringo water. Although fish was significant as diet for *C. gariepinus*, zooplankton also featured in the stomachs for all the size groups. This fish has been described as a voracious predator that eats almost anything (Bruton, 1979) and its ability to feed both at the bottom and at the surface enables it to survive in the turbid lake. This species probably lacks strong jaws to utilize the available mollusks in the lake. Predation on zooplankton by adult *C. gariepinus* has also been reported by Dadebo (2009) in Lake Chamo in Ethiopia. The use of zooplankton as food by adult *C. gariepinus* is probably a pointer that the lake lacks alternative larger prey for the fish. Its wide, subterminal mouth enables it to suck in large amounts of water which is flushed through the gills for filter feeding. Efficiency of zooplankton capture is ensured by the large number of gill rakers which increase with size of the fish (Bruton, 1979). Dependence on zooplankton by the larger *C. gariepinus* results in competition with other fish species which could result in the reduction of forage success. This study further shows that *C. gariepinus* selects the largest cladoceran, *D.*

barbata, which offers most energy compared to other species. However, being a non-visual filter feeder, it is probable that the fish fed in areas with high density of the prey. Burgis (1973) found high densities of *D. barbata* just above the surface of mud in Lake George. There are similar habitats in Lake Baringo where the species probably also occur.

That the cladocerans are favoured more than the abundant copepods, as prey by fish predators in the lake corroborates earlier studies. Zaret (1980) and O'Brien (1987) reported that zoopanktivorous fish often take cladocerans in preference to copepods because copepods have a more erratic mode of motion and are, as such, not easy to capture, a fact that could also explain the results of the present study.

The generally low numbers of zooplankton in the stomachs of *O. niloticus* observed in this study corroborates earlier findings by Busienei (2003) in the lake and could be attributed to turbidity of the lake water which reduces visibility of the fish and on its feeding rhythms.The lack of clear zooplankton species selectivity pattern could be due to the preference of other available food items in the lake. In this study high turbidity may have forced the species to heavily rely on algal matter which dominated the diet of *O. niloticus*. The shift of prey with increase in size reported in this study is a foraging strategy used by the predator fish to meet their increasing energy demands (Lazzaro, 1987; Wotton, 1998). This kind of phenomenon is necessitated by the increase in gape size thus allowing ingestion of larger food items. The predator fish would therefore always try to minimize the cost of prey capture by selecting the larger prey that they can catch and ingest with ease. The energy returns are normally commensurate with the size of the prey and the cost of capture in line with optimal foraging theory and the associated search benefits.

6.5. Conclusion

The study revealed that while *P. aethiopicus* fed mainly on molluscs, the diet of *C. gariepinus* was dominated by fish and detritus while *O. niloticus* fed predominantly on algae in Lake Baringo. Zooplankton, however, featured as an item in the diets of both *C. gariepinus* and *O. niloticus*. This variation in the diets of the three main fish species in Lake Baringo as found in this study leads to the rejection of hypothesis 5, that there are no significant differences in the diet of the main fish species in the lake.

The catches of *O. niloticus*, which once dominated Lake Baringo, have declined due to deteriorating water quality especially increasing turbidity. Besides reduction of the euphotic zone, the turbid water also reduces feeding efficiency of the visual feeding fish. *C. gariepinus* in Lake Baringo lacks suitable food due to low densities of macroinvertebrates. The fish, particularly the adults, have thus taken to feeding on zooplankton especially *D. barbata* thus competing for prey with its juveniles and other fish species especially *O. niloticus* leading to its reduced growth. *P. aethiopicus* which was introduced into the lake has flourished due to occurrence of its main food item, the molluscs for which there is no competition.

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CHAPTER SEVEN

7.0. GENERAL CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

As a freshwater body, Lake Baringo is important to the communities in its basin and the whole county as a source of water for domestic use and watering of livestock, income generation through irrigation, tourism, biodiversity conservation and fishing. The water quality of the lake has, however, deteriorated over time. Incoming water through rivers is the source of pollutants in the form of silt, nutrients and ions materials that come from the catchment as a result of anthropogenic activities. The study shows that there is no significant spatial variation in physico-chemical factors due to the lake's small size, shallowness and wind mixing while temporal variations in physico-chemical variables is significant due to changes in the lake in volume of water resulting from variation in the rainfall pattern in the catchment. The study revealed significant spatial and temporal variations in phytoplankton biomass, estimated as chlorophyll *a*. Fluctuation in the volume of water in the lake have several consequences to the abiotic and biotic components through changes in concentration/ dilution of solutes in the lake.

Besides low diversity of zooplankton, especially Copepoda with only three species, this study also showed that there were both spatial and temporal variations in zooplankton diversity. These are attributed to reduced heterogeneity of habitats and stressful conditions arising from changes in the physico-chemical factors. The insignificant spatial variation in the abundance and biomass of zooplankton also arises due to the small size of the lake and habitat homogeneity.

