FACTORS THAT AFFECT ABUNDANCE AND DISTRIBUTION OF SUBMERGED AND FLOATING MACROPHYTES IN LAKE NAIVASHA, KENYA

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Plate 1. A photograph of shoreline of Lake Naivasha with principal emergent vegetation, the Giant sedge (*Cyperus papyrus L.)*, floating macrophyte, water hyacinth [*Eichhornia crassipes* (Mart.) Solms] and associated vegetation and aquatic birds at the background. (Photograph by the author-April 2003.)

Declaration

I, Ngari, A. N., do here declare that this is my original work and has not been presented for a degree in any other institution. All sources of information have been acknowledged by means of reference.

Ngari, A. N. — Date: 7th July 2005

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Dedication

To

Ngari (dad),

Liberata (mum)

and Runji (uncle).

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May God bless you all.

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Abbreviations

a.s.l. - above sea level

CO_2 – Carbon dioxide

DIC - Dissolved Inorganic Carbon

EMCA - Environmental Management and Coordination Act

GPS - Geographic Positioning System

KWS – Kenya Wildlife Service

LCP – Light Compensation Point

LNROA - Lake Naivasha Riparian Owners Association

Nm^{-2} - Newton per square meter

PAR – Photosynthetic Active Radiation

pers. observ. – personal observation

p.s.i - pounds per square inch

Regr. coeff. - regression coefficient

SRP - soluble reactive phosphorus

TP - total phosphorus

viz.- videlicet

VLIR-IUC-UoN – Vlaamse Interuniversitaire Raad-Interuniversity co-operation-University of Nairobi

ABSTRACT

The present study was conducted in Lake Naivasha (0° 45'S, 36° 20'E), a fresh water lake, which occupies a closed basin more or less circular in shape with no apparent out-flow. Lake Naivasha is relatively small with an area of about 100 km^2 (Harper, 1999). The lake is located in the eastern arm of the Great Rift Valley. Three rivers, the Malewa (1730 km^2, watershed), the Gilgil (420 km^2, watershed) and Karati (135 km^2, watershed) enter the lake in the northern part in a delta mainly covered by the giant sedge, *Cyperus papyrus* L.

A preliminary study was carried out in the month of February 2003 with an aim of familiarizing with the study area. The accessibility of the various points of the lake was assessed. A total of eight points were established considering the absence or presence of the target groups of macrophytes, the lake morphometry, main river inlets, depth and the riparian human activities of the lake among other factors. Hence, the sampling areas were established to provide a range of sites having different characteristics. The sites were located using a hand held Global Positioning System (GPS), Garmin 12XL. A study was carried out to find out the current status of Lake Naivasha floating and submerged macrophytes. The species abundance and distribution within the lake were evaluated. The study was carried out from the month of February to July 2003.

The rake-sampling method developed by Jessen and Lound (1962) was applied in sampling of submerged macrophytes. Sampling of floating vegetation was carried out using quadrats at the eight sample sites. Within an area measuring 10 by 30m, 1 by 1m

quadrats were thrown randomly six times and the species present recorded, that is, both the floating and associated species.

Water physico-chemical parameters were also studied. Secchi depth measurements were all below 100cm in all stations located in the Main Lake and they did not exceed 150cm at the Crescent Island Lake. Spatial variation of water clarity differed significantly (one-way ANOVA: $F_{7, 40}=51.91$; $p<0.05$). Highest mean concentration of soluble reactive phosphorus was registered at Malewa River Inlet sampling site. A concentration mean of $29\pm6.9\mu gL^{-1}$ was recorded at Malewa River Inlet while Crescent Island Lake site had the lowest mean of $15\pm3.6\mu gL^{-1}$. However, there was no significant difference in mean concentrations of soluble reactive phosphorus in the eight stations (one-way ANOVA: $F_{7, 40}=1.23$; $p>0.05$). Malewa River Inlet sampling site had on average the highest concentration of nitrates ($225\pm102\mu gL^{-1}$) while Crescent Island Lake had the lowest amounts ($34\pm12\mu gL^{-1}$). For measurements on conductivity, Malewa River Inlet sampling site had the lowest mean conductivity ($168\pm47\mu Scm^{-1}$) while Crescent Island Lake had the highest ($317\pm15\mu Scm^{-1}$). Of the eight sample sites, Crescent Island Lake had highest substratum gradient followed by Hippo point.

The prevailing wind direction was found to be mostly southeasterly. Southeasterlies constituted 51% of the total number of times the direction was determined. Southerlies made up 27% with a proportion of 15% blowing to the west. The soil textural characteristic of sediments was investigated for the established stations. Highest amounts of sand were found at Hippo point (93-97%) and Crescent Island Lake (89-91%) while Kasarani (10-27%) had the lowest proportion.

Two major floating species were found to occur: *Eichhornia crassipes* (Mart.) Solms and *Salvinia molesta* Mitchell. Sample sites such as Central Landing Beach, Malewa River Inlet and Kasarani had the highest percentage frequencies of *E. crassipes* (100%) followed by Sher Agencies which had 93.3% frequency. Kasarani had the highest amount of *S. molesta* (61.1%) while Crescent Island Lake and Central Landing Beach recorded none. Hippo point and Kamere had almost the same amount of *S. molesta. Nymphaea* sp a floating-leaved plant, was found in small quantities (0.3%).

Submerged aquatic macrophytes recorded were: *Potamogeton octandrus* Poir, *Potamogeton pectinatus* L., *Najas horrida* Magn, *Potamogeton schweinfurthii* A, *Ceratophyllum demersum* L. and *Nitella* sp. with percentage frequencies of 15.2%, 12.2%, 12%, 3.2%, 1% and 0.8% respectively. There was significant difference in distribution and abundance of both floating and submerged macrophytes between the sample stations at 0.05 significance level.

Factors studied in relation to their influence on aquatic macrophytes were: nature of substratum, wind direction, pH, Secchi depth, nutrients, lake bed slope and depth. These factors were found to affect the distribution and abundance of the macrophytes importantly. Wind direction was found to be the most important environmental factor influencing the abundance and distribution of free-floating macrophytes in Lake Naivasha. The percentage sand was also significant ($p<0.05$, Regr. coeff. = -0.749) in influencing the abundance and distribution of free-floating macrophytes. On the other hand, the nature of substratum and slope affected the location and abundance of submerged plants within the lake significantly. For example, the proportion of sand in the sediments together with slope explained 86.3% of the total plant variation encountered in abundance of *P. octandrus*.

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

A lake can be divided into various functional and or structural ecological units (Hutchinson, 1967). The units or zones are classified according to the kind of flora found there and their location along the ecotone. The zones are pelagial, littoral and profundal.

The pelagial or pelagic zone consists of the open free water, while the profundal zone comprises of the bottom of fine sediments and free of vegetation. The littoral zone can be divided into several sub zones depending on their placements and characteristics along a gradient from the dry land to the profundal zone as follows: the epilittoral zone lies entirely above the water and is unaffected by spray; the supralittoral zone also lies entirely above the water level but is subject to spraying by waves. The eulittoral zone encompasses the shoreline region between the highest and lowest seasonal water levels, and is often influenced by the effect of the breaking waves. The infralittoral zone is subdivided into three zones in relation to the commonly observed distribution of macrophytic vegetation: the uppermost zone is sometimes referred to as zone of emergent rooted vegetation; the middle zone also called zone of floating leaved rooted vegetation; and lower zone or zone of submerged rooted or adnate macrophytes. The eulittoral and the infralittoral zones collectively constitute the littoral zone. Below the littoral zone is a transitional zone, the littoriprofundal, occupied by scattered photosynthetic algae and bacteria. The littoriprofundal zone which grades into profundal zone is adjacent to the metalimnion of stratified lakes. This lacustrine zonation was put forward by Hutchinson (1967). A lacustrine zonation of a typical freshwater lake is shown in Figure 1.1.

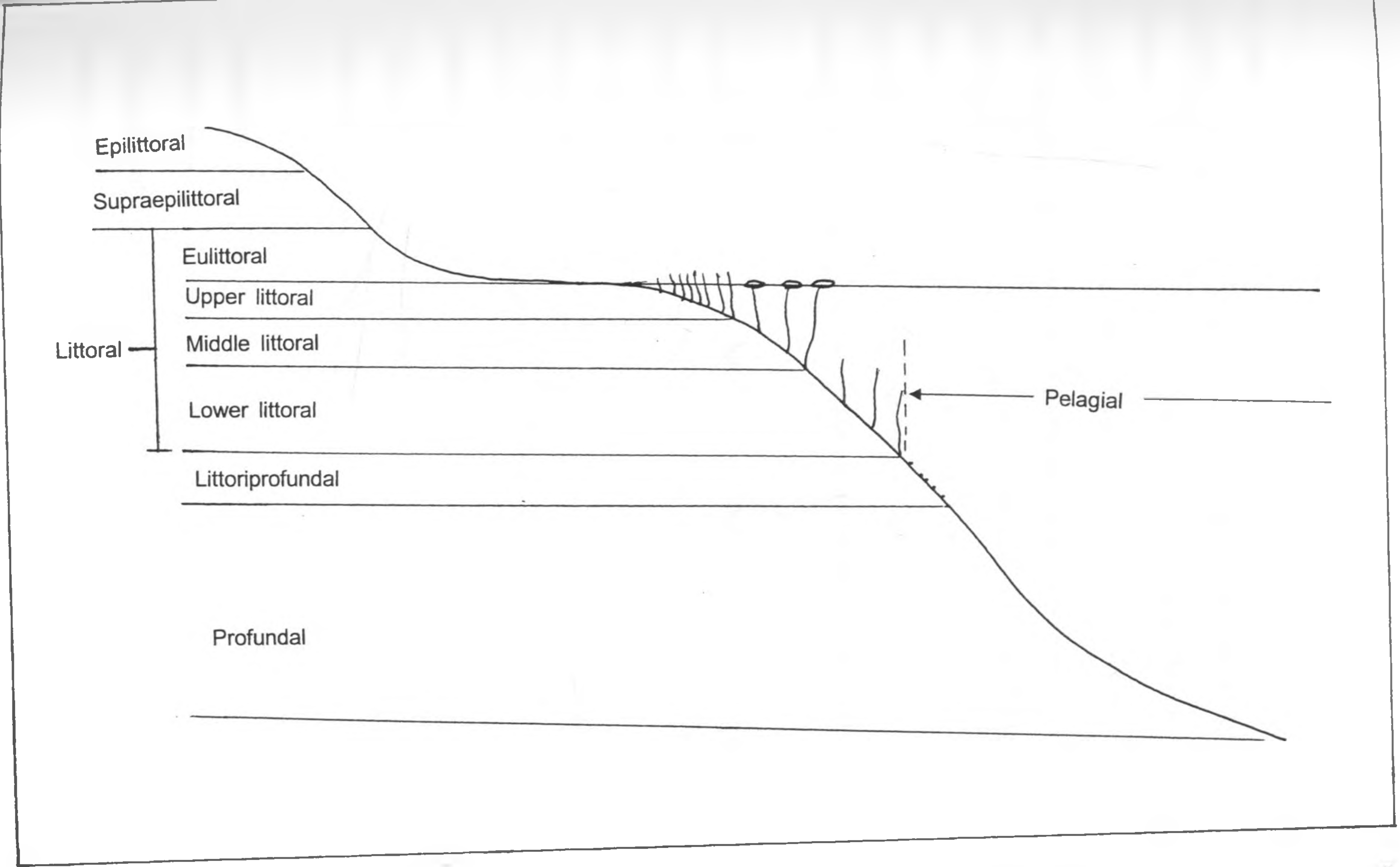

Figure 1.1: A lacustrine zonation of a typical freshwater lake (Redrawn after Hutchinson, 1967)

In many enquiries into botanical aspects of lakes, one encounters an array of rather arbitrary definitions of both sessile and floating flora of aquatic systems (Arber, 1920; Gessner, 1955; Sculthorpe, 1967; Hutchinson, 1975). Many definitions are strictly botanical and ignore major system interrelationships, hence, little implications in ecological studies. For example, words such as 'hydrophyte' are ambiguous; even though the term 'hydrophyte' generally refers to vascular aquatic plants it can include any form of aquatic plant. The term aquatic macrophyte as is commonly used, including in this work, refers to macroscopic forms of aquatic vegetation, and encompasses macroalgae, few species of mosses and ferns adapted to the aquatic habitat as well as angiosperms (Wetzel, 1983).

Numerous lines of evidence indicate that aquatic angiosperms originated on the land (Wetzel, 1983). Adaptations and specialization to the aquatic habitat have been achieved by a few angiosperms and pteridophytes. Consequently, the richness of plant species in aquatic habitats is relatively low compared to their terrestrial communities. Aquatic macrophytes have evolved in many diverse groups, and often demonstrate extreme plasticity in structure and morphology in relation to changing environmental conditions. These factors in combination with the very heterogeneous condition of their littoral habitat make difficult the precise ecological classification of this group into growth forms.

Numerous classification systems have been proposed and used. The primary groups of aquatic angiosperms, rooted and non-rooted have been subdivided according to types of foliage and inflorescence and whether these organs are emergent, floating on the water surface, or submerged. Differences in the extent of emergence or submergence

Among the attached macrophytes, the classification identifies three groups of plants. The first group of plants is made up of emergent macrophytes. These occur on water-saturated or submerged soils, from the point at which the water table is about 1.5m below the soil surface to where the sediment is covered with approximately 1.5m of water. The second group of aquatic macrophytes consists of floating-leaved macrophytes. These are primarily angiosperms that occur attached to submerged sediments at water depths from about 0.5 to 3m. They posses leaf with long petioles to enable the leave blades spread on water surface. The other group of attached aquatic macrophytes are the submerged plants. These ones comprise of a few pteridophytes, numerous mosses and charophytes and many angiosperms. They occur at all depths within the photic zone but vascular angiosperms occur only to about 10 m or 1 atm hydrostatic pressure.

The freely floating macrophytes are a diverse group of plants both in form and habit. They are typically unattached on the substratum and occur within or upon the water. The present study attempts to investigate the abundance and distribution of submerged and floating (free and attached) macrophytes.

The occurrence and the subsequent abundance of aquatic plants in a habitat is governed by many underlying factors. These could be either abiotic or biotic. For example, the availability of nutrients in an aquatic system, plays an important role on where the macrophytes are found, their structure and diversity. Aquatic systems are nutrient rich habitats compared to the terrestrial ones, but nutrient limitations can occur due to competition for the available nutrient fractions with other autotrophs within the system (Wetzel, 1983). This is particularly the case when there is abundant growth of periphyton on the surfaces of the submerged species and presence of large amounts of algae (Wetzel, 1983). Submerged species absorb a great deal of nutrients through their leaves and other body surfaces. Nitrogen and phosphorus are the most limiting nutrient elements for the C3 floating plants like *Eichhornia crassipes*. However, floating plants, especially the invasive ones, are known to be tolerant to low nutrient concentrations (Mitchell, 1985).

The nature of the substratum on which plants are anchored, is an important factor that determines the types and the amount of vegetation found in a particular locality. The textural composition of soil determines the stability of the substratum on which the plants are attached. Soil texture is also closely related to the chemical constituents of a soil sample. Soil with high amounts of clay and silt are known to be more fertile than sandy soils (Barko & Smart, 1986). In studies that were carried out on distribution of water hyacinth in Lake Victoria, it was found that localities with low amounts of sand and high amounts of clay/silt had high abundance of the floating species as well as the emergent macrophytes (Twongo, 1995).

Water clarity is another physical factor that has a direct influence on the submerged macrophytic component in aquatic ecosystems. The amount and quality of light that reaches the bottom is a function of the amount and nature of particles suspended in the water column. Photosynthetic algae growing in water medium utilizes the same kind of electromagnetic radiation that the vascular plants use during photosynthesis. Hence, excessive algal growth may negatively impact on the submerged vascular species. Other foreign particles in water absorb, scatter or reflect radiation with a net effect of overall reduction of amount and quality of light reaching the submerged vegetation.