This study demonstrates that changes in zooplankton abundance and biomass is influenced by changes in some physico-chemical factors, notably turbidity and conductivity, and chlorophyll *a* in Lake Baringo. The high turbidity, arising from siltation and resuspension of sediments, in the lake results in decreased primary productivity due to reduced light availability. Changes in water volume and conductivity, due to the rainfall amounts in the catchment, results in the changes in conditions in the aquatic environment which may interfere with the survival of different zooplankton species in the lake. This is shown by the temporal variations in their relative abundance and biomass.

The study revealed that diel vertical migration of zooplankton occurs in Lake Baringo but unlike in clear lakes, high proportions of zooplankters ascend to the surface waters during the day and descend to the lower depths during the night. It shows that DVM in the lake is controlled by light with the organisms remaining at the surface water during the day where they feed on phytoplankton with minimal risk of predation by visual feeding fish because of the turbid water.

The study showed that while *P. aethiopicus* fed mainly on molluscs in Lake Baringo, *C. gariepinus* diet was dominated by fish and detritus and *O. niloticus* fed predominantly on algae. Zooplankton also featured as an item in the diets of *C. gariepinus* and *O. niloticus* of all length classes. The composition and density of the lake's fishery has changed with time with the once dominant *O. niloticus* being surpassed by catches of the introduced *P. aethiopicus*. This is attributed to the changing water quality especially turbidity which suppresses algal production and also interferes with the feeding and reproduction efficiency of *O. niloticus* in contrast with *P. aethiopicus* which feeds by groping and detects its prey by use of barbels. The turbid conditions in the lake has led to near extinction of submerged macrophytes which besides provision of nutrition for many fauna, provide substrate for some algae and also refugia for zooplankton and juvenile fish against predators.

7.2 Recommendations

Considering that the lake has no surface outlet, the concentration of most of these pollutants would be cumulative and remain in the lake for a long time and will worsen unless the situation is arrested. It would be prudent to investigate the nutrients dynamics in the lake, both autochthonous and allochthonous, with an aim of reducing the latter. This can be alleviated through afforestation programmes and reduction of the number of livestock in the area. The areas around the lake should also be protected by fencing and planting suitable grasses like vetiver which can withstand water logging and drought. Ground cover loss in Lake Baringo basin has been caused by keeping large number of cattle, goats and sheep which feed and trample on grass. It has been demonstrated by the Rehabilitation of Arid Environment Trust (RAE) that land cover in the catchment can be improved by reduced trampling through fencing (Plate 7.1).

Plate 7.1: The area protected by RAE with established ground cover (left) compared to unprotected area (right) in Lake Baringo catchment.

Restoration of vegetation cover through afforestation in the catchment would produce noticeable benefits by reducing soil erosion thus suspended solids that end up in the lake and this would ultimately improve transparency and allow development of aquatic macrophytes. Macrophytes and their resultant detritus are important in the diet of commercially important fish species in the lake such as *C. gariepinus* and *O. niloticus*. Moreover, macrophytes are known to provide hiding places for zooplankton and juvenile fish against predators. Other benefits of macrophytes in the lake include reducing the impact of wind-mixing through sediment resuspension and the control of algal blooms by shading.

The population around Lake Baringo has increased in the recent times due to thriving tourism and increase in the number of hotels especially around Kampi Ya Samaki (Plate 7.2). This calls for the county government to institute strict town planning and infrastructure development plans considering the amount of wastes produced in the town and the risk of these reaching the lake. A buffer zone of up to 100 meters around the lake should be maintained to avoid cases of destruction, displacement and pollution that occur around the lake when there is a rise in water level. Provision of ground cover in the buffer zone will reduce the amount of solid wastes reaching the lake thus improving transparency and more production in the lake. Pollution control measures

should be extended to the islands, especially Kokwa, where there are hotels and other development projects.

Plate 7.2: Soi lodge, one of the hotels at the shores of Lake Baringo

To conserve the lake's biodiversity, measures should be taken to avoid introduction of new aquatic species in the basin without proper ecological considerations. Already there are fears that different strains of *O. niloticus* may have been introduced into fish ponds in the basin in the ongoing aquaculture Economic Stimulus Programme (ESP). It is not clear the origin of seeds used by the fish farmers in the basin. Such fish species could get into the lake through rivers after high rainfall as was observed in Lake Naivasha's invasion by common carp, *Cyprinus carpio*. Any aquaculture activities in Lake Baringo basin should use fingerlings from the lake's fish strains.

Despite the significance of hippopotamus and crocodiles in conservation and tourism, there is need to determine the carrying capacity of the lake for these animals considering that during low water levels *P. geminatum,* the grass on which hippopotamus depends most for food is usually decimated. The existence of the grass, and other macrophytes, in the lake are greatly affected by the fluctuating lake levels as was seen during the severe drought of 1994/1995 when hippos had

to be fed on hay by Mr. Murray Roberts (Olilo- personal communication). The establishment of the lake's carrying capacity at different seasons and culling of the animals if necessary would avoid human- wildlife conflicts. The same exercise should be carried out on crocodile population in the lake. Crocodiles are thought to be heavily predating on the lake's fish especially gilled fishermen catches. This calls for comprehensive studies on the lake's resources by the institutions already represented in the county including Egerton University, Kenya Marine and Fisheries Research Institute, Kenya Forestry Research Institute, Kenya Agricultural Research Institute, Kenya Wildlife Service and a number of Non-Governmental Organizations to elucidate how they can be sustainably managed. For better management of the lake, there is need to come up with a management plan to help in sustainable utilization of its resources. The stakeholders should be advised on the importance of keeping the ecosystem's integrity. Involvement of the Beach Management Units (BMUs) will be important as these are the institutions dealing directly with fishermen.