Herbivory on the aquatic plants is a key factor that determines the condition of a plant species in an area. Introductions of various exotic animals in Lake Naivasha have been blamed on the decline of submerged vegetation within the lake (Harper *et al.*, 1998). Introduced fishes and the Louisiana Red Swamp crayfish, for example, feed on the submerged plants. Population explosions of the crayfish have been correlated with submerged plants population crush in the lake. Over the years, the control of the invasive plant species have been conducted by use of natural enemies that feed on the target plant. For example, *Salvinia* and *Eichhornia* weevils were introduced in Lake Naivasha to control *Salvinia* and *Eichhornia* weeds respectfully, that had found their way into the lake.

Change in water level is another factor that impacts on both floating and submerged vegetation. When the water level goes down, floating species get stranded and if they are not well adapted to such conditions of low soil moisture, then they are greatly and negatively impacted upon. Submerged species have poorly or no developed structures that prevent desiccation. Therefore, apart from losing a lot of water on exposure they are more exposed to the herbivores such as water birds.

Other factors that influence the occupation of a locality by the aquatic plants include the water chemistry, human activities within the riparian land and the water body, presence of pollutants, climatic factors, the lake morphometry, competition between different species utilizing a common ecological niche among other factors.

This study was designed to find out the current composition, distribution pattern and abundance of the floating and submerged macrophytic components in Lake Naivasha. An attempt is also made to investigate the influence of some selected abiotic factors on the distribution and abundance of the said vegetation. A preliminary study was carried out in the lake in the month of February 2003 with an aim of familiarizing with the study area and to collect logistical data that would be used to formulate a comprehensive work frame for the whole study. The study also allowed for assessement of accessibility of the various points within the lake.

1.2 Justification, Hypothesis, Aim and Objectives

1.2.1 Justification: In any ecosystem, biotic and abiotic factors influence the ecology of organisms. Previous studies in Lake Naivasha (Harper *et al.*, 1998; Christine, 1995) have concentrated on assessing the biotic influences on the macrophytes of Lake Naivasha. These studies have not, however, evaluated the influence of the abiotic factors on the abundance and distribution of floating and submerged macrophytes. This study was, therefore, undertaken to assess the influence that the abiotic factors have on the abundance and distribution of floating and submerged macrophytes in Lake Naivasha.

The results of this study will provide information for better understanding of the lake ecology. Such information is important for effective management of the lake, with respect to, for instance, fish habitat improvement, protection of sensitive wildlife areas, aquatic plant management, and water resource regulations.

1.2.2 Hypothesis: Abiotic factors significantly influence the abundance and distribution of floating and submerged aquatic vegetation in Lake Naivasha.

1.2.3 Aim: The present study focuses on the aquatic macrophytic component of Lake Naivasha. The study aims at finding out the relationship that the floating and submerged plants have with some abiotic factors within the lake.

1.2.4 Overall objective: To evaluate the influence of some abiotic factors on the abundance and distribution of floating and submerged aquatic vegetation in Lake Naivasha.

1.2.5 Specific objectives:

(i) To review the species composition of both floating and submerged plants present in Lake Naivasha;

(ii) To determine the abundance and distribution of macrophyte population; and

(iii) To relate some physical and chemical environmental factors to the abundance and distribution of floating and submerged plants in Lake Naivasha.

1.3 Literature Review

1.3.1 The distribution of floating aquatic plants in Africa

Plants which occur in water bodies in Africa and are free-floating are *Eichhornia crassipes*, all African species of *Azolla* and *Salvinia, Ricciocarpus natans* (*L*) Corda, African species of *Spirodela*, *Lemna*, *Pistia stratiotes L.* and *Ricia* (Mitchell, 1985). *Ricia* and other genera of Lemnaceae may float with their photosynthetic organs mostly below the water surface. A summary of free-floating plants present in Africa is given in the Table 1.1.

Table 1.1. Surface–floating aquatic plants present in Africa

Plant	Distribution in Africa
BRYOPHYTA	
Ricciaceae	
Riccia fluitians L. Corda	pan-African
Ricciocarpus natans (L.)	tropical & subtropical
PTERIDOPHYTA	
Azollacae	
Azolla pinnata R. Br. *var africana* (Desv.) Bak	pan-African
A. nilotica Deene ex Mett. (e)*	eastern tropical & sub-tropical
A. filiculoides Lam. (a)**	South Africa
Salviniaceae	
Salvinia nymphellula Desv. (e)	western tropical
S. hastata (e), S. *molesta*	eastern tropical & sub-tropical Kenya, Tanzania, Zaire, Zambia, Botswana, Namibia, Zimbabwe, South Africa, Mozambique
Parkeriaceae	Mauritius tropical & subtropical tropical
ANTHOPHYTA	
Araceae	
Pistia stratiotes L.	Tropical & subtropical
Pontederiaceae	Sudan, Egypt, Kenya, Tanzania, Zaire, Zambia, Botswana, Namibia, Zimbabwe, South Africa, Mozambique
Lemnaceae***	
Lemna spp.	Pan-African
Spirodela spp	Pan-African
Wolffia spp	Pan-African
Wolfiella spp	Pan-African

**e=endemic to Africa*
***a=alien introduction to Africa: distribution given in terms of countries from which incidences have been reported*
****following the taxonomic treatment of Landolt (1980)*
[Source: Mitchell, (1985)]

1.3.2 Adaptations and ecological strategies in floating plants

Aquatic plants that float on the water surface occupy a distinctive habitat that requires a particular adaptation. Such plants are not limited to a particular zone in the hydrosere as they are not affected by water depth. However, surface-floating plants tend to dominate the offshore margins of the littoral vegetation continuum because they are not removed or are pushed to those zones by wind or current. To adequately exploit the aquatic habitat, the floating aquatic plants must be adapted to cope with challenges presented by this habitat. Plants floating on the water surface have to contend with three main problems:

(a) maintenance of positive buoyancy;

(b) absorption of nutrients from the most dilute part of the ecosystem, namely surface waters; and

(c) lack of anchorage so that they are at the mercy of wind and current.

1.3.2.1 Maintenance of positive buoyancy

a) Non-wettable surfaces.

One of the most noticeable features of free-floating macrophytes is their ability to repel water from the upper surface of the leaf. Water dropped on the plant surface leave off immediately or builds up into spherical droplets because of surface tension effects. In addition, surface may be roughed by a sculptured epidermis, as in *Azolla*, by multicellular papillae as in *Salvinia molesta* D.S. Mitchell [*S. auriculata*]. That these surfaces are important in maintaining buoyancy is shown by the effect on the plants by adding an ionically positive detergent, such as calcium dodecyl-benzene sulphate, which causes *Azolla* and small *Salvinia* plants to sink within 2-3 minutes. This effect of detergent chemicals has been employed in the development of herbicides specific to these plants (Diatloff *et al.*, 1979).

b) Wettable surfaces

The water-repellant nature of upper surfaces of surface-floating plants is matched with water-attractive nature of the lower surfaces of the leaves and any other submerged portions of the plants. Such an adaptive feature is particularly important in that the plant is not in direct nutrient rich substrate. Nutrient absorption also takes place through these surfaces hence intimate water contact is a paramount requirement (Mitchell, 1985).

1.3.2.2 Nutrient absorption

For effective absorption, a large surface is important. Many plants have an increased surface area through production of hairs and the development of much branched, or dissected, absorptive organs; e.g. the dense cover of lateral roots on the numerous adventitious roots of *E. crassipes* and the much dissected submerged axes (classically regarded as leaves) of *S. molesta*.

A number of authors (White, 1936; Steinberg, 1946; Penfound and Earle, 1948; Landolt 1957; Mitchell, 1970; Musil & Breen, 1977; Cary & Weerts, 1983) have investigated the nutrient requirements of *E. crassipes*, *S. molesta* and members of Lemnaceae. These studies show that the growth rate of these plants is low in nutrient poor conditions and greatly accelerated as nutrients become available in otherwise optimum conditions. Two features that reflect the adaptation of these plants to the generally low nutrient status of their immediate environment are noteworthy:

(a) the plants have a capacity to tolerate low nutrient status in the water for long periods even though growth has apparently ceased (*S. molesta* has survived for over six months in distilled water) (Mitchell, 1985); and,

(b) the plants have a capacity for the luxury uptake of phosphorus, i.e., the absorption and accumulation of phosphorus in excess of immediate needs. Many of these plants also exhibit association with nitrogen fixing microorganisms. For example, there is symbiotic association between *Azolla* and nitrogen-fixing blue-green alga *Anabaena azollae* (Eames, 1936; Kawamatu 1956*a*, 1956*b;* Ashton and Walmsley, 1976*).* The alga is contained in cavities in the leaves of the plant, and the macrophyte is apparently dependant on its presence for normal growth. *E. crassipes* has been shown to be associated with the nitrogen-fixing *Azotobacter chroococcum*, which becomes established in the mucilaginous coating of the base of the petiole (Purchase, 1977).

1.3.2.3 Adaptation to lack of anchorage

The roots of free floating plants such as *E. crassipes* do not penetrate a firm substratum at the bottom of a water body. However, in simple experiments in which submerged portions of the plants are removed, the stability of the individual plant is greatly affected. This is particularly true for the plants whose leaves project more or less vertically from water surface, e.g. *E. crassipes.* Further, two factors are important in the formation of stable plant communities:

(a) rapid colonization of the available suitable area; and

(b) interlocking of individual plants in the community.

Studies of the growth rates of *S. molesta* by Mitchell (1970), Gaudet (1973), Mitchell and Tur (1975), Carry and Weerts (1983) and Toerien *et al.* (1983) have shown that under optimum temperature conditions (25-30°C), high light intensity, and non-limiting supplies of nutrients, increase in plant population is exponential, and the plant is capable of doubling in terms of leaves number in 2-3 days and occasionally in less than 2 days. In the field, the plant has a doubling time of eleven days (Mitchell & Tur, 1975). *E. crassipes* and members of Lemnaceae are similarly capable of attaining remarkably rapid rates of growth for vascular plants. A doubling time, in terms of numbers of plants, of 6.2 days has been recorded for *E. crassipes* growing in sewage ponds and in most tropical waters where nutrients are not limiting, doubling times of 10-12 days can be expected (Bagnall *et al.*, 1974).

That most free floating aquatic plants exhibit remarkable rapid rates of population growth is an obvious adaptation for them to occupy the available colonizable area as quickly as possible and thereby stabilize the situation so that most other aquatic plants are unable to compete with them. In the process of an innoculum growing outwardly, a plant shows modifications to suit the differing circumstances at different stages of successions. Individual plants become interlocked with one another through the interweaving of the branches in *S. molesta* and through the entanglement of offsets in *E. crassipes*. As a consequence, the plants anchor onto each other and by expanding to fill the available surface become a fixed mat that is difficult to dislodge, thereby counteracting the disadvantage of being fixed to substratum.

1.3.2.4 Adaptations to reproduction and survival strategies

It is apparent that free-floating aquatic plants depend primarily on rapid growth and vegetative multiplication for establishment of stable communities. Sexual reproduction is frequently limited to the extent to which plants are crowded together. For example, in *S. molesta* there is increase in sporocarp production as plants become crowded (Mitchell, 1970; Ashton, 1977), while in contrast, *E. crassipes* flowers are often infrequent in tightly crowded populations, though flowering is dependant on the time of the year. But generally the free-floating aquatic plants have a relatively low sexual reproductive capacity (Mitchell, 1985).

Members of Lemnaceae produce specialized vegetative perennating structures called turions. In *Spirodela polyrrhiza* (L.) Schleiden, such structure occur as modified fronds which are devoid of air spaces, swollen, more darkly coloured and filled with starch. The turions are produced in response to the onset of adverse growth conditions and sink to the bottom until favourable conditions return.

1.3.3 Problems caused by surface-floating plants in Africa

Problems caused by floating aquatic plants as weeds have been reported from many of localities in Africa (Table 1.2). The plants that are alien to Africa have caused the main problems and of the four species listed in the table only *Pistia stratiotes* is native to Africa. *Azolla pinnata* var. *africana* and members of the Lemnaceae occasionally cover water troughs, ponds and small lakes and can cause nuisance by inhibiting drinking of water by domestic animals, blocking pump intakes and tainting water (Wind, 1961; Jacot-Guillarmod, 1979).

Free-floating weeds can have serious ecological and economic impacts of both rivers and lakes. The weeds cause major detrimental impacts on water use. In drainage canals they

Table 1.2. Examples of problems caused by *Salvinia molesta* in Africa.

Location	Type of waterbody	Nature of problem or interference	Source
Kenya Lake Naivasha	Rift Valley lake	Recreation	Gaudet, 1976
Democratic Republic of Congo Barrage d'Inga	Man-made lake	Water quality	Van Himme, 1973
Zaire River	River	Navigation	Little, 1965*a*
Ndola Dambo	Town water supply	Recreation	Mitchell, 1985
Zambia and Zambabwe Lake Kariba	Man-made lake	Fishing navigation Recreation, spreads Schistosomiasis	Boughey, 1963; Mitchell, 1969; Mitchell & Rose; 1969; Marshall & Junor, 1981; Hira, 1969
Mozambique Cabora Bassa	Man-made lake	As above for Lake Kariba	Bond & Roberts, 1978
Botswana and Namibia Chobe/Linyani system	River flood plain	Flow	Edwards & Thomas, 1977
South Africa Swatvlei	River estuary	Flow, boating, Stock drinking	Jacot-Guillarmod, 1979

After Mitchell, 1985.

greatly reduce flow, which can result in flooding and damage to canal banks and structures. In irrigation canals, they impede flow and clog intakes of pumps used for conveying irrigation water. The weeds can severely interfere with navigation of both recreational and commercial craft in addition to interfering with boating by fishermen and water skiers in recreational waters. The weeds interfere with swimming, and estate values and tourism can be reduced due to limitations on water.

Water hyacinth was noted to be seriously affecting fish production, transport, power generation, water supply and human health in Lake Victoria (UNEP, 1998). A massive floating vegetation cover hampers navigation and landing of fishing boats, leads to overheating of ferry engines and out board motors and depletes the shallow water of oxygen. The latter affects the biological functioning of fish, thereby negatively impacting

on productive levels. The waterweed also affects production by disrupting important food chains. Through their vegetative cover the *Eichhornia* and *Salvinia* weeds shade phytoplankton from sunlight, an important ingredient in photosynthesis. On transport, *Eichhornia*, for instance, led to the closure of Kendu Bay Pier at one time (UNEP, 1998).

In Uganda, the effects on transport have been worse necessitating huge expenditures in mechanical and manual removal of the weed. The weed at one time completely clogged the power generation plant at Jinja and also Kisumu water supply pipes (UNEP, 1998). The underside of the weed is said to harbour poisonous snakes and snails that carry disease vectors for bilharzia.

From Table 1.2, it can be deduced that the water bodies most at risk are those where there is high degree of human interference (man-made lakes, canals, etc) and where the presence of the plant interferes with human use of the water, thereby constituting it to be a weed by definition. The removal of the free-floating weeds by some form of control merely restores the conditions they are most suited to exploit and in which they are readily dispersed. Mechanical and chemical removal is, therefore, likely to be a continuing process.

1.3.4 Adaptations of submerged aquatic vegetation

Among the vascular submerged macrophytes, numerous morphological and physiological adaptations are found to allow existence in totally aqueous environment. Some adaptations have been developed to cope with, for example, mechanical support, absorption of nutrients and raw materials for photosynthesis among others.

1.3.4.1 Mechanical support

Submerged aquatic vegetation such as members of Nadjaceae and Potamogetonaceae have little or no mechanical strengthening tissue in stems and leaf petioles. Schlerenchyma and collenchyma are usually absent. No secondary growth occurs and no cambium can be recognized (Wetzel, 1983). If these plants are removed from the water, they hang limply. They are normally supported by water all around them and so have no need of mechanical strengthening. Indeed, this would be a distinct disadvantage, as it would limit flexibility in the event of changes in water level or water movements.