There is need for futher studies on zooplankton diversity in the lake by widespread sampling in all habitats in the lake and the adjoining Lake Kijirtit. More studies are needed on the vertical migration of zooplankton especially on the persistent distribution of *D. barbata* at all depths. There is also need to determine important phytoplankton species used for food for *O. niloticus*. Lastly, for better understanding of the ecosystem there is need for further investigations on the various components of the trophic levels from nutrients through plankton to mammals with an aim of developing models to aid in understanding the ecological processes within the lake.

APPENDICES

Appendix 1: Physico-chemical variables (mean ± SE) measured during the study period from April 2008 to March 2010.

Month	Depth	Secchi	Turbidity	Temp.	DO	Conductivity	Ammonium	Nitrates	SRP	Silicates	Chl *a*
A08	4.8±0.13	23.5±0.87	83.7±0.96	27.0±0.26	6.1±0.14	476.3±12.13	51.7±4.62	8.1±0.67	4.5±0.66	27.0±0.70	18.2±4.3
M	4.9±0.13	31.9±0.64	78.3±0.89	26.0±0.14	6.4±0.38	586.9±0.97	33.0±2.30	2.8±0.35	14.2±0.72	28.4±1.17	8.8±1.43
J	4.9±0.14	31.9±0.51	77.1±1.09	26.6±0.23	6.1±0.17	591.9±0.98	62.3±4.88	2.1±0.30	10.9±0.62	23.1±0.24	23.3±1.64
J	4.8±0.14	29.0±0.53	79.9±1.45	25.3±0.23	6.2±0.17	590.6±0.52	134.1±24.41	5.2±0.53	40.5±7.78	30.7±1.39	27.1±3.03
A	4.9±0.13	32.0±1.05	76.0±1.24	28.8±0.52	6.1±0.14	565.7±0.99	82.8±22.6	3.9±0.13	5.13±0.21	26.9±0.50	22.5±1.02
S	4.9±0.16	32.9±0.70	70.6±0.78	26.6±0.16	6.4±0.16	609.1±1.31	56.8±5.91	4.6±0.50	26.9±0.92	33.6±0.51	15.9±1.31
O	5.0±0.16	32.9±1.97	108.7±2.28	26.7±0.23	6.0±0.09	646.4±6.36	30.6±5.69	5.9±0.19	12.5±0.47	28.8±0.96	13.9±1.75
N	5.3±0.15	30.0±0.90	145.1±4.66	27.0±0.38	7.1±0.10	620.5±2.82	35.3±1.66	7.8±0.40	8.2±1.03	28.6±0.15	11.4±0.70
D	5.2±0.13	34.0±0.69	67.4±2.21	27.9±0.13	7.1±0.09	578.2±2.84	44.0±1.99	9.0±0.72	8.3±0.78	28.4±0.90	10.3±1.28
J09	4.9±0.12	36.8±1.39	90.6±1.24	29.3±0.58	6.7±0.11	605.0±9.35	34.8±1.93	5.9±0.18	26.1±1.43	28.6±0.72	11.7±0.69
F	4.6±0.13	33.0±1.07	77.3±0.53	27.1±0.45	7.6±0.19	601.5±3.57	42.4±1.67	2.5±0.09	10.6±2.46	33.2±0.68	15.5±0.57
M	4.7±0.17	31.0±1.0	73.4±2.33	27.1±0.37	8.1±0.05	652.6±4.50	39.6±1.35	3.7±0.09	11.6±2.04	29.9±0.43	15.0±0.40
A	4.4±0.14	30.1±0.85	85.2±3.19	27.6±0.37	7.9±0.23	657.3±2.51	28.7±4.63	4.1±0.15	4.6±0.41	22.4±1.03	6.5±0.37
M	4.1±0.15	33.3±1.8	67.9±3.74	27.6±0.41	7.2±0.23	661.7±1.58	15.1±1.10	2.7±0.17	9.1±1.00	27.5±0.56	11.4±0.68
J	4.0±0.14	31.7±0.63	71.2±0.89	26.5±0.57	6.3±0.11	683.3±3.07	16.8±1.75	4.8±0.39	18.2±1.26	23.9±0.77	4.9±0.38
J	3.6±0.15	31.7±0.63	61.6±1.63	27.7±0.23	6.5±0.13	716.1±2.49	43.2±8.31	6.2±0.40	22.3±1.4	26.5±0.44	21.9±1.04
A	3.7±0.14	27.0±0.66	90.1±2.24	28.7±0.36	6.5±0.14	734.7±3.91	75.7±5.69	10.2±0.66	14.4±0.69	26.1±0.19	11.9±0.25
S	3.5±0.13	21.0±0.54	118.2±3.9	25.9±0.19	7.3±0.09	761.3±2.56	46.9±1.22	4.2.0±0.2	16.9±1.24	25.3±0.51	12.7±0.58
O	3.4±0.14	21.0±0.54	84.8±1.16	26.9±0.20	7.5±0.13	770.1±0.69	79.8±6.61	10.3±0.77	14.9±0.91	26.2±0.28	17.6±0.64
N	3.4±0.13	14.0±0.26	118.7±1.76	26.3±0.33	6.9±0.14	826.6±2.73	73.5±12.97	11.9±2.08	46.3±6.47	30.9±0.85	30.7±2.84
D	3.3±0.14	14.1±0.39	130.5±2.78	28.9±0.49	7.0±0.23	846.9±3.04	46.5±7.84	32.6±1.01	58.3±10.8	31.2±2.34	26.2±2.31
J10	3.5±0.14	10.4±0.13	210.7±6.34	26.9±0.87	7.0±0.13	838.2±4.10	23.2±3.66	11.4±1.25	53.4±9.09	24.6±0.78	14.8±1.97
F	3.9±0.16	15.0±0	191.6±3.43	24.3±0.04	4.3±0.17	825.3±4.05	26.5±3.84	12.5±0.86	58.8±9.75	26.3±0.67	10.7±0.82
M	3.9±0.14	9.9±0.75	202.5±11.34	30.0±0.20	8.3±0.16	806.3±11.64	31.2±4.43	15.3±0.94	73.4±10.8	27.6±0.42	8.5±0.76