1.3.4.2 Dissolved Inorganic Carbon (DIC) absorption

Carbon dioxide diffuses about ten thousand times slower in water than in air. This problem is compounded by the relatively thick unstirred layer that surrounds aquatic plant leaves. The unstirred layer in aquatic plants is a layer of still water through which gases and nutrients must diffuse to reach the plant leaf. It is about 0.5 mm thick, which is about ten times thicker than in terrestrial plants. The result is that approximately 30 mgL^{-1} free carbon dioxide (CO_2) is required to saturate photosynthesis in submerged aquatic plants (George, 1985). The low diffusivity of CO_2 in water, unstirred layer and the high CO_2 concentration needed to saturate photosynthesis have imposed a major limitation on photosynthesis. The DIC limitations on aquatic macrophytes and its corollary, the need to conserve carbon, are becoming increasingly apparent as important ecological features of aquatic environments (George, 1985)

Submerged aquatic plants have adapted to CO_2 limitation in several ways. They have thin, often dissected leaves. This increases the surface area to volume ratio and decreases the thickness of the unstirred layer. They have extensive air channels, called aerenchyma, that allow gases to move freely throughout the plants (Wetzel, 1983). This allows respired CO_2 to be trapped inside the plant and in some species even allows CO_2 from the sediment to diffuse into the leaves. *Potamogeton pectinatus* has hollow elongated cylindrical leaves containing air. Many species of aquatic plants also are able to photosynthesize using bicarbonate as well as CO_2. This is important, since at pH values between 6.4 and 10.4 the majority of DIC in freshwater exists in the form of bicarbonate.

1.3.4.3 Nutrient absorption

Submerged plants lack the external protective tissues required by land plants to limit water loss. The epidermal (outermost) layer shows very little, if any, sign of cuticle formation. All the surface cells appear to be able to absorb water nutrients and dissolved gases directly from the surrounding water (George, 1985). As a result, the internal system of tubes (xylem), which normally transports water from the roots to all parts of the plant, is often greatly reduced, if not absent. Thus, if these plants are removed from the water, they wilt very quickly, even if the cut stems are placed in water. This is because the normal water transport system is poorly developed. As might be expected, there are also no stomata (breathing pores) on the leaves. Roots, which normally play a very important role in the absorption of nutrients and water from the substrate, are often also reduced and their main function is anchorage (Wetzel, 1983). The root hairs, which function in absorption, are often absent. Many species have very specialized leaf shapes. The submerged leaves (e.g. *Najas, Potamogeton, Ceratophyllum*) are often highly dissected or divided. This has the advantage of creating a very large surface area for absorption and photosynthesis. It also minimizes water resistance and hence potential damage to the leaves.

1.3.4.4 Changes in water level

Changes in water level bring in a combination of factors that a plant has to be adapted to for its survival in water. For example, increase in height of a water column above a plant subjects the plant to reduced light intensity and increased hydrostatic pressure. Many submergents exhibit distinct morphological variations in relation to light intensity. Shade-adapted leaves are finely divided, whereas on the same plant growing at higher light intensities (shallower depths) leaves can be larger and much more lobate. Some insights into the mechanisms of photosynthetic adaptation of submerged macrophytes in relation to water depth have been gained by investigations of Spence and Chrystal (1970a, 1970b) on *Potamogeton* species. From estimates of relative rates of photosynthesis and respiration per leaf area and per pigment constant of the species and sun and shade leaves, it was concluded that (a) surface area increases, respiration and leaf thickness decreases with depth and light reduction, and (b) higher net photosynthetic capacity per unit of shade-adapted leaves of *Potamogeton* at low irradiances is achieved by lowered respiration per area. The latter may result from reduction in leaf unit per area.

Normal growth can be inhibited when certain submerged angiosperms e. g., *Hippurus sp.* are exposed to even very moderate increases in hydrostatic pressure (Gessner, 1955). Increased pressure of as little as 0.5 atm, equivalent to about 5m depth also triggers increased growth of internodes similar to the effects of low light intensity (Hutchinson, 1975). The growth of internodes leads to an elongated plant hence coming closer to the water surface.

1.3.4.5 Reproduction

Further morphological variations are found among temperate aquatic macrophytes that overwinter by the formation of winter buds (turions). In the fall, many common macrophytes (e.g., *Utriculalia, Myriophyllum, Potamogeton*) form masses of aborted leaves with very short internodes in the axils of lower leaves (Weber & Nooden, 1974, 1976a, 1976b; Winston & Gorham, 1979; Satroutomo, 1980a, 1980b). These turions separate from the mother plant and sink or float some distance away, and serve as a means of vegetative propagation (Weber & Nooden, 1974). Many submerged vegetation persists for years by this means, without a sexual cycle. Turion formation is absent among the same species in the tropics, but can easily be induced when plants near maturity or exposed to low water temperatures (less than 10 to 15°C) and short photoperiods (van der Valk & Bliss, 1971).

1.3.4.6 Adaptation to low light intensity

Plant chlorophyll absorbs light at wavelengths of 400 to 700 nm. This is termed Photosynthetically Active Radiation (PAR). The intensity of full, natural sunlight is approximately 2,000 $\mu mols^{-1}m^{-2}$, or 100 klux, of PAR (Wetzel, 1983). Light is however attenuated rapidly in freshwater so that submerged aquatic plants receive far less than this amount. Submerged aquatic plants are adapted to the low light levels found in freshwater, and are classified as shade plants on the basis of these adaptations. For instance, aquatic plant chloroplasts, which are the organelles that contain chlorophyll, are often located in the top cell layer of leaves to ensure that as much light as possible is absorbed. Additionally, photosynthesis is saturated at only 15 to 50% full sunlight intensity. Thin leaves and chloroplasts in the epidermis also reduce the amount of leaf tissue that sunlight must penetrate in order to reach photosynthetic cells in submerged plants. This maximizes photosynthetic efficiency in the reduced light conditions of aquatic habitats. Aquatic plants also have a low light compensation point (LCP). The LCP is the point at which the rate of photosynthesis equals the rate of respiration and growth stops. This allows them to grow at depths that receive only 1 to 4% full sunlight (20 to 80 $\mu molm^{-2}s^{-1}$ PAR).

1.3.5 The ecological importance of aquatic macrophytes

Aquatic macrophytes represent an important functional habitat in aquatic ecosystems. As for invertebrates, they serve as a nutrition source, a spatial habitat or both. In running waters, this habitat is usually the most abundantly populated one (Linhart, 1998). In standing waters, the phytal habitat seems to be preferred by macroinvertebrates to the bare bottom (Soszka, 1975a; Lodge, 1985; Cyr & Downing, 1988a; KornijóW & Kairesalo, 1994; Savage & Beaumont, 1997), though contrary results exist (Pardue & Webb, 1985).

1.3.5.1 The submerged macrophytes: Submerged aquatic vegetation, which include both true seagrasses in saline conditions and freshwater angiosperms are among the most productive ecosystems in the world. They perform a number of irreplaceable ecological functions which range from chemical recycling to physical modification of the water column and sediments to providing food and shelter for commercial, recreational, as well as ecologically important organisms (Thayer *et al.*, 1997). Many birds species such as coots, waterfowl and small mammals e.g. beavers and muskrats feed on submerged vegetation.

Diverse invertebrate communities exist among the submerged vegetation. The abundance of, for example, phytophilous invertebrates is probably related to a suite of factors, including plant morphology, surface texture, epiphytic algal growth and community composition, nutrient content of the plant tissues, and the presence of defensive chemicals (Cyr & Downing, 1988a). Different combinations of these factors create various microhabitats, which should result in different assemblages of organisms that depend either directly or indirectly on the submerged species. Table 1.3 list invertebrates observed on submerged aquatic vegetation from Lake Naivasha between 1992 and 1994. The aquatic vegetation provides the invertebrates with shelter from predators (Diehl, 1992) and acts as spawning and attachment sites (Rooke, 1984; 1986a, b).

Phytophilous organisms are not equally abundant on all plant parts (Cyr & Downing, 1988a) and their community composition with respect to specific submerged vegetation have frequently been examined. Studies have found out that relative abundance and composition of littoral Cladoceran communities is a function of microhabitat principally governed by the species of submerged aquatic vegetation (Difonzo & Campbell, 1985; Rooke, 1986a).

Table 1.3. A list of invertebrates observed on submerged aquatic vegetation from Lake Naivasha between 1992-1994.

	Average number of macroinvertebrates per 100 g air-dried macrophytes		
Macro-invertebrates	***Najas horrida***	***Potamogeton pectinatus***	***Potamogeton schweinfurthii***
Micronecta	250	280	170
Chironomids	180	140	60
Snails	40	40	210
Mites	20	60	60
Ostracoda	40	70	440
Leech	20	0	0
Crayfish	20	0	0
Ephemeroptera	0	20	40
Oligochaeta	0	20	0
Choncostrans	0	0	20
Flatworms	0	0	200

(After Harper *et al.*, 1999)

1.3.5.2 The floating vegetation: In favourable conditions, both *S. molesta* and *E. crassipes* plants form dense mats, which out-compete less vigorous water plants for both light and space. *E. crassipes* remains the world's most problematic aquatic weed despite widespread and various approaches to its control (Heard & Winterton, 2000). For example, the management of the weeds at Naivasha has focused upon biological control measures with the introduction of *Salvinia* weevil, *Cyrtobagus salviniae* Calder & Sands, in early 1990s and an *Eichhornia* weevil (*Neochetina* sp.) also in the early 1990s.

Because of their size and integrity, floating mats offer a colonization opportunity for other herbaceous and woody plants usually found in the littoral zone of lakes. In Lake Kariba, *Salvinia* provided a substratum stable enough for the growth of a number of emergent aquatic and semi-aquatic plants such as *Ludwigia*, *Typha* and *Scirpus* with a total of 40 plant species recorded (Boughey, 1963). Over a period of 10 years, Penfound and Earle (1948) found 63 plant species: 33 aquatic; 21 wetland and 9 terrestrial plants, growing on mats of *E. crassipes* in Louisiana in the southern United States. Floating mats may also provide a habitat for invertebrates and juvenile fish (Oliver & McKaye, 1982; Sazima, 1985; Gopal, 1987; Dibble *et al.*, 1996). The invertebrates can be both aquatic species associated with roots or terrestrial species in the aerial vegetation parts.

E. crassipes has an ability to root in damp mud and so in Naivasha, as in other locations, it has colonized the littoral zone. The littoral zone may overwhelmingly be dominated by both floating plants in the shallow water and rooted plants on the shore edge. The dominance has a physical stability, for as water level changes, rooted plants can float and *vice versa.*

It is thus possible that the classic zonation of vascular plants from dry land to open water, described by Gaudet (1977) (Figure 1.2) has been altered for Lake Naivasha. Gaudet classified 108 plant species in a primary successional sequence from the lake edge to dry land after a period of naturally low water levels that occurred between 1971 and 1973. The zones were: the seedling zone dominated by *Nymphaea nouchali* Burm. seedlings that did not survive further drying; the sedge zone dominated by *Cyperus papyrus, Cyperus digitatus L.* and *Cyperus immensus L.* and further inland, the composite zone dominated by species of *Conyza, Gnaphalium* and *Sphaeranthus.*

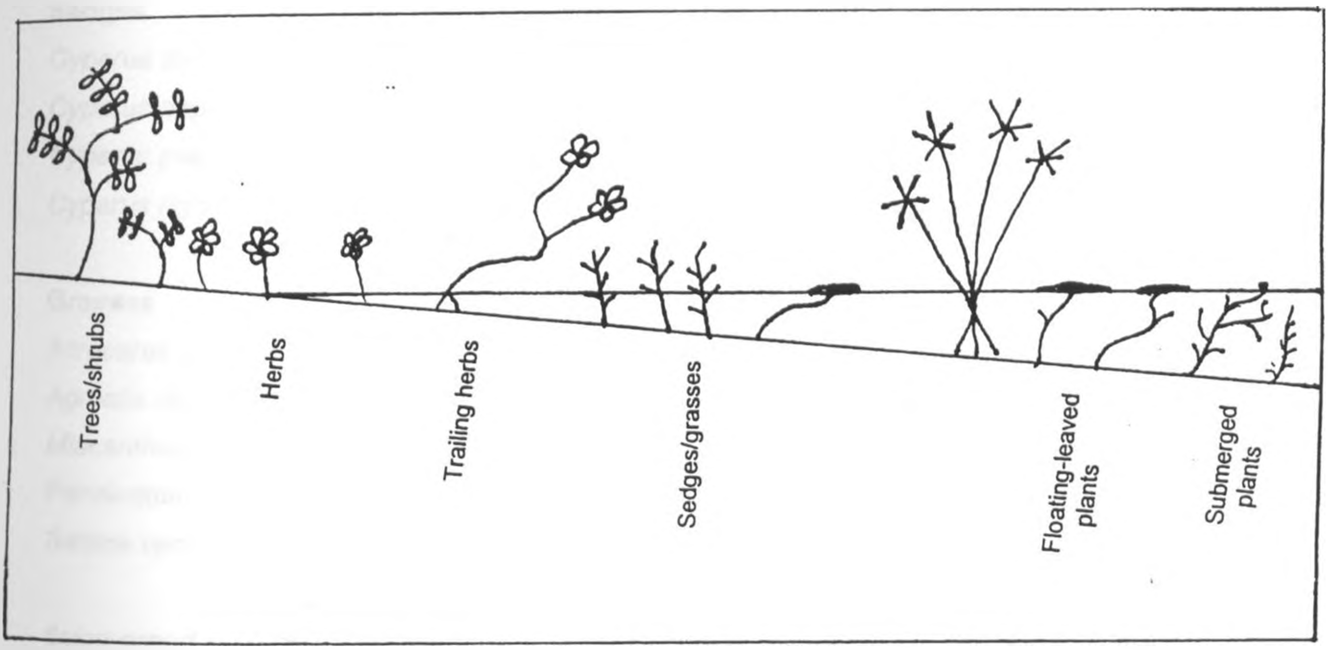

Figure 1.2: Hydroseral succession of plants species around the shore of Lake Naivasha in the 1970s (after Gaudet, 1977)

The floating mats of aquatic macrophytes have been observed to play a very important ecological role in Lake Naivasha. Fifty-one species of plants and different kinds of micro- and macroinvertebrates were recorded (Tables 1.4 and 1.5) on or in floating mats of *E. crassipes* and *S. molesta* between 1988 and 1998 in Lake Naivasha (Adams *et al.*, 2002).

Table 1.4. Species list of plants recorded on floating mats of *Salvinia molesta* and *Eichhornia crassipes* in Lake Naivasha, between 1988 and 1998.

Floating species	**Herbaceous species**
Azolla Africana Desv.	*Basella alba* L.
Eichhornia crassipes (Mart.) Solms	*Bidens pilosa* L.
Pistia stratiotes L.	*Circium arvense* L.
Salvinia molesta Mitchell	*Callitriche truncate* L.
Wolffia arhiza DW	*Commelina benghalensis* L.
Conyza sp.	*Crassocephalum picridifolium* (DC.) S. Moore
	Crotalaria barkae Schweinf.
Sedges	*Crassula schimperi* Fisch. & C.A. Mey.
Cyperus dives Delile	*Diplanche fusca* L.
Cyperus papyrus L.	*Gnaphalium luteo-album* L.
Cyperus pectinatus Vahl	*Hydrocotyle sp*
Cyperus rigidifolius Steud.	*Ipomoea cairica* L.
	Iris sp.
Grasses	*Lythrum rotundifolium* L.
Acroceras zizanioides (Kunth) Dandy	*Polygonum salicifolium* Brouss. ex Willd.
Agrostis stolonifera L.	*Polygonum senegalense* Meisn
Miscanthium sp	*Sphaeranthus napierae*
Pennisetum clandestinum Hochst. ex Chiov.	*Tagetes minuta* L.
Setaria verticillata (L.) P. Beauv	*Typha latifolia* L.
	Pycnostachys coerulae L.
Submerged species	*Pycnostachys deflexifolia* L
Najas horrida Magn.	*Senescio* sp.
Nymphaea nouchali Burm.	*Veronica* sp.