Appendix 2: Abundance of important zooplankton species (mean ± SE), in Ind. l^{-1}, in Lake Baringo between April 2008 and March 2010.

Month	Nauplii	Cyclopoida	*D. excisum*	*M. micrura*	*C. cornuta*	*D. barbata*	*B. angularis*	*B. calyciflorus*	*B. falcatus*	*F. opoliensis*	*K. tropica*	*Hexarthra* sp
A08	9.4±0.83	8.5±1.01	2.1±0.22	1.2±0.15	2.5±0.34	1.3±0.27	0.01±0.01	0	0.3±0.05	2.2±0.22	0.6±0.12	0
M	8.3±0.91	9.2±0.68	3.4±0.48	2.1±0.13	0.8±0.14	0.2±0.05	0.01±0.01	0.01±0.09	0	0.4±0.08	2.9±0.41	2.50±0.49
J	6.6±1.04	8.5±0.76	3.2±0.35	3.8±0.38	1.3±0.12	1.1±0.10	0.01±0.01	0.03±0.03	0.5±0.07	7.3±0.82	0.2±0.07	0
J	22.9±4.45	23.9±2.35	5.1±0.65	1.7±0.25	1.2±0.16	4.2±0.70	0.04±0.02	0	0.9±0.12	6.8±0.67	0.2±0.07	0.04±0.02
A	13.9±1.76	23.2±2.60	5.8±0.66	1.3±0.11	3.3±0.56	1.2±0.18	0.20±0.07	0.21±0.18	1.4±0.25	8.1±1.26	1.5±0.48	0.95±0.34
S	36.8±1.64	30.7±2.16	4.1±0.56	0.9±0.11	1.3±0.15	0.9±0.22	0.68±0.15	0.33±0.07	0.4±0.10	15.1±1.48	2.1±0.35	1.60±0.41
O	29.6±3.41	15.5±1.11	3.1±0.28	0.6±0.12	1.0±0.14	1.6±0.21	1.63±0.20	1.00±0.15	0.8±0.13	7.8±1.12	2.3±0.33	3.38±0.57
N	27.8±3.29	25.3±4.40	2.3±0.44	0.3±0.07	0.8±0.06	5.4±1.80	0.25±0.04	0.15±0.05	0.5±0.12	10.5±1.67	0.7±012	1.15±0.24
D	9.5±0.80	9.7±1.10	1.8±0.31	0.3±0.06	0.4±0.10	0.9±0.11	0.60±0.10	0.17±0.07	0.4±0.10	2.7±0.35	0.9±0.21	0.004±0.0
J09	30.7±2.03	16.1±1.89	2.2±0.29	1.3±0.19	1.4±0.20	0.7±0.15	1.22±0.33	0.08±0.03	0.7±0.16	6.3±0.58	1.3±0.20	0.36±0.14
F	26.5±3.34	14.6±0.84	9.7±2.55	.04±0.02	0.1±0.05	0.2±0.04	0.87±0.13	0.13±0.03	0.6±0.12	3.9±0.27	1.7±0.41	0.17±0.06
M	57.4±7.60	14.0±2.40	5.8±0.99	0.4±0.09	0.05±0.02	0.4±0.13	0.57±0.14	0.09±0.03	0.6±0.13	13.9±1.70	0.8±0.17	0.20±0.08
A	23.9±3.06	22.6±1.41	5.2±0.62	4.1±0.44	0.4±0.14	0.7±0.12	2.37±0.57	0.31±0.06	0.8±0.11	19.9±1.57	0.4±0.09	0.81±0.21
M	31.9±2.68	23.9±1.63	3.7±0.88	2.3±0.35	4.2±0.36	0.8±0.17	1.21±0.28	0.24±0.05	0.3±0.10	7.4±0.97	0.3±0.06	1.22±0.36
J	33.1±2.78	15.5±0.99	3.4±0.50	0.9±0.13	1.4±0.18	0.1±0.02	0.47±0.07	0.29±0.06	0.2±0.05	2.8±0.45	0.7±0.10	0.37±0.09
J	33.6±4.90	8.1±0.50	7.4±0.71	0.5±0.09	1.46±0.15	0.2±0.04	0.27±0.06	1.47±0.20	0.1±0.02	2.2±0.44	0.2±0.02	0.16±0.06
A	33.1±6.75	5.5±0.62	8.6±1.32	0	0.04±0.02	0.02±0.01	0.04±0.02	0.87±0.08	0	0.9±0.14	0.2±0.05	0.02±0.01
S	87.1±5.76	9.3±0.83	9.3±1.09	0	0.3±0.07	0.4±0.12	0	0.76±0.11	0	3.3±0.34	0.1±0.03	0.13±0.05
O	31.7±2.42	21.8±2.06	16.3±1.50	0.01±0.01	0.9±0.19	0.9±0.16	0	1.14±0.30	0	12.5±0.84	0.3±0.07	0.09±0.04
N	49.1±4.20	27.5±3.64	8.5±1.55	0.4±0.09	2.7±0.40	7.4±1.08	0.051±0.03	2.06±0.52	0	17.9±1.25	3.6±0.62	0.09±0.04
D	43.9±2.14	39.7±4.75	5.2±0.61	1.4±0.21	0.9±0.19	6.6±1.23	0.16±0.06	2.16±0.36	0	24.9±2.06	14.3±2.77	0.50±0.10
J10	90.2±4.98	39.2±3.68	1.8±0.31	0.3±0.07	2.6±0.51	5.1±0.64	0.03±0.03	1.04±0.14	0	3.4±0.41	127.116.8	1.25±0.26
F	78.9±7.28	31.5±2.34	3.1±0.34	1.8±0.62	3.8±0.47	4.0±0.61	0.49±0.09	2.06±0.40	0.1±0.03	17.0±1.84	13.6±1.75	9.12±1.81
M	103.0±8.13	34.0±3.70	2.5±0.40	0.1±0.03	1.3±0.24	1.0±0.25	1.04±0.42	1.28±0.23	0.9±0.20	18.6±1.55	14.9±2.28	20.01±2.64

Appendix 3: Biomass of zooplankton species (mean ± SE), in µg.l^{-1}, in Lake Baringo between April 2008 and March 2010.

Month	Nauplii	Cyclopoida	Calanoida	*D. excisum*	*M. micrura*	*C. cornuta*	*D. barbata*	*B. calyciflorus*	*B. falcatus*	*F. opoliensis*	*K. tropica*
A08	0.58±0.05	20.13±2.37	19.61±4.68	8.90±0.91	6.66±0.83	3.07±0.42	6.117±1.29	0	0.04±0.01	0.07±0.01	0.02±0.004
M	0.51±0.06	21.79±1.59	4.22±0.93	14.37±2.0	11.75±0.71	1.02±0.17	1.02±0.22	0	0.03±0.01	0.09±0.01	0.02±0.005
J	0.41±0.06	20.09±1.78	1.53±0.40	13.27±1.5	21.50±2.16	1.53±0.15	5.19±0.49	0.01±0.01	0.07±0.01	0.21±0.02	< 0.01
J	1.43±0.28	56.44±5.55	2.56±0.43	21.60±2.7	9.56±1.45	1.45±0.20	20.49±3.41	0	0.13±0.02	0.20±0.02	< 0.01
A	0.86±0.11	54.89±6.13	0.59±0.26	24.23±2.8	7.10±0.60	4.00±0.69	5.81±0.86	0.07±0.06	0.19±0.04	0.24±0.04	0.06±0.02
S	2.29±0.10	72.39±5.08	0.49±0.16	17.36±2.4	5.02±0.61	1.63±0.19	4.32±1.04	0.11±0.02	0.06±0.02	0.44±0.04	0.08±0.01
O	1.84±0.21	36.63±2.62	0.31±0.23	12.84±1.2	3.24±0.68	1.24±0.18	7.61±1.00	0.34±0.05	0.12±0.02	0.23±0.03	0.09±0.01
N	1.73±0.20	59.55±10.4	0	9.46±1.86	1.66±0.38	0.91±0.07	26.24±8.72	0.05±0.02	0.07±0.02	0.31±0.05	0.05±0.004
D	0.59±0.05	22.83±2.59	0.06±0.06	7.37±1.30	1.64±0.33	0.54±0.13	4.30±0.54	0.06±0.02	0.06±0.01	0.08±0.01	0.03±0.01
J09	1.90±0.13	37.87±4.45	0	9.45±1.21	7.40±1.07	1.69±0.25	3.60±0.70	0.03±0.01	0.10±0.02	0.19±0.02	0.05±0.008
F	1.64±0.21	34.46±1.99	0	40.7±10.7	0.20±0.09	0.17±0.06	0.93±0.18	0.04±0.01	0.09±0.02	0.12±0.01	0.06±0.02
M	3.57±0.47	33.08±5.65	0	24.3±4.18	2.13±0.49	0.07±0.02	1.99±0.60	0.03±0.01	0.09±0.02	0.41±0.05	0.03±0.01
A	1.49±0.19	53.28±3.32	0	21.90±2.6	23.30±2.49	0.53±0.18	3.19±0.57	0.10±0.02	0.11±0.02	0.59±0.05	0.02±0.003
M	1.86±0.16	52.40±3.20	0	11.02±2.3	10.89±1.26	4.78±0.43	4.45±0.89	0.06±0.02	0.03±0.01	0.21±0.03	< 0.01
J	1.93±0.16	36.51±2.72	0	13.03±1.9	5.47±0.87	1.81±0.22	0.53±0.11	0.10±0.02	0.02±0.01	0.08±0.02	0.02±0.003
J	2.19±0.31	19.47±1.18	0	31.9±3.03	2.71±0.52	1.76±0.19	0.90±0.22	0.49±0.07	0.01±0.003	0.07±0.01	0.01±0.001