Source: Adams *et al.* (2002)

Table 1.5. List of invertebrates recorded on *Eichhornia crassipes* at Lake Naivasha.

Insecta (aquatic)	**Insecta** (terrestrial)
Coleoptera	Collembola
Hydaticus sp.	Thysanoptera
Rhantus sp	Orthoptera
Cybister sp.	Dermaptera
Helochares sp.	Cicanoidea
Berosus sp.	Staphylinidea
Eochrus sp.	Formicidae
Canthyrus sp.	
Hydrovatus sp.	**Aranaea**
Methles sp	Hydracarina
Synchortus sp	Arachinida(terrestrial)
Bidessus sp.	
Helodidae	**Crustacea**
	Procambrus clarkia Girard
Hemiptera	Ostracoda
Micronecta sp.	Copepoda
Plea sp.	
Mesovelidae	**Mollusca**
Lygaieda	*Bulinus* sp
	Physa acuta
Diptera	Diplura (terrestrial)
Culicidae	
Ceratopogonidae	**Turbellaria**
Chironomidae	*Dugesia* sp
Tipulidae	
Schiomyzidae	**Oligochaete**
	Almia emeni Michaelsen
Odonata	*Branchiura sowerbi* Beddard
Enallagma sp.	*Potamothrix* sp
Ephemeroptera	
Chloean sp.	
Trichoptera	
Economus sp.	

After Adams *et al.* (2002)

Cyperus pectinatus Vahl was the most frequent sedge, and appeared to have an important role in binding the mat, thereby facilitating colonization by other species. Herbaceous colonizers such as *Hibiscus* and *Sesban* within the mats were observed to increase in the *E. crassipes* mats from 1989, the time it was first seen in the lake.

The study by Adams *et al.* (2002) also observed that fauna associated with mats is concentrated in the zone in between the leaves and the aquatic roots of the plants. Within the zone, dead plant material is continuously being broken down and intermixed with wind blown-dust in which the earthworm *Almia emini* Michaelsen (most abundant) appeared very important. Young individuals of *Micronecta scutellaris* were common in and amongst the roots of the *E. crassipes*. In contrast, *S. molesta* mats were found to harbour a very limited fauna, both with regard to species diversity and number of individuals. Invertebrate density decreased with mat size by a power relationship, with density more or less constant for islands above approximately 10 m^2 in area.

1.3.6 Some factors affecting distribution and abundance of aquatic vegetation

1.3.6.1 Nutrients

Nutrient content is one of the most important factors affecting growth and establishment of aquatic macrophytes (Sculthorpe, 1967). Nutrient status of various habitats offers a wide range of assemblages of plants. Plants in fresh water are often limited by the availability of essential nutrients especially nitrogen and phosphorus during a period of optimal growth in the tropics (Mitchell, 1974). Baruah (1981) reported that low concentration of phosphorus and nitrogen tend to reduce plant population as well as biomass in aquatic systems.

A phosphorus concentration of 0.1 mgL^{-1} in the water has been reported as being critical for growth (Haller *et al.*, 1970) while a value of 20 mgL^{-1}proved to be optimal for growth of water hyacinth (Haller & Sutton, 1973). Increase in nitrogen level from 1 mgL^{-1} to 25 mgL^{-1}increased total dry weight of water hyacinth plants linearly but had little effect upon the mean weight per plant (Chardwick & Obeid, 1966). Degougi (1984) also reported that the growth of *E. crassipes* responded directly to the levels of nutrients in water especially those of nitrogen and phosphorus. The study also observed that maximum growth with large number of daughter plants was obtained at higher concentration of phosphate-phosphorus and nitrate-nitrogen. Belaboorip (1984) observed that, an increase in phosphate-phosphorus lowered doubling time in the growth of *E. crassipes*.

The concentration of nutrients as well as relative growth rate and doubling time of water hyacinth varies from time to time in Lake Naivasha. It has been suggested that this seasonal variation in productivity of water hyacinth was as a result of variation in concentration of both nitrogen and phosphorus (Kariuki, 1992). Kariuki reported a range of mean concentration of total nitrogenous and phosphate nutrients to be 6.30-10.8 mgL^{-1} and 0.237-0.346 mgL^{-1}respectively. Phosphorus and nitrogen, as in other tropical African lakes, have been reported to be the limiting factor to algal biomass in Lake Naivasha (Kalff, 1982). Enrichment experiment within Lake Naivasha water samples suggested that both phosphorus and nitrogen limited algal biomass (Anon, 1978). Njuguna (1982) found high ratios of N/P, which indicates phosphorus deficiency. Other elements such as carbon, silicon and sulphur are important constituents of organisms and their supply has had a major influence on the lakes ecology.

1.3.6.2 Changes in the water level

Fluctuations in water level have major impacts on the distribution and abundance of aquatic plants. For example, annual water fluctuations coupled with drifting by currents were reported to cause destruction of more than 90% of the floating population in Lake Oklawacha (Rodman Reservoir) in USA (Hestand & Carter, 1977). Many tropical African lakes experience fluctuating water levels, which in turn influence their area and temporal abundance and distribution of macrophytes. Well-studied natural examples include Lake Chad (Carmouze *et al.*, 1983) and Lake Chilwa (Kalk *et al.*, 1979), whilst man-made lakes such as Lake Kariba mimic these fluctuations in a more regular fashion.

Lake Naivasha experiences changes in its water level controlled by rainfall received in the high altitude areas of its catchment (Vincent *et al.*, 1979). During prolonged dry seasons, Lake Naivasha water level drops to leave behind an extensive dry area at the shore (draw-down) which can be as wide as 250m (pers. oberv.) in areas with an almost flat littoral zone. This in turn adversely affects the distribution, and abundance of aquatic vegetation. In Lake Naivasha, about 28% of *E. crassipes* was reported to die due to decrease in lake level (Kariuki, 1992). During the times of high water level, 'stranded' floating plants are uprooted by rising water and are easily distributed to other places by wind. On the other hand, rise in water level increases the column above the submerged species which reduces the amount of light reaching these species as well as adding hydrostatic pressure on them.

1.3.6.3 Lake morphometry

The morphometry of a lake is an important factor in determining the distribution of aquatic plants. Duarte and Kalff (1986) found that the slope of the littoral zone of Easton Lake

(USA) could explain 72% of the observed variability in the growth of submerged plants. Engel (1985) also reported that gentle slopes supported more plant growth than steep slopes in Easton Lake.

1.3.6.4 Water transparency

Water transparency is an important growth factor of the submerged plants. Water molecules and foreign particles held in water column absorb, scatter and reflect the radiation as it falls on the water. These processes enhance the attenuation of light as it travels through a water column. Light energy transmission through a water column follows Beer's law (Wetzel, 1983) as shown in the equation below:

$$I_z = I_o \ e^{-\eta z} \text{ ------------------------------(i)}$$

Where

I_z = irradiance at depth z;

I_o = irradiance at the lake surface; and

η = extinction coefficient.

The extinction coefficient (η) is constant for given a wavelength. The relationship above is, however, imperfect in nature because sunlight is a composite of many wavelengths. Moreover, the natural total extinction coefficient (η_t) is influenced not by water itself (η_w) but also by absorption of particles suspended in the water (η_p), and particularly by dissolved, coloured compounds (η_c). Thus the *in situ* extinction coefficient (η_t) is a composite of these components (Åberg and Rhode, 1942) and is summarized as:

$\eta_t = \eta_w + \eta_p + \eta_c$.------------------------------(ii)

where,

η = extinction coefficient;

η_t = total extinction coefficient;

η_w = extinction coefficient due to water itself;

η_p = extinction coefficient due to absorption of particles suspended in the water; and

η_c = extinction coefficient due to dissolved, coloured compounds.

At low concentrations the particulate suspensoids have relatively little effect on absorption. With high turbidity, however, the effect is quite significant, particularly at lower wavelengths of the visible spectrum. Hence, in systems with low water transparency, only a limited amount of light reaches the bottom of the lakebed where submerged plants are found. Such habitats are likely to have low vegetation populations compared to the ones with clear water, which allow more and quality light to penetrate.

1.3.6.5 Shoreline land use

Land use practices can have a strong impact on the aquatic plant community and, therefore, the entire aquatic community. Practices such as farming and construction, for example, can directly impact the plant community through increased sedimentation from erosion. Increased nutrient input from run-off from fertilized farmland, increased toxic substances and urban run-off all reduce water quality, hence, negatively affecting aquatic life (Parsons, 2001).

1.3.6.6 Herbivory

Aquatic plants are important food constituents of aquatic animals. Natural enemies of aquatic weeds have been used by the aquatic systems managers to control the spread of the aquatic weeds in various parts of the world. For example, weevils that are natural enemies of *Salvinia* and *Eichhornia* species have been introduced as part of management strategy of the two invasive floating species in Lake Naivasha.

Small mammals such as coypu have been blamed for massive reduction of floating-leaved vegetation in Lake Naivasha. While the emergent component has been primarily lost through agricultural destruction, the submerged component of Lake Naivasha has been destroyed by grazing impacts of crayfish (Harper *et al.,* 1998). The study suggested that the submerged macrophyte destruction could only be mitigated by some kind of biocontrol over the crayfish.

1.3.6.7 Sediments composition and shoreline vegetation

Many species of plants depend on the sediment in which they are rooted for their nutrients and anchorage. The nutrient content and texture of the sediment will determine the type and abundance of macrophyte species that can survive in a location (Barko & Smart, 1986). The availability of mineral nutrients for growth is highest in sediments of intermediate density, such as silt and lowest in sandy sediments (Barko & Smart, 1986).

The shoreline environments suitable for the establishment and proliferation of *E. crassipes* were studied in Uganda during the early surveys of the weed in Lake Victoria. They included among other factors soft muddy bottom rich in organic matter (Twongo, 1995). Such substrata also supported emergent vegetation, which protected the floating macrophytes from the effect of wind hence supporting most *E. crassipes* populations.

In Lake Naivasha, localities that have black silty soils harbour most of emergent vegetation mainly *Cyperus* spp., especially where the main rivers enter the lake. Such soils are particularly important during low levels of the lake since the floating plants get anchored at the margins of the draw-down and sometimes survive the dry spell (Kariuki, 1992). On the other hand, areas that are dominated by sandy sediment have limited *Cyperus* spp. for instance and sometimes colonized by different species altogether (Kariuki, 1992).

There is a large difference between sediment composition from West to East of Lake Naivasha. From North to West of the lake, the debris of papyrus and *Salvinia* leaves predominantly flocculate organic material, while the eastern part contains more sand and inorganic particles (Christine, 1995). According to Clark and Baroudy (1990) the most common substrate of the lake is mud softened by decomposing Papyrus together with submerged macrophytes. The other, rarer types are rocks and hard mud.

1.3.7 The Naivasha basin

1.3.7.1 Location and regional setting

Naivasha basin lies south of the equator in central Kenya and about 100 km northwest of Nairobi. It is a basin of endorheic (no outlets) drainage. Situated at an altitude of 1890 m above sea level, the lake basin is the highest of all Rift Valley lake basins (Njuguna, 1982).

It owes its origin to tectonism and volcanism. Three distinct bodies of water, viz: Naivasha, Oloiden and Sonachi, of diverse morphometric, physical, chemical and biological conditions occupy the basin. Their boundaries were determined by tectonic faulting and resultant volcanicity associated with the formation of the East African or Gregory Rift Valley, its string of volcanoes and chain of closed basin lakes. The breadth of the valley in this region is between 45km and 75km and is still volcanically active. The basin total catchment area is 3270 km^2 (Njuguna, 1982).

Rift escarpments flank the basin both on its eastern and western sides. The Kikuyu escarpment (3,906m), Kinangop Plateau (2,483m) and Eburru Range (2,668m), an outlier volcanic pile of the Mau Escarpment (3,098m), separate it from Nakuru-Elmentaita basin to the west (Njuguna, 1982). A barrier to the south is formed by an extinct volcano, Mt. Longonot (3,000m), its lava sheets and other smaller volcanoes. The barrier is breached at one point by Njorowa Gorge in Hell's Gate National Park. Njorowa Gorge is a former outlet of a once bigger Pleistocene lake that stretched from Longonot to Menengai Crater and included the present day Nakuru, Elmentaita and Naivasha basin lakes (Njuguna, 1982). Hot springs, geysers and steam vents near the gorge are now being harnessed for geothermal power generation at Olkaria.

1.3.7.2 Geology and soils

The geology of Naivasha basin has been described by Thompson and Dodson (1963). Rocks and sediments in this area fall into two major categories: lavas and lacustrine deposits. The basic lavas include tephrites, basalts, trachytes, pumice, ashes, tuffs and agglomerates. The acid lavas consist of rhyolite, commedite, obsidian and pyroclastics. Lake deposits though covering large areas are not thick. They are mainly composed of reworked volcanic material and autochthonous organic matter. The geologic structure is characterized by faulting on the flanks and valley floor, and a slight folding in Njorowa Gorge. In the high areas of the catchment are noncalcerous black or grey soils overlying yellow brown compact subsoils with iron concretions (Ongweny, 1973). Soils in the Nyandarua Range and the Kinangop Plateau are high altitude young soils with predominantly montmorillonite clays and recent lacustrine deposits are found along the northeastern shores of the main lake while along the southeast shores, diatomite occurs up to 1.5m thickness.

The geological history records reveal substantial changes in climate during the last 30,000 years. From 12,000 BP to 9,200 BP a large lake (612 km^2) that included the present day Naivasha lakes, Nakuru and Elmentaita overflowed southwards draining through Njorowa Gorge (Richardson & Richardson, 1972). By 9,200 BP the gorge was downcut to it present level (2,089 m) and a 400 km^2 lake occupied the Naivasha basin until 5,700 BP. Decreasing rainfalls reduced the size of the lake and the basin was closed. Around 3,000 BP, the lake is said to have dried out completely and remained dry for 100 years. During the past 3,000 years small fluctuating lakes have existed in the basin.

1.3.7.3 Climate and hydrography

The climate of Naivasha basin is warm and semi-arid. The rainfall regime falls between equatorial (two rainy seasons) and tropical (one rainy season) regimes and is characterised by two maxima in single year. The average rainfall is bimodal with a main pulse in November. The mean annual precipitation for Naivasha Township is 620 mm. This is much less than the mean value for evaporation from open lake (1735 mm). In the moist highland parts of the drainage area, i.e., on the slopes of Nyandarua Range, the mean annual precipitation gets as high as 2000 mm. Naivasha basin lies in the depression closer to the eastern Rift Valley wall and thus experiences a double rain shadow effect from both east and west. Prevailing easterly winds precipitate the moisture on the eastern Rift Valley highlands, the Nyandarua Range and Kinangop Plateau. Moisture that would be brought in by the westerlies is left in the Mau Range.

The warmest month in the region is March while the coolest is July. Warm temperatures and low rainfall make January and February the driest months with high evaporation rates. Evaporation exceeds precipitation almost throughout the year. Soil water deficiency prevails for most of the year in Naivasha's rift floor. In the highlands, rainwater is plentiful and finds its way to the lakes as runoff in the main river courses. Lake levels represent the end result of the complex interrelationships between the various components of the lake basin. Vincent *et al.* (1979) have found a highly significant correlation between the levels of the Lake Naivasha and rainfall at highland stations in Kenya with a periodicity of about seven years. These observations have led to the thought that Lake Naivasha can act as an indicator of a set of climate parameters related to upper level airflow over East Africa.