A	2.06±0.42	12.97±1.47	0	36.16±5.6	0	0.05±0.02	0.10±0.05	0.30±0.03	0	0.03±0.004	0.01±0.002
S	5.41±0.36	21.81±1.96	0	39.09±4.6	0	0.41±0.09	1.99±0-.56	0.26±0.04	0	0.10±0.01	< 0.01
O	1.97±0.15	51.51±4.86	0	68.56±6.3	0.05±0.05	1.21±0.24	4.79±0.76	0.39±0.10	0	0.37±0.03	0.01±0.003
N	3.05±0.26	64.94±8.58	0	35.55±6.5	1.99±0.52	3.25±0.49	35.95±5.25	0.70±0.18	0	0.53±0.04	0.13±0.02
D	2.73±0.13	93.58±11.2	0	21.94±2.6	7.66±1.21	1.18±0.23	31.81±5.98	0.74±0.12	0	0.73±0.06	0.54±0.10
J10	5.61±0.31	92.30±8.67	0	7.65±1.30	1.55±0.40	3.15±0.62	24.73±3.10	0.36±0.05	0	0.10±0.01	4.78±0.63
F	4.90±0.45	74.21±5.52	0	13.03±1.4	10.46±3.54	4.71±0.58	19.60±2.95	0.70±0.14	0.01±0.01	0.50±0.05	0.51±0.07
M	6.40±0.51	80.15±8.72	0.40±0.30	10.63±1.67	0.33±0.16	1.54±0.30	4.89±1.20	0.44±0.08	0.13±0.03	0.55±0.05	0.56±0.09

Appendix 4: The physico-chemical parameters measured in Lake Baringo in 2010.

Date	Time	Depth	Temp	pH	Cond	DO
26/01/2010	8	0	23.2	8.92	862	6.10
26/01/2010	8	1	22.6	8.85	858	6.20
26/01/2010	8	2	22.3	8.85	858	6.20
26/01/2010	8	3	22.2	8.85	860	5.80
26/01/2010	8	4	22.1	8.83	858	3.20
26/01/2010	12	0	29.90	8.86	859	8.47
26/01/2010	12	1	28.57	8.84	856	7.37
26/01/2010	12	2	25.97	8.83	854	6.90
26/01/2010	12	3	25.23	8.82	854	6.17
26/01/2010	12	4	25.03	8.82	852	4.73
26/01/2010	16	0	29.03	8.86	854	8.37
26/01/2010	16	1	27.20	8.83	854	7.10
26/01/2010	16	2	26.10	8.79	853	6.77
26/01/2010	16	3	25.80	8.82	853	5.63
26/01/2010	16	4	25.20	8.81	831	4.93
26/01/2010	20	0	26.00	8.89	846	7.40
26/01/2010	20	1	24.87	8.83	844	7.00
26/01/2010	20	2	24.60	8.80	840	6.83
26/01/2010	20	3	23.67	8.77	837	6.37
26/01/2010	20	4	23.30	8.78	839	6.23
26/01/2010	24	0	23.83	8.80	835	5.73
26/01/2010	24	1	23.43	8.78	834	5.43
26/01/2010	24	2	23.47	8.85	837	5.23
26/01/2010	24	3	23.07	8.83	834	4.17
26/01/2010	24	4	23.07	8.82	834	4.20
26/01/2010	4	0	22.03	8.93	823	5.73
26/01/2010	4	1	22.17	8.88	823	5.30
26/01/2010	4	2	21.90	8.90	827	4.73
26/01/2010	4	3	22.23	8.91	833	4.47
26/01/2010	4	4	21.97	8.84	832	3.70

Appendix 5: The physico-chemical parameters measured in Lake Baringo in February 2010.

Date	Time	Depth	Temperature	pH	Conductivity	DO
23/02/2010	8	0	24.43	8.86	837	4.87
23/02/2010	8	1	24.43	8.85	838	4.77
23/02/2010	8	2	24.40	8.85	837	4.57
23/02/2010	8	3	24.17	8.81	801	4.07
23/02/2010	8	4	24.17	8.75	814	3.10
23/02/2010	12	0	29.77	8.10	813	8.57
23/02/2010	12	1	29.40	8.65	801	8.00
23/02/2010	12	2	28.13	8.60	792	7.63
23/02/2010	12	3	28.43	8.60	794	7.33
23/02/2010	12	4	27.77	8.64	793	4.50
23/02/2010	16	0	32.27	9.92	823	9.13
23/02/2010	16	1	29.93	8.74	795	8.67
23/02/2010	16	2	27.73	8.69	807	7.23
23/02/2010	16	3	26.43	8.67	808	6.73
23/02/2010	16	4	27.07	8.67	798	4.57
23/02/2010	20	0	26.00	8.92	809	6.70
23/02/2010	20	1	25.67	8.83	801	6.43
23/02/2010	20	2	25.43	8.73	802	6.27
23/02/2010	20	3	25.23	8.71	800	6.13
23/02/2010	20	4	24.73	8.72	797	4.07
23/02/2010	24	0	24.47	8.93	795	5.70
23/02/2010	24	1	24.23	8.67	791	5.23
23/02/2010	24	2	23.77	8.82	792	4.53
23/02/2010	24	3	23.43	8.79	787	4.17
23/02/2010	24	4	23.33	8.72	791	3.03
23/02/2010	4	0	23.83	8.91	795	4.83
23/02/2010	4	1	23.67	8.83	798	4.53
23/02/2010	4	2	22.30	8.79	790	4.17
23/02/2010	4	3	22.97	8.73	793	3.63
23/02/2010	4	4	22.73	8.80	799	3.20

Appendix 6: The diel vertical distribution of zooplankton, in numbers, in Lake Baringo in January 2010.

Date	Time	Depth	Copepoda	Cladocera	Rotifera	Nauplii	Cyclopoida	Total zooplankton	*Keratella*
Jan-10	8	0	235	8	299	166	69	542	281
Jan-10	8	1	154	8	152	111	42	313	594
Jan-10	8	2	177	16	136	132	44	328	494
Jan-10	8	3	183	14	168	139	44	365	371
Jan-10	8	4	117	14	60	77	40	191	218
Jan-10	12	0	450	23	610	266	184	1083	85
Jan-10	12	1	360	14	572	240	120	946	146
Jan-10	12	2	243	11	245	180	63	499	550
Jan-10	12	3	301	21	240	247	54	562	443
Jan-10	12	4	34	12	26	24	11	73	426
Jan-10	16	0	459	17	521	338	121	997	238
Jan-10	16	1	490	28	465	359	131	983	136
Jan-10	16	2	305	11	273	264	41	589	132
Jan-10	16	3	244	11	270	212	32	524	232
Jan-10	16	4	22	9	5	10	13	37	262
Jan-10	20	0	247	17	382	161	86	646	387
Jan-10	20	1	406	17	432	270	136	855	311
Jan-10	20	2	295	21	397	211	84	713	144
Jan-10	20	3	181	8	156	136	46	344	160
Jan-10	20	4	29	16	5	14	15	50	231
Jan-10	24	0	157	10	234	110	46	401	258
Jan-10	24	1	155	8	243	104	50	406	153
Jan-10	24	2	235	14	324	169	66	572	377
Jan-10	24	3	239	17	389	181	58	645	219
Jan-10	24	4	167	9	64	99	68	240	52
Jan-10	4	0	70	7	88	42	28	165	24
Jan-10	4	1	178	16	152	130	48	346	3
Jan-10	4	2	201	11	155	142	58	367	4
Jan-10	4	3	233	8	236	182	52	477	61
Jan-10	4	4	170	16	45	113	57	231	31

Appendix 7: The percentage diel vertical distribution of zooplankton in Lake Baringo in January 2010.

Date	Time	Depth	Copepoda	Cladocera	Rotifera	Nauplii	Cyclopoida	Total zooplankton	*Keratella*
Jan-10	8	0	27	14	37	27	29	31	36
Jan-10	8	1	18	13	19	18	18	18	19
Jan-10	8	2	20	26	17	21	18	19	17
Jan-10	8	3	21	23	21	22	18	21	21
Jan-10	8	4	13	24	7	12	17	11	7
Jan-10	12	0	32	28	36	28	43	34	36
Jan-10	12	1	26	18	34	25	28	30	34
Jan-10	12	2	18	14	14	19	15	16	14
Jan-10	12	3	22	26	14	26	13	18	14
Jan-10	12	4	2	15	2	2	2	2	1
Jan-10	16	0	30	22	34	29	36	32	34
Jan-10	16	1	32	37	30	30	39	31	30
Jan-10	16	2	20	14	18	22	12	19	18
Jan-10	16	3	16	14	18	18	9	17	18
Jan-10	16	4	1	13	0	1	4	1	0
Jan-10	20	0	21	22	28	20	23	25	28
Jan-10	20	1	35	22	31	34	37	33	32
Jan-10	20	2	25	27	29	27	23	27	29
Jan-10	20	3	16	10	11	17	12	13	11
Jan-10	20	4	3	20	0	2	4	2	0
Jan-10	24	0	16	17	19	17	16	18	0
Jan-10	24	1	16	13	19	16	17	18	0
Jan-10	24	2	25	24	26	25	23	25	0
Jan-10	24	3	25	29	31	27	20	28	0
Jan-10	24	4	18	16	5	15	23	11	0
Jan-10	4	0	8	12	13	7	12	10	0
Jan-10	4	1	21	28	22	21	20	22	0
Jan-10	4	2	24	20	23	23	24	23	0
Jan-10	4	3	27	13	35	30	21	30	0
Jan-10	4	4	20	28	7	19	23	15	0

Appendix 8: The diel vertical distribution of zooplankton, in numbers, in Lake Baringo in February 2010.