Breezes over the lakes are common in the morning. In the afternoon winds up to 11 kmh^{-1} are typical. Winds come from the south with the importance of the easterly and westerly components depending on the season (Njuguna, 1982). The pattern described is not uniform throughout the basin and rregularities are quite common. Highlands surrounding the lakes and the valley floor provide most of the water that maintains the lakes. The principal sources of the water that maintains the lakes are the rivers (Malewa, Gilgil, Karati and Marmonet), seepage of ground water and precipitation. Water loss is mainly through evaporation, evapotranspiration and seepage out. River Malewa is the main water source.

The lake basin has been described as a 'hydrographic window' (Thompson & Dodson, 1963) because water can pass freely through the porous volcanic rocks, which constitute 80% of the rocks in the basin. In addition, lava flows are usually well jointed, often vesicular and allow free movement of water. Large percolation rates through the underlying rocks were initially suggested by Leakey (1931). Water input into the lake occurs in the NE and NW sections and seepage out in the S and SE sections of the basin (Gaudet & Melack, 1981). The rate of seepage appears to be related to the amount of rainfall on the catchment.

1.3.7.4 Economic importance of the basin

The basin has attracted the attention of humans for a long time. Stone Age Man hewed blocks of obsidian for tool manufacture near Fischer's tower at the northern end of Njorowa Gorge at a cliff several kilometres from Naivasha Town (Leakey, 1942). A prehistoric site was discovered at the base of this cliff and is believed to have been at the edge of the Gamblian Lake (Leakey, 1931).

As early as 1800s geologists such as Fischer, Thompson von Honel Teleki, and Gregory made brief stopovers at the lakes' shores while on their varied routes. In the recent past the basin has witnessed an influx of people and a tremendous human population increase. The number of people living within 5 km of the lake has risen from 50,000 in 1977 to about 250,000 today (unpublished). The economic importance of the basin lies in the lakeside farming. The riparian land has come under intensive agriculture due to the readily available water and rich volcanic soil. Extensive flower farms have developed attracting job seekers with a consequence of the population increase. Plate 2 is a photograph of the eastern side of the lake showing flower farming activities. Arrow A points at the eastern side of the Main Lake and B green houses in flower farms. Dairy farming and

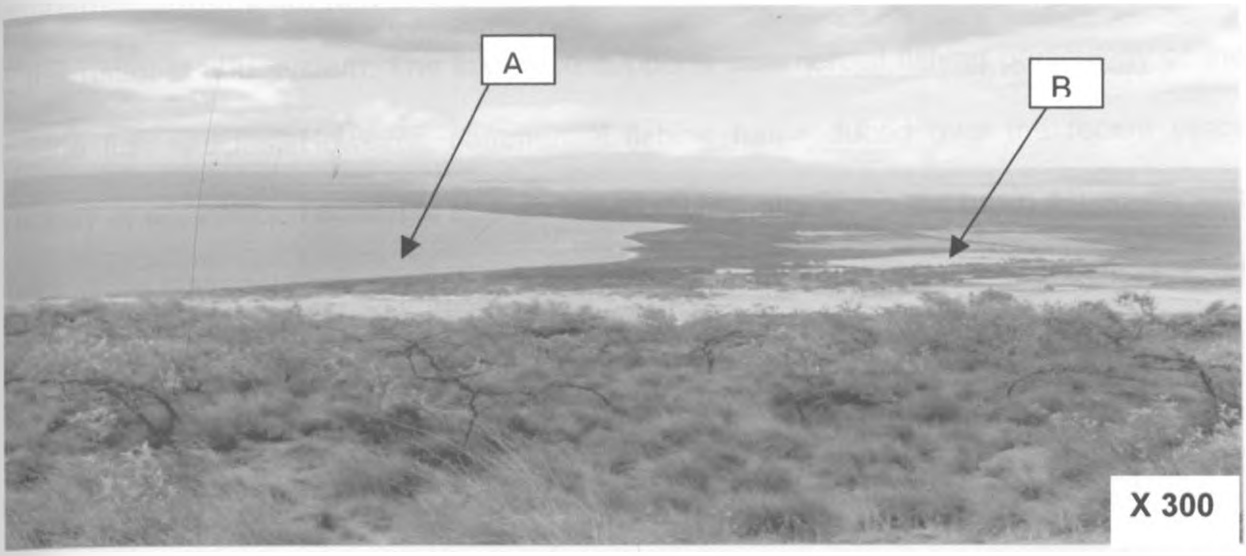

Plate 2. A photograph showing farming activities in the riparian lands of Lake Naivasha. Arrow A points at the lake while B green houses in flower farms (photo by the author, 2003).

Plate 3. Boating activities in Lake Naivasha. Note the sandy/rocky shore at Crescent Island Lake basin (Photo by the author, 2003)

stockbreeding are both of equal importance locally. The lake ecosystem hosts the largest geothermal power plant (under expansion) in the world and it is projected to be a big boost to the national grid system. The lake also supports commercial fishing particularly of the tilapine fish species. However, commercial fishing has reduced over the recent years (Hickley *et al.*, 2002). Tourism is also an important industry within the basin especially with Hell's Gate National Park being near the lake. Bird watching, boating as well as sport fishing are common activities taking place in the lake. Plate 3 is a photo of boating activities, a major tourist attraction, captured in Lake Naivasha. Ecologically, the basin contains a fascinating hybrid of aquatic, semi-arid and wetland ecosystems.

1.3.8 The study area

The present study was conducted in Lake Naivasha (0° 45'S, 36° 20'E) a fresh water lake, which occupies a closed basin more or less circular in shape with no apparent out-flow (Figure 1.3). Lake Naivasha is relatively small with an area of 100 km^2 (Harper, 1999) making it the third largest lake in Kenya after Turkana (7,200 km^2) and Victoria (Kenya part, 3,755 km^2, total area 69,000 km^2). The lake surface area has, however, fluctuated depending on the amount of precipitation, water inflow and loss in the catchment during a particular period. The highest recent level (217 km^2) was recorded in 1917 and the lowest level (93 km^2) in 1959 (Gaudet, 1973). The rim of an ancient crater forms a crescent shaped peninsula in the eastern part of the lake where its maximum depth is found. The lake is one of the only two freshwater lakes in Kenya's Rift Valley. Lake Baringo, the other freshwater lake, lies to the North of Naivasha.

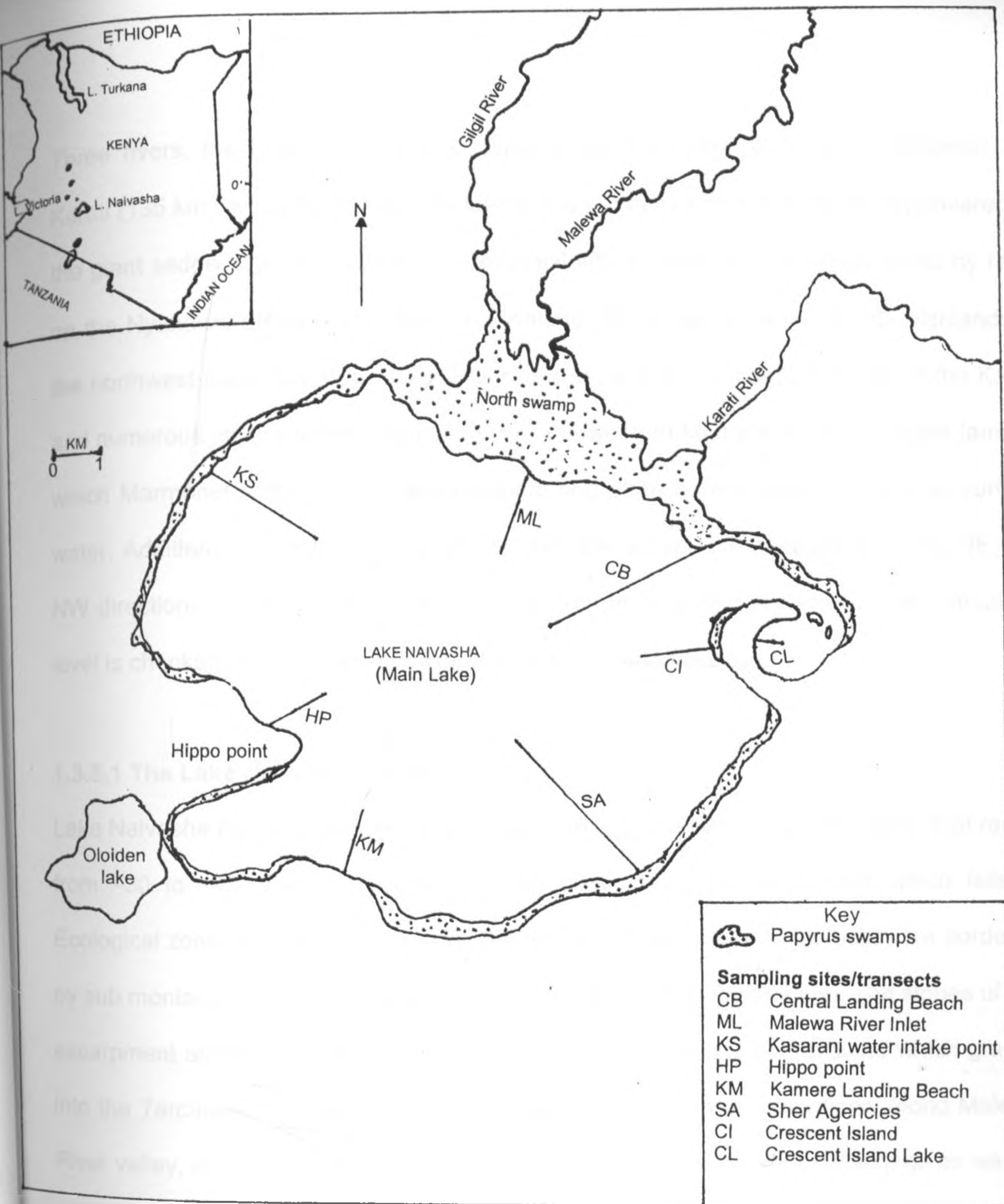

Figure 1.3 Map of Lake Naivasha showing sampling sites/transects (modified after Harper, *et al.*, 2002)

Three rivers, the Malewa (1730 km^2, watershed), the Gilgil (420 km^2, watershed) and Karati (135 km^2, watershed) enter the lake in the northern part in a delta mainly covered by the giant sedge, *Cyperus papyrus* L. Perennial flow is maintained in the Malewa by rains on the Nyandarua Range and Kinangop Plateau. Rains falling on the Bahati highlands to the northwest keep flow in the Gilgil River to at least 2,100 m contour. Flows in the Karati and numerous other streams originating from the western Mau and Eburru Ranges (among which Marmonet is the largest) are seasonal and often do not reach the lake as surface water. Additional inflow to the lake comes from the subsurface seepage from the NE and NW directions (Thompson & Dodson, 1963). With no apparent surface outflow, the lake's level is checked by evaporation, evapotranspiration, and seepage.

1.3.8.1 The Lake Naivasha ecosystem

Lake Naivasha falls in a marginal area of semi arid climate with moisture indices that range from –30 to –40. The area consists of woodland savannah vegetation, which falls in Ecological zone IV (Pratt *et al.*, 1966). The wetter northern parts of the basin are bordered by sub montane tropical evergreen forest dominated by *Podocarpus* spp. The slopes of the escarpment above Naivasha are covered by tropical *Settaria* spp. grassland which grades into the *Tarchonanthus camphoratus* L. bushland typical of the valley floor. Along Malewa River valley, is riverine vegetation dominated by *Salix hutchinsii* Skan which, gives way to papyrus swamp as the river enters the lake. The lake is surrounded by an *Acacia xanthophloea* Benth. woodland.

The Lake Naivasha ecosystem is endowed with a diversified wild life. A complex vegetation of terrestrial, water-tolerant and wetland plants emerges due to the frequent water level changes (Harper, 1987). Gaudet (1977) described 43 plant families and 108 species of lacustrine flora. Emergent macrophytes, which are dominated by sedges particularly *C. papyrus*, are the most important lake vegetation component. Papyrus forms a fringing zone around most of the lake and was observed to play an important ecological role within the lake (Gaudet & Muthuri, 1981). In the open water, the floating vegetation comprises of *Salvinia* and *Eichhornia*. Submerged macrophytes consist of mainly *Potamogeton* spp.

Lake Naivasha is famous for its avifauna and has been routinely included on the bird watchers itineraries. There are large numbers of various birds species such as: white neck cormorant, herons, pelican, African spoon bill, long-toed plover, cape teal, white winged black tan, coots, kingfishers, sacred ibises and fish eagles among others.

Hippos (*Hippopotamus amphibious L.*) and several other species of large animals such as buffaloes live in the riparian land. Hell's Gate National Park (managed by Kenya Wild Service, KWS), with an access corridor to the lake is home to many large species of game. Mammals living around the lake are gazelles, monkeys, impalas, dikdiks, kongoni, zebras and giraffes. The rich biodiversity has led to the lake's recognition as a water body of international importance, hence, a Ramsar site (Ramsar, 1999). The most common fish in Naivasha are *Oreochromis leucostictus* (Trewewas) and *T. zillii* Gervais. which were introduced between 1920 and 1970 and *Micropterus salmoides* Lacepede introduced between 1925 and 1955 (Ramsar, 1996). Other fish present are *Barbus amphigrama* Blgr., *Poecilia reticulata* Peters, and *Cyprinus carpio.*

1.3.8.2 Lake Naivasha aquatic vegetation

The aquatic vegetation of Lake Naivasha was first described by Beadle (1932) who carried out studies of species zonation across a fringing papyrus swamp on the eastern shore opposite Crescent Island. Dominant outside the papyrus clumps were water lilies (*Nymphaea caerulae* L.) and *Hydrocotyle* spp. together with *Ceratophyllum demersum L.* and *Potamogeton* spp. Gaudet (1977) listed 25 species of aquatic macrophytes in the shallow water zone of the lake. Ten of these species were submerged, eight were essentially free-floating and the remainder were either emergent or associated with floating vegetation, e.g. *Utricularia* spp.

The major component of the vegetation was Papyrus (*Cyperus papyrus*), particularly in the northern delta of the main rivers feeding the lake. This swamp was shown to affect the whole ecosystem through uptake of nutrients and sediment from the inflowing rivers and subsequent slow release to the lake water as fine organic particulate matter and accumulated swamp peat (Gaudet, 1979; Gaudet & Muthuri, 1981).

Salvinia molesta Mitchell was reported in the lake in 1961 and was confirmed in 1964 when 60 hectares of the weed was discovered near Crescent Island (Harper, 1987). This weed was controlled using herbicides and the weed receded in early 1970s. After the 1978-9 rises in water level it spread to cover an area of up to 20% of the lake surface. There was no trace of *Salvinia* plants at the Crescent Island Basin in 1984 (Harper, 1987). A survey conducted in 1968-1969 revealed that submerged plants occupied 10 km^2, floating plants 4 km^2 and emergents, particularly papyrus, 19 km^2 (Gaudet, 1976).The most common plants found are listed in Table 1.6.