Date	Time	Depth	Nauplii	Cyclopoida	Copepoda	Cladocera	Rotifera	Total zooplankton	*Keratella*	*Filinia*
Feb-10	8	0	63	27	90	11	31	133	9.7	19
Feb-10	8	1	135	47	183	23	116	322	40.7	75
Feb-10	8	2	95	25	120	14	68	202	18.7	47
Feb-10	8	3	98	22	120	20	32	172	10.0	21
Feb-10	8	4	59	26	85	18	5	108	0.3	4
Feb-10	12	0	294	180	474	33	207	713	56.7	57
Feb-10	12	1	143	62	205	17	94	315	42.0	42
Feb-10	12	2	112	36	148	22	49	219	34.7	35
Feb-10	12	3	103	21	125	15	34	174	22.0	22
Feb-10	12	4	68	19	87	31	31	149	24.0	24
Feb-10	16	0	223	97	320	14	63	398	14.7	28
Feb-10	16	1	197	65	262	20	41	322	13.7	21
Feb-10	16	2	101	20	121	18	27	166	7.3	16
Feb-10	16	3	50	16	66	24	19	109	1.7	16
Feb-10	16	4	28	8	37	18	15	69	1.3	12
Feb-10	20	0	73	32	105	13	55	173	16.3	31
Feb-10	20	1	97	35	131	19	49	199	14.0	29
Feb-10	20	2	139	41	180	27	56	263	14.7	32
Feb-10	20	3	81	28	109	21	29	160	11.0	17
Feb-10	20	4	69	18	87	17	12	116	2.7	7
Feb-10	24	0	112	40	152	22	30	204	10.7	17
Feb-10	24	1	85	26	112	20	54	186	13.7	35
Feb-10	24	2	151	28	179	24	73	277	24.3	44
Feb-10	24	3	117	25	142	21	66	230	26.0	34
Feb-10	24	4	71	37	108	24	15	147	3.5	8
Feb-10	4	0	103	34	137	24	41	202	9.7	24
Feb-10	4	1	123	29	153	24	56	233	18.0	33
Feb-10	4	2	159	46	204	20	60	285	23.3	32
Feb-10	4	3	130	46	176	21	45	242	13.0	22
Feb-10	4	4	77	34	111	40	80	231	13.0	60

Appendix 9: The percentage diel vertical distribution of zooplankton in Lake Baringo in February 2010.

Date	Time	Depth	Nauplii	Cyclopoida	Copepoda	Cladocera	Rotifera	Total zooplankton	*Keratella*	*Filinia*
Feb-10	8	0	14	18	15	13	12	14	12	11
Feb-10	8	1	30	32	31	27	46	34	51	45
Feb-10	8	2	21	17	20	17	27	22	24	28
Feb-10	8	3	22	15	20	23	13	18	13	13
Feb-10	8	4	13	18	14	21	2	11	0	3
Feb-10	12	0	41	57	46	28	50	45	32	32
Feb-10	12	1	20	19	20	14	23	20	23	23
Feb-10	12	2	16	11	14	18	12	14	19	19
Feb-10	12	3	14	7	12	13	8	11	12	12
Feb-10	12	4	9	6	8	27	7	10	13	13
Feb-10	16	0	37	47	40	15	38	37	38	30
Feb-10	16	1	33	31	32	21	25	30	35	22
Feb-10	16	2	17	10	15	19	16	16	19	18
Feb-10	16	3	8	8	8	25	12	10	4	18
Feb-10	16	4	5	4	5	19	9	6	3	13
Feb-10	20	0	16	21	17	13	27	19	28	27
Feb-10	20	1	21	23	21	20	24	22	24	25
Feb-10	20	2	30	27	29	28	28	29	25	27
Feb-10	20	3	18	18	18	22	14	18	19	14
Feb-10	20	4	15	12	14	18	6	13	5	6
Feb-10	24	0	21	26	22	20	13	20	14	13
Feb-10	24	1	16	17	16	18	23	18	17	25
Feb-10	24	2	28	18	26	22	31	27	31	32
Feb-10	24	3	22	16	21	19	28	22	33	24
Feb-10	24	4	13	24	16	22	6	14	4	6
Feb-10	4	0	17	18	18	18	14	17	13	14
Feb-10	4	1	21	15	20	18	20	20	23	19
Feb-10	4	2	27	24	26	16	21	24	30	19
Feb-10	4	3	22	24	22	16	16	20	17	13
Feb-10	4	4	13	18	14	31	28	19	17	35