Table 1.6. Macrophytes common to Lake Naivasha in 1929-1931 and 1970

1929-1931	1970
Submerged	
Najas horrida	*Najas horrida*
Utricularia sp.	*Utricularia sp*
Ceratophyllum demersum L.	*Ceratophyllum demersum* L
Potamogeton pectinatus	*Potamogeton* spp
Floating-leaved	
Nymphae sp	*Nymphae caerulea* Saviney
Hydrocotyle ranunculoides L	*Hydrocotyle ranunculoides L*
Free-floating	
Lemna sp	
Lemna trisulea L	
Wolffia arrhiza (L) Wimmer	
Pistia stratiotes L	
Salvinia molesta Mitch.	
Emergent	
Cyperus papyrus L	*Cyperus papyrus* L
Ludwigia stolonifera (Guill. and perr.) Raven	*Ludwigia stolonifera* (Guill. & perr.) Raven
Cyperus digitatus spp. auricomus. (Spreng.) Kük	*Cyperus digitatus* Roxb. Spp.*Auricomus* (Spreng.) Kük
	Cyperus latifolius Poir.
	Cyperus imbricatus Retz.
	Typha sp.
	Scirpus sp.
	Polygonum pulchrum Blume
	Enhydra fluctuans Flour

After Gaudet (1976)

Harper (1987) reported no submerged aquatic vegetation in the Main Lake in early 1980s. However, some species previously reported from the Main Lake were found in a dense macrophyte zone growing between 0.5 m and 4m depths in Oloidien Lake, South west of the Main Lake. Also, small quantities of *Wolfia arhiza* were found in Mennels lagoon and the North swamp. *Pistia stratiotes* L. was sparse but ubiquitous. *Ceratophyllum*, another species known to have been very abundant in the lake in 1960's (Harper, 1987) was also not found at this locality. *Nymphaea* plants were only seen scattered in various localities.

In 1988, Lake Naivasha witnessed the arrival of *Eichhornia crassipes* (or water hyacinth) in its waters. Water hyacinth is the world's most noxious aquatic weed. The plant is a very bulky, free-floating macrophyte. Therefore in Lake Naivasha, significant floating macrophytes were *S. molesta, Nymphaea caerulea* and *Eichhornia* (Harper & Adams, 1998).

1.3.8.3 Changes in submerged aquatic vegetation of Lake Naivasha

The specific composition and distribution of submerged aquatic vegetation of Lake Naivasha have been observed to vary from time to time. These changes have been linked to climatic conditions and human interferences, which are either planned or accidental. Introductions of exotic fishes and the Louisiana crayfish have been blamed for the decreasing aquatic macrophytes. The population crush of crayfish has been observed to correlate with increase in submerged macrophytes (Harper *et al.*, 1998).

The vegetation changes that have occurred at Lake Naivasha have been described to have taken place in three phases (Harper, 1992). The 'normal' phase occurred up to the late 1970s. This is the period when a scientific investigation on Lake Naivasha vegetation was carried out by Beadle (1932). A zonation survey was carried out together with certain physico-chemical parameters, across a fringing swamp of *C. papyrus* on the eastern shore of the lake. After the normal phase, there followed a 'reduced' phase (1975-1983). This is the period when reductions of the floating-leaved plants were noted in parts of the lake. Litterick *et al.* (1979) listed the most important submerged species as shown in Table 1.7. At that time, no mention of *P. schweinfurthii* was made.

Table 1.7. List of submerged species present in Lake Naivasha in 1979.

Potamogeton pectinatus L.
Potamogeton thunbergii Cham. & Schltdl.
Potamogeton octandrus Poir.
Ceratophyllum demersum L.
Najas flexilis (Slender Naiad)
*Najas pectinata** (Parl.) Magn.
Utricularia reflexa Oliv.
Utricularia gibba L.
Nitella knightiae J. Gr. & Steph. *(algae)*
Nitella oligospora (algae)
Chara braunii Gmelin. *(algae)*

Source Litterick et al. (1979)

* The species *N. pectinata* was actually *N. horrida*. *N. pectinata* is endemic to Egypt and has not been found in Lake Naivasha.

In 1982/3 no submerged or floating-leaved vegetation was found in the Main Lake (Harper, 1987). Floating vegetation was dominated by the introduced *S. molesta*, often associated with *C. papyrus* and *Pistia stratiotes* L. together with water edge species such as *Hydrocotyle ranunculoides* L. that often colonize the *S. molesta* mats. This floating community moved in rafts or islands of varying size about the lake as a result of wind action, covering about a quarter of the lake surface. As the lake level reduced following the failure of the rains in 1983, these floating rafts became stranded. Large areas of the northern and western parts of the lake, particularly between the two main inflows in the area designated by Gaudet (1977) as the North swamp, became dry and were reclaimed for agriculture. By the end of 1987, the area of mature papyrus swamp at the lake was reduced to around 2 km^2 from a former 12km^2 (Harper *et al.*, 1990).

The period between 1985 and 1987 has been referred to as 'recovery' phase. Between 1985 and 1987, extensive beds of submerged macrophytes developed in most of the shallow regions of eastern half of the lake starting with *Potamogeton octandrus*, which were first found in sparse beds confined to shallow mud around the inner shores of Crescent Island in 1984 (Harper, 1992). Zonation was apparent, especially in the gently–shelving shallow littoral to the south of Crescent Island Lake where the beds extended horizontally about 400 m from the shore to a vertical depth of 2.5 m. *P. octandrus* dominated the shallows below 1 m depth, *P. schweinfurthii* was found less commonly at all depths but only *Najas horrida* occurred below 2.25 m, in scattered clumps. At this period *N. caerulea* germinated in the shallow areas around Crescent Island Lake (Harper, 1992). Macrophytic algae were also observed during this period though in low amounts. These were *Nitella* sp. and *Chara* sp. (Christine, 1995). Studies carried out in the lake in 1998 showed that the lake supported four main species of submerged macrophytes: *Potamogeton pectinatus* L, *P. schweinfurthii*, *P. octandrus* Poiret and *Najas horrida* Magn. (Harper & Adams, 1998).

1.3.8.4 Lake Naivasha bathymetry

Hubble (2001) provide a bathymetric map of Lake Naivasha referring to the lake-surface of 1886 m a.s.l. (Figure 1.4). From the map, the lake may be said to constitute two semi-separate basins: the Main Lake basin and the Crescent Island crater in the east.

The Main Lake is characterized by a smooth flat relief with a maximum depth in the southeast of the lake. The flat bottom topography contrasts sharply with the hilly topography of the surrounding land, indicating that the lake basin is filled with large amounts of sediments Åse *et al.* (1986). A shallower area in the northern end is interpreted as a deltaic sediment accumulation deriving from the inflows of the major rivers.

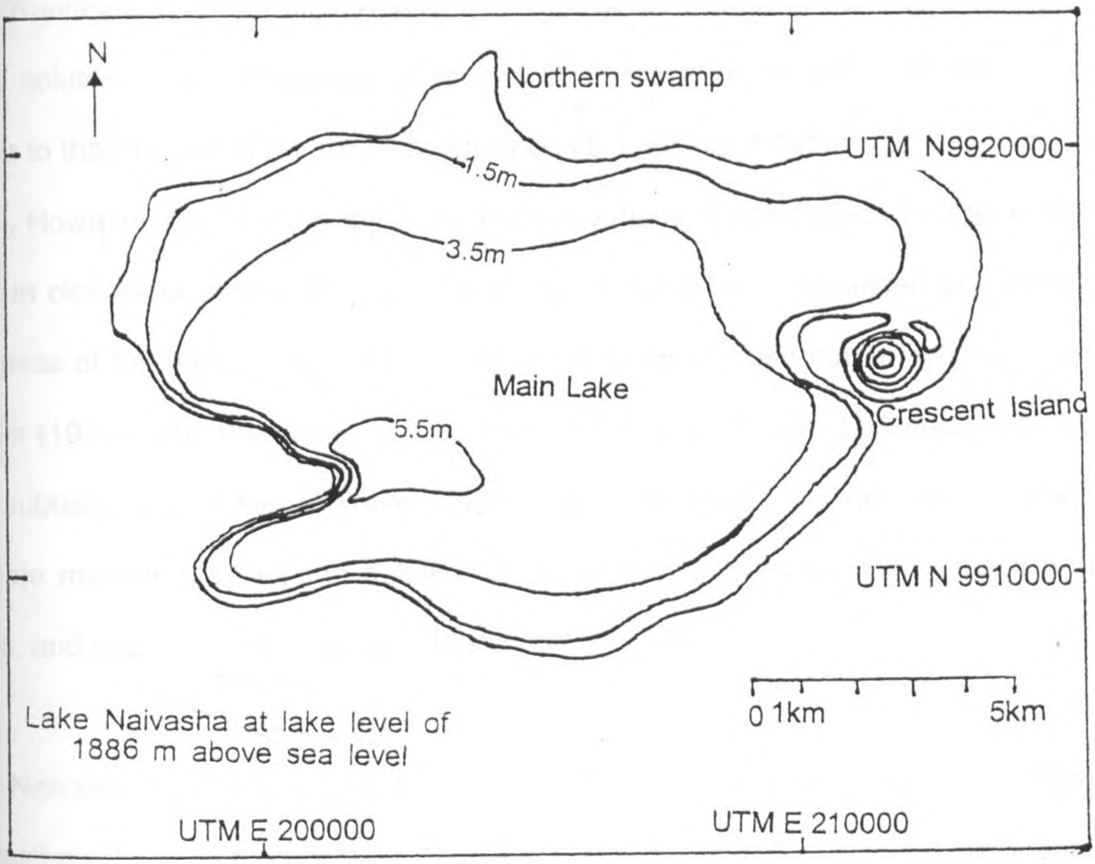

Figure 1.4: Bathymetric map of Lake Naivasha. Water depths were drawn at 2m intervals. The lake contour represents a water level of approximately 1886m above sea level (adapted from Hubble, 2001)

1.3.8.5 Lake level

The changes in lake level dates back in 1880 when the lake almost dried. The level has varied 10m in the last century, and this has been correlated to the meteorology of the surrounding areas (LNROA, 1993). From 1931 to 1952, the lake level dropped vertically by 8m (Litterick *et al.*, 1979).

1.3.8.6 Lake Naivasha physical and chemical properties

Lake Naivasha water is slightly alkaline, with sodium and calcium bicarbonates as the major solutes. The composition of the water in terms of mineral composition is almost similar to that of most Rift Valley lakes formed by leaching of recent volcanic rocks (Kilham, 1971). However, the lake's water is anomalously dilute in comparison with other Rift Valley lakes in closed-basin systems. Several proposals have been advanced to account for the freshness of the lake. Gregory (1921) suggested that the lake has an underground outlet. Beadle (1932), and Thompson and Dodson (1963) also strongly believed in the existence of a subterranean outlet. However, to date such an outlet has not been located. Other possible mechanisms include deflation and burial of salt layers, ion removal by aquatic plants, and underground seepage (Gaudet, 1978, 1979).

Lake Naivasha has experienced tremendous changes in water transparency. Secchi depth measurements as high as 3.7m to 5.7m were recorded in 1979 (Burgis & Symoens, 1987). Transparency has reduced since 1983 with Harper (1987) recording Secchi depth measuring 0.5m to 1.64m. Christine (1995) observed transparencies as low as 0.2m to

0.8m in the Main Lake. The changes in land use, witnessed in the recent times have been blamed for decline in water clarity. The depletion of the forests on the Kinangop, Mau and Eburru escarpments has adversely affected the ecosystem such that El Niño rains caused more erosional damage than contribution of water to Lake Naivasha (Gitahi, pers. comm.). In addition, increased population around the lake has increased demand for more land for cultivation. Such activities encourage soil erosion with a net effect of the lake sedimentation through run-off. Milbrink (1977) recorded a maximum alkalinity of over $3meqL^{-1}$ and a minimum of $20meqL^{-1}$ at low and high water levels respectively. Conductivity was observed to range between $260\mu mhoscm^{-1}$ to $445\mu mhoscm^{-1}$ at high and low water levels respectively. Njuguna (1982) recorded conductivity range of 300-350 $\mu mhoscm^{-1}$ in the Main Lake. In terms of pH, Milbrink (1977) recorded pH of 8.8 and was reported to be the highest recorded ever. More values of chemical parameters from Litterick *et al*. (1979) and Harper (1995) are presented in Tables 1.8 and 1.9 respectively.

Oxygen varies with depth and the distance from the shore. However, due to frequent winds the water of the lake is well mixed and this mixing also makes thermal and solute barriers only temporal (Christine, 1995).

Table 1.8. Chemical composition of River Malewa and Naivasha basin lakes (Litterick *et al.*, 1979).

Chemical parameter (mgL^{-1})	River Malewa	Main Lake	Cresent Island Lake	Lake Oloiden	Lake Sonachi
Na^+	9	40	52	125	1900
K^+	4.3	20	30	82	333
Ca^{2+}	8	21	17	9	4.1
Mg^{2+}	3	6.4	7.5	6.9	5.1
HCO_3^-	70	192	231	496	2837.4
CO_3^{2-}	0	10.6	15	43	960.2
SO_4^{2-}	6.2	6.2	4.8	7.1	36
Cl^-	43	14	17	32	224
F^-	0.4	1.5	1.5	8	67.5
SiO_4	17.2	34	36	44	77

Table 1.9 Chemical composition of River Malewa, Naivasha and Oloiden lakes (Harper, 1995)

Chemical parameter	River Malewa	Main Lake	Cresent Island Lake	Lake Oloiden
Conductivity (S/cm)	151	353	385	2500
pH	6.83	8.16	8.4	9.5
Total alkalinity (mg/l)	63.6	135.6	166	1033.6
Total hardness Ca (mg/l)	26.6	41	44.1	*
Total hardness (mg/l)	38	65.6	69.7	*
SO_4^{2-} (mg/l)	*	*	*	*
F^- (mg/l)	0.46	1.5	1.93	1.17
Total iron (mg/l)	*	*	0.02	0
Sulphur (mg/l)	*	0.03	0.02	0.05
Ammonia (mg/l)	*	0.27	0.18	0.05
Nitrate (mg/l)	0.4	0.4	0.2	0.65
P total (mg/l)	0.08	0.1	0.09	0.19
N total (mg/l)	0.8	0.2	*	4.1

**Not determined*
P=phosphorus

CHAPTER 2: MATERIAL AND METHODS

2.1 The Sampling Strategy

A total of eight points were selected considering the absence or presence of the target groups of macrophytes, the lake morphometry, main river inlets, depth and the riparian human activities of the lake among others. The sampling areas were established to provide a range of sites having different characteristics. The characteristics would have different impacts on the target macrophytes hence variably influencing them ecologically. In this study, the ecological values considered were abundance and distribution of both floating and submerged macrophytes. It was also considered important to spread the sampling sites within the lake as much as possible so as to have a good representation of the whole lake.

For the purpose of easy reference and labelling on the map (Figure 1.3), the sites established were subjectively coded. The sites, their respective codes, GPS readings and associated characteristic(s) are summarized in Table 2.1. The sites were marked using a hand held Global Positioning System (GPS), Garmin 12XL. This was done during a familiarizing survey making it easier to locate them during the sampling occasions that followed. During the actual sampling, random sampling was carried out at various points so as to note the plant species that were not present at the selected sampling sites. Sampling process was designed to take place during both dry and the rainy seasons.

Table 2.1. The sites, their respective codes, GPS readings and associated characteristic(s).

Station /site	Name	Code	GPS point/ Reading (37M/UTM)	Characteristic(s)
1	Central Landing Beach	CB	0210035/9917808	a shallow area providing an almost flat lake bed
2	Malewa River Inlet	ML	0205421/9919738	a turbid area where the principal rivers enter the lake
3	Kasarani Water Intake Point	KS	0199629/9919595	a site to the northwest of the lake with minimal influence of both rivers and human activities such as farming
4	Hippo point	HP	0200872/9912941	a site to the southwest of the lake with a steep lake bed
5	Kamere	KM	0202121/9910226	a site to the south of the lake, it's a public entry point to the lake, washing and animal watering takes place here
6	Sher Agencies	SA	0205843/9909038	a site to the southwest of the lake, farming activities take place in the riparian land
7	Crescent Island	CI	0210258/9914492	a site to the east of the lake, its riparian vegetation has been overgrazed by wild animals
8	Crescent Lake	CL	0212533/9915387	an almost completely enclosed sub-basin

2.2 Fieldwork Methods

2.2.1 Preliminary study: A pilot study was carried out so as to familiarize with the main submerged and floating vegetation. This opportunity was also utilized to familiarize with the macrophytes associated with floating species. A general collection of vegetation was carried out and identification was done using relevant keys, colleagues, herbarium facilities and personnel at University of Nairobi. The accessibility of the sampling sites was also assessed in that dangerous animals such as hippopotami are found more frequently in some areas more than others within the lake. The applicability of the sampling techniques was also assessed. The actual sampling in Lake Naivasha for the present study was carried out from the month of February to July 2003. This period of time offered an opportunity to observe how the abundance and distribution of the aquatic vegetation was affected by seasonality. February to April was the dry season while May to July was the wet season.

2.2.2 Transects*:* During the pilot study, transects were marked using GPS unit. They were marked perpendicularly from the shore and ran towards the deep part of the lake so as to reach 4.5m depth.

2.2.3 Water*:* Water sampling for nutrient analysis was carried out within zones 1 and 2 where most of the submerged vegetation was found to occur. Water samples were collected using a MacVuti sampler at a constant depth of 1metre.

2.2.4 Temperature, Conductivity and pH*:* Measurements for temperature and pH were made using a portable Jenway Model 3071 (-30±150°C) meter. Conductivity was measured with a probe using a portable Jenway Model 4070 (0-2000μS) electrode.

2.2.5 Water transparency*:* Water transparency was determined by the extinction of a 20cm diameter Secchi disc. Secchi depth is the depth at which the disc vanishes and this occurs when irradiance is approximately 15-20% of the incidence radiation.

2.2.6 Wind*:* Wind direction was determined using a hand held wind vane. By holding the vane from a stationary boat the wind direction was noted.

2.2.7 Sediments: Were collected using an Ekman grab. Three samples were collected from each site and put in separate plastic bags.

2.2.8 Submerged macrophytes*:* The rake-sampling method developed by Jessen and Lound (1962) was utilized in sampling of submerged macrophytes. In eutrophic lakes, submerged vegetation will rarely occur beyond 10 m depth because of low water transparency (Wetzel, 1983). Lake Naivasha is classified as a eutrophic lake (Njuguna, 1982). Thus, sampling was limited to the 0-4.5 m depth zone. To avoid bias during sampling, the 0-4.5 m depth zone was divided into three zones. Hence, sampling depth zones were: 0-1.5 m, 1.5-3 m and 3-4.5 m. Figure 2.1 below illustrates how the zones appeared from the shoreline to the 4.5 m depth.

A sampling point was randomly located in each depth zone along each transect. At each sampling location/depth zone an aquatic weed rake was dragged along the lakebed to

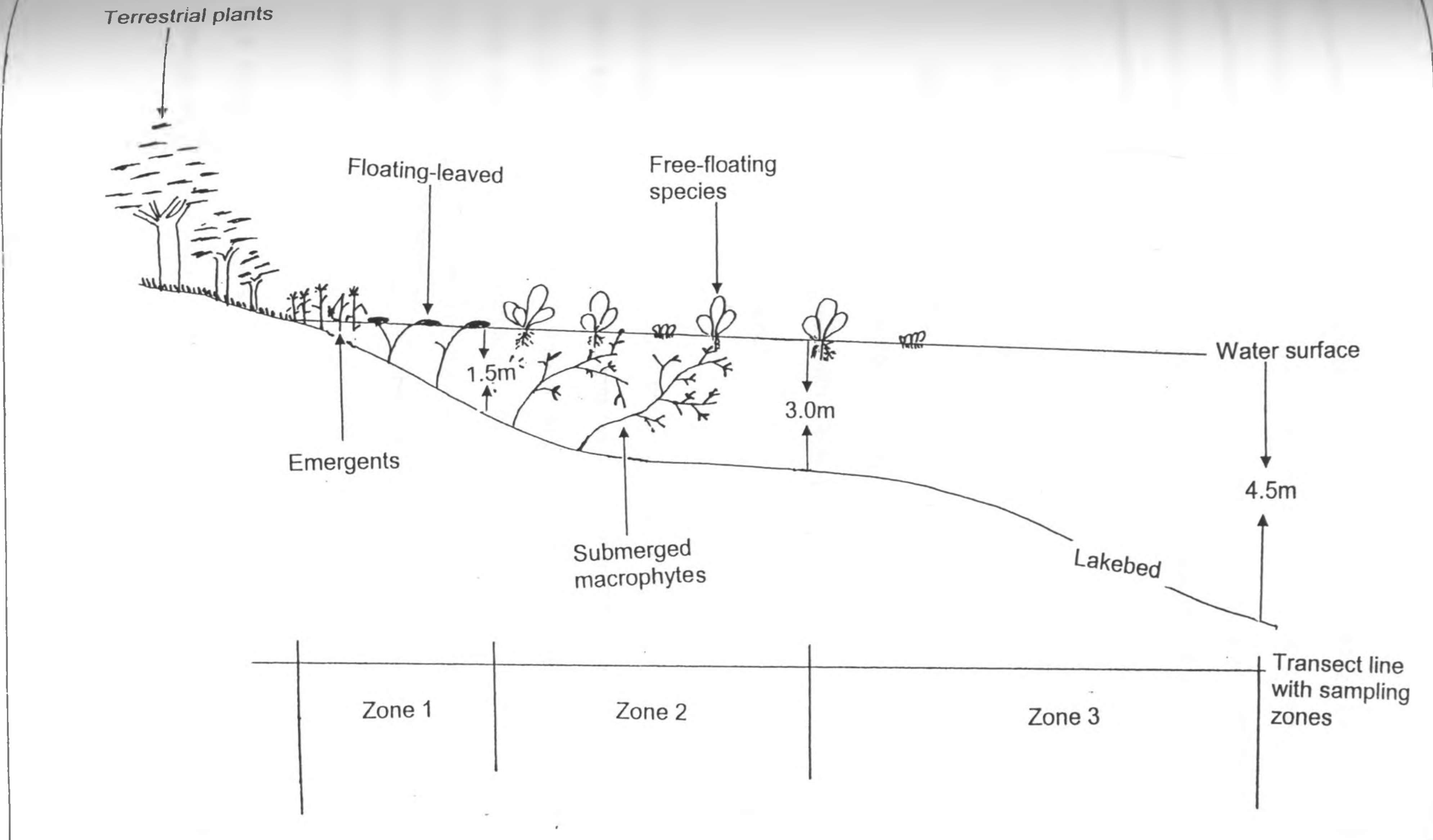

Figure 2.1. Diagram showing sampling zones along a transect.

sample the submerged macrophytes as per Jessen and Lound (1962). Four rake samples were taken at each sampling zone. The aquatic plant species present on each rake sample were recorded. The species recorded included aquatic vascular plants and types of algae that had morphologies similar to vascular plants. The abundance of each species was represented as percentage frequency, i.e.,

$$Pf_{sp} = \frac{R_{sp}}{R_{total}} \times 100 \text{ -------------------------------(iii)}$$

where

Pf_{sp} = Percent frequency of a species;

R_{sp} = Number of rakes with species; and

R_{total} = Total number of rakes.

Visual inspection and random sampling were done between transect lines in order to record the presence of any species that did not occur at the established sampling sites. Specimens of all plant species present were collected and pressed in a plant press for further identification in the herbarium. Although aquatic rakes can be biased against macrophytes that can slip through the tines of the rake, they are effective methodologies especially when consistency is to be observed. For this reason, this methodology was used in all sampling occasions.

2.2.9 Floating macrophytes*:* Sampling of floating vegetation was carried out using quadrats at the eight sample sites. Within an area measuring 10 by 30m, 1 by 1m quadrats were thrown randomly six times and the species present recorded, that is, both the floating and associated species.

2.2.10 Lake bed gradient: To get the gradient of lake bed or a sample transect line, the distance between a particular depth and the shore was determined using a hand held GPS unit. The depth of a sample point was measured using a graduated rope onto which a weight was attached. The gradient was computed as:

$$G = \frac{D}{SH} \text{ ----------------------------------(iv)}$$

where,

G = Gradient of lake bed;

D = Depth; and

SH = Distance from the shore.

2.3 Laboratory Analyses

2.3.1 Nutrients

2.3.1.1 Nitrogen compounds

Ammonium nitrogen

Most of ammonia in fresh water exists in the ionic form (NH_4^+). A phenol-hypochlorite method using nitroprusside as a catalyst is recommended for the measurement of ammonium in water (Solorzano, 1969; Harwood & Kühn, 1970). Hence, phenolhypochlorite method according to Wetzel and Likens (1991) was adopted for analysis of ammonium in this study.

Nitrate and Nitrite

By far the best method for analysis of NO_3-N in water is to reduce the nitrate in alkaline-buffered solution to nitrite by passing the sample through a column of copper-cadmium metal filings (Wood *et al.,* 1967). Nitrate was analysed on filtered water samples run through a reduction copper-cadmium column and then the resultant nitrite was measured by the sensitive diazotization method according to Lenore *et al.* (1989). Nitrite concentration of the original sample was determined prior to reduction of NO_3 to NO_2 by the same diazotization technique. The concentration of NO_3-N was then calculated by subtracting the concentration of reduced NO_3 from NO_2 determined prior to reduction from the same sample.

2.3.1.2 Phosphorus compounds

Soluble reactive phosphate-phosphorus (PO_4-P)

This biologically available form of phosphorus was analysed from a filtered water sample using Whatman GF/C glass-fibre filter paper. The analysis followed the method after Mackereth *et al.* (1978) where filtered water was allowed to react with a composite reagent of molybdate, ascorbic acid, and trivalent antimony. The molybdic acids formed are then converted by reducing agents to a blue-coloured complex. Colour intensity is directly proportional to the phosphate content. Concentration of phosphate was then determined calorimetrically.

Total Phosphorus (TP)

Total Phosphorus determination followed the potassium persulphate digestion of unfiltered water sample for 1 hour at 1.03×10^4 Nm^{-2} (1.5 p.s.i) in an autoclave (Mackereth *et al.*, 1978). The method used on the soluble reactive phosphate described above was used to analyze for phosphate in the digested sample.

2.3.2 Soil texture analysis

Texture analysis involves getting the relative proportions of sand, clay and silt. Based on the proportions of different particle sizes a soil textural category maybe assigned to the sample. Categorization of soil particles was as: sand (2.00-0.05), silt (0.05-0.002) and clay (<0.002). The first stage in particle analysis was the dispersion of the soil sample into individual soil particles. This is because soil particles are often bound into aggregates hence the requirement for dispersion using a dispersing agent. The hydrometer was then used based on Stokes Law, that is, the settling velocity of a particle is proportional to the square of its radius (Bouyoucous, 1962). The settling velocity is also a function of liquid temperature, viscosity and specific gravity of the falling particle. Therefore corrections were made for the temperature of the liquid.

2.4 Data Analysis

2.4.1 Variations and comparisons between parameters

Variations and interdependences among different parameters were assessed by Analysis of Variance and correlation coefficients respectfully by using Minitab for windows version 13.20-computer program.

2.4.2 Multiple regressions

Multiple regression is a statistical tool, which has two main functions. One is to establish a linear prediction equation that can enable a better prediction of a dependant variable than would be possible by a single independent variable. Typically, the researcher aims at a subset of all predictor variables that explains a significant and appreciable proportion of variance of the dependant variable, hence, sometimes wading off the cost of measuring more predictors that may not be necessary. In this study, regression analysis was used to identify the important environmental variables that possibly affected the distribution and abundance of aquatic plants encountered during the study. The second purpose of multiple regression is to estimate and fit a structural model to “explain” variation in the observations of the dependant variable in terms of independent ones. Among a set of putative *casual variables* the ones that affect the dependant variable significantly and appreciably and the estimates of the relative magnitudes of the contributions of the independent variables are sought.

On performing a regression, the predictor equation that is obtained can either be presented in conventional or standardized form. In standardized form, multiple regression equation is given as

$$\mathbf{Y^1=b^1y_1.X_1+\text{-------------}+by^1{}_k.X^1{}_k} \text{ -------------------------(V)}$$

Where, Y=the dependant variable

X_k=K^{th} independent variable

b^1y_1=standard partial regression coefficient.

One advantage of standard partial regression equation over the conventional one is that it gives the standard partial regression coefficient. The standard partial regression coefficient enables the researcher to compare directly the relative standardized strengths of the effects of several independent variables on the same dependant variable. This eliminates the effect of differences in measurement scale for different independent variables. Standard partial regression coefficient express the average change in standard deviation units of dependent variable, Y, for one standard deviation unit of each independent variable, X, the other one(s) being kept constant. Since standard partial regression coefficients are free of the original measurement scale, unlike in conventional regression equation, they were used to estimate the relative importance and influence of each of the independent variables on dependent ones considered in the study.

To determine the subsets that apparently explained most of variation in vegetation data, Best Subsets Regression was carried out (Sokal & Rohlf, 1981). Best subsets regression generates regression models using the maximum R^2 criterion by first examining all one-predictor regression models and then selecting the two models giving the largest R^2. Best Subsets is an efficient way to select a group of "best subsets" for further analysis by selecting the smallest subset that fulfills certain statistical criteria. The subset model may actually estimate the regression coefficients and predict future responses with smaller variance than the full model using all predictors (Hauck & Donner, 1977). For the regression analyses, Minitab and Statistica versions 13.20 and 6.0 (for windows), respectfully, computer programs were used.

CHAPTER 3: RESULTS AND DISCUSSION

3.1 Environmental Factors

3.1.1 Water transparency

Lake Naivasha is a turbid lake with low water transparency. Secchi depth measurements were below 100cm in all stations located in the Main Lake and they did not exceed 150cm at the Crescent Island Lake sampling station situated in the Crescent sub basin. Crescent Island Lake sampling site had the highest readings with a mean of 120±7.9cm and the lowest was Central Landing Beach (21.9±3.2cm). The rest of the stations had intermediate average Secchi depth readings. Spatial variation of water clarity differed significantly (one-way ANOVA: $F_{7, 40}=51.91$; $p<0.05$). Crescent Island Lake site differed significantly from all the other stations. Mean Secchi depth readings for various stations in Lake Naivasha are shown in Figure 3.1. During the study period, the water clarity monthly variation was not significantly different as for the spatial variations. Mean monthly Secchi depth variation is shown in Figure 3.2.

Water transparency is one of the environmental variables that determine plant species distribution and abundance in water bodies. Apparently, there is a lower measure of water transparency in the Main Lake basin than the Crescent basin. Waters in sites that are located to the northern part of the lake generally have more turbidity than those that are in the other parts of the lake. This can be attributed to the effect of the feeder rivers bringing

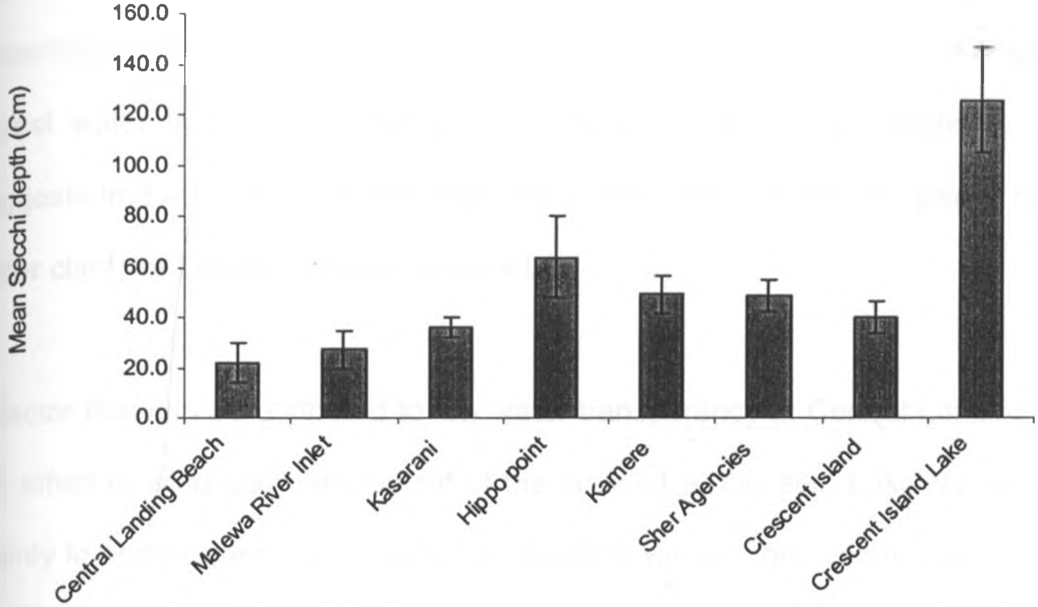

Figure 3.1: Mean spatial Secchi depth variations at various sampling stations in Lake Naivasha (February-July, 2003). The vertical bars indicate standard errors of means.

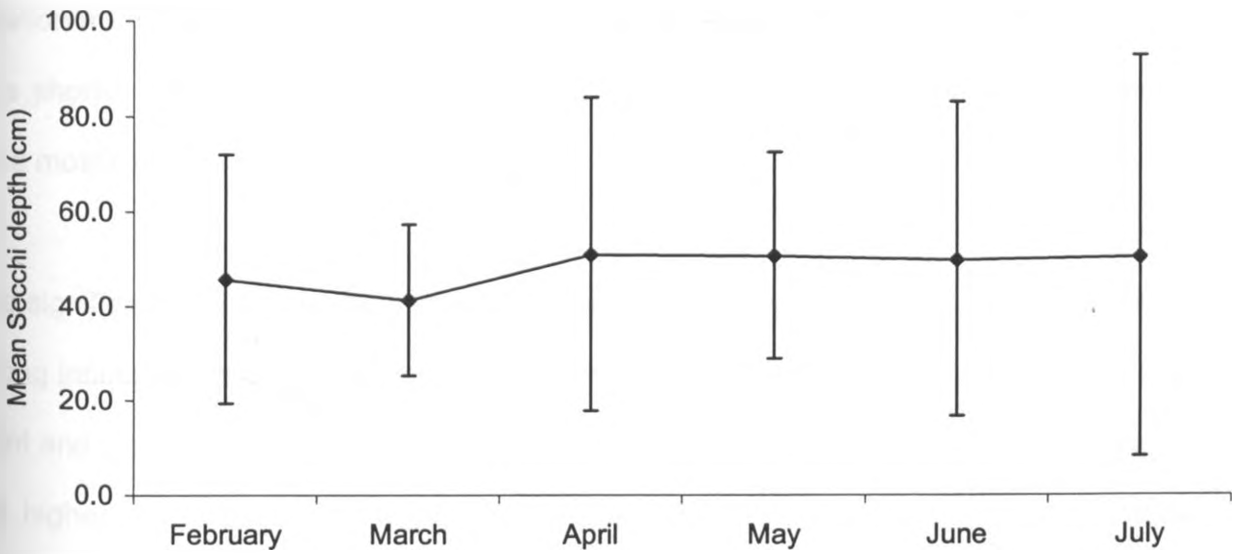

Figure 3.2: Mean monthly Secchi depth variations in Lake Naivasha (February-July, 2003)

with them suspended material into the lake. Central Landing Beach site had the lowest water transparency. It was however expected that, Malewa River Inlet site would have the lowest water transparency due to its close proximity to River Malewa. This anomaly suggests that apart from the influence of the river, other factors also play a role in the poor water clarity of Central Landing Beach site.

A factor that can be attributed to low water transparency at Central Landing Beach site is the effect of wind and the gradient of the lakebed at this site. Lake Naivasha is exposed mainly to southeasterly and southerly prevailing winds. This means that, there is a mixing effect of water by wind and, hence, areas that are gently sloping or shallowest will be affected most. In the process, re-suspension of sediments will be a recurrent phenomenon leading to low water transparency in such places. Central Landing Beach site would also experience stronger winds than Sher Agencies, for example, since the latter occurs at a location from the direction the wind comes. This has an impact of exposing Sher Agencies to a shorter fetch than Central Landing Beach, which is located in the direction that the wind mostly blows.

The significant and strong correlation between water transparency and soil texture imply a strong influence on this water parameter by the nature of substratum. Sites such as Hippo point and Crescent Island Lake had substrata that were sandy and at times rocky and had the highest water transparency readings. Conversely, sites Kasarani, Central Landing Beach, Kamere, Sher Agencies and Crescent Island had silty/clayey substrata, hence had comparatively low water transparency. Being denser than silt or clay, sandy particles tend to settle to the bottom faster than the former, hence leaving the water clear.

The transparency of the water of Lake Naivasha has reduced tremendously over the years. Secchi depth measurements ranged between 370cm and 570cm in late 1970s in the Crescent Island Lake (Litterick *et al.*, 1979). This reduced to between 30cm and 150cm in 1995 (Christine, 1995). The present study has revealed a further drop in water clarity with Crescent Island Lake recording an average of 125 cm Secchi depth reading, the highest recorded in the whole of Lake Naivasha. Transparency varied between 100cm and 150cm in late 1970s, but has dropped to between 12.5cm and 97cm in the Main Lake according to the findings of the present study.

The fall in water transparency in Lake Naivasha can be attributed to changes that are taking place in the catchment of the lake. The agricultural land, which has been put under active farming, has increased with a rise in population. There has been wanton tree felling in the forests where the main River Malewa draws its water to Lake Naivasha (Gitahi, pers. comm). These activities have an impact of increasing the soil load transported down to the lake through run off, hence increased poor water clarity.

3.1.2 Nutrients

Phosphorus

Two different forms of phosphorus were investigated in the present study. These were soluble reactive phosphorus and total phosphorus. Concentrations of the two forms are shown in Figures 3.3 and 3.4. Highest mean levels of soluble reactive phosphorus were registered at Malewa River Inlet sampling site. A concentration mean of 29±6.9μgL^{-}1 was recorded at Malewa River Inlet while Crescent Island Lake site had the lowest mean of 15±3.6μgL^{-1}. However, there was no significant difference in mean concentrations of soluble reactive phosphorus in the eight stations (one-way ANOVA: F_7, 40=1.23; p>0.05).

The mean monthly concentrations of soluble reactive phosphorus ranged between 9 and 38μgL^{-1} and were significantly different. Malewa and Central Landing Beach stations had the highest concentration of total phosphorus with 159±74μgL^{-1} and 173±88μgL^{-1} respectively. Crescent Island Lake site had the lowest concentration of total phosphorus with 50±27μgL^{-1}. The seasonal variation exhibited by the two forms of phosphorus was similar (Figure 3.4). Both forms increased in concentration in the rainy months of May to July except that total phosphorus showed an overall increase, which was more than that

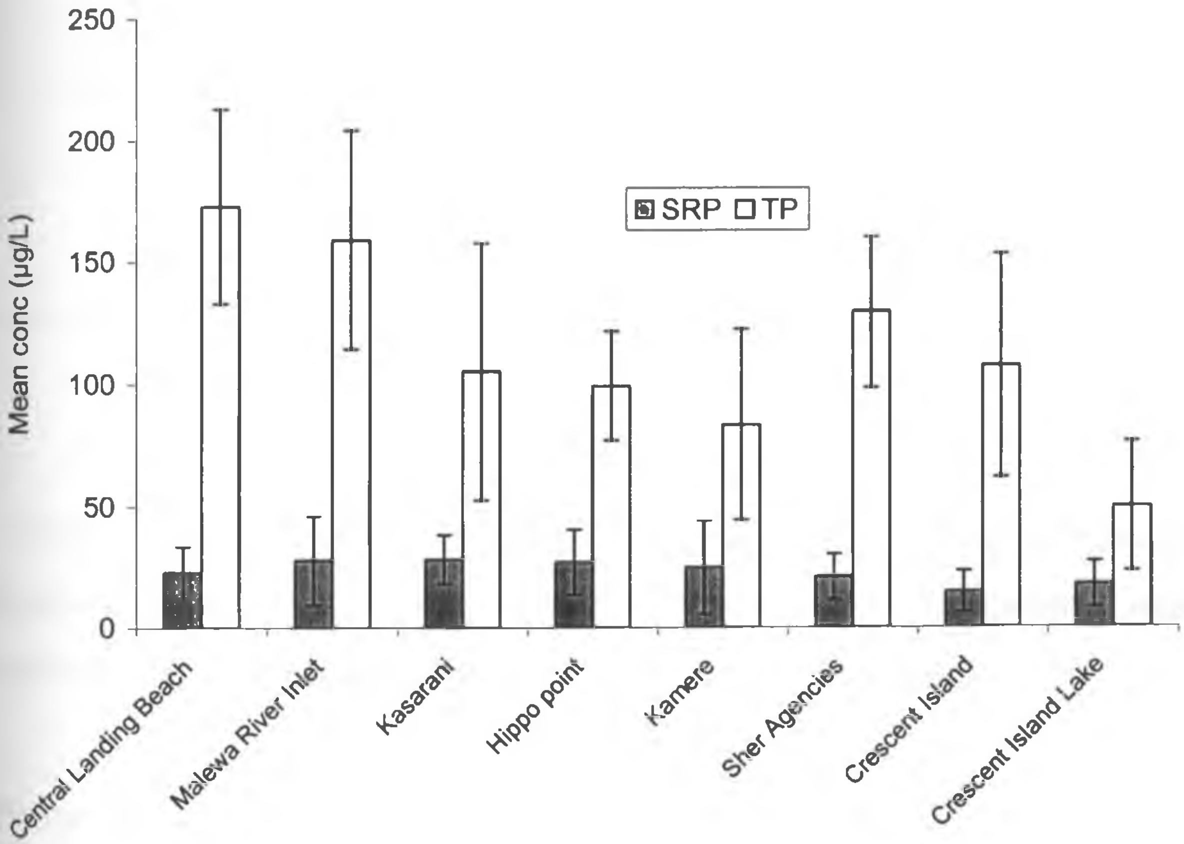

Figure 3.3: Mean spatial concentration of total phosphorus (TP) and soluble reactive phosphorus (SRP) in Lake Naivasha (March-July, 2003).

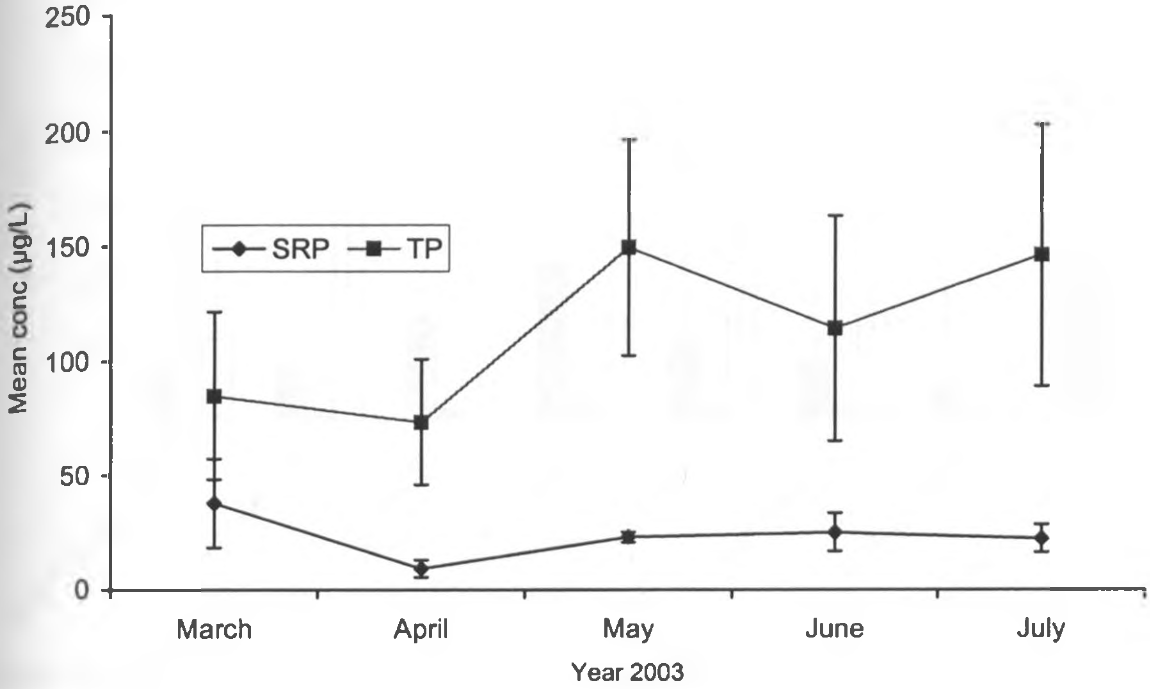

Figure 3.4: Mean monthly concentration of total phosphorus (TP) and soluble reactive phosphorus (SRP) in Lake Naivasha (March-July, 2003

of soluble reactive phosphorus. This was possibly so because the run off brought in phosphorus bound in the suspended material that had not been decomposed to release soluble reactive phosphorus by the time this study was being completed.

Nitrogen

Three forms of nitrogen were investigated. These were: nitrates, nitrites and ammonia. Spatial and temporal concentrations of the three forms of nitrogen are shown in Figures 3.5 and 3.6 respectively. The mean concentration of ammonia

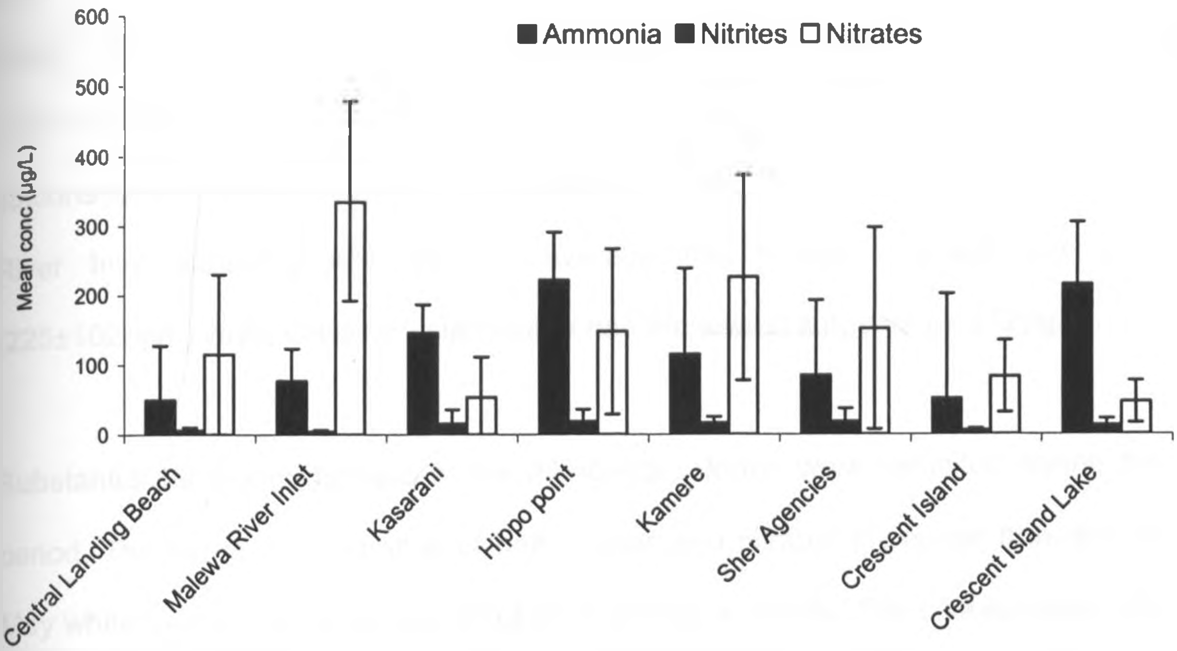

Figure 3.5: Spatial concentration of ammonia, nitrites and nitrates at various sampling stations in Lake Naivasha (March-July, 2003).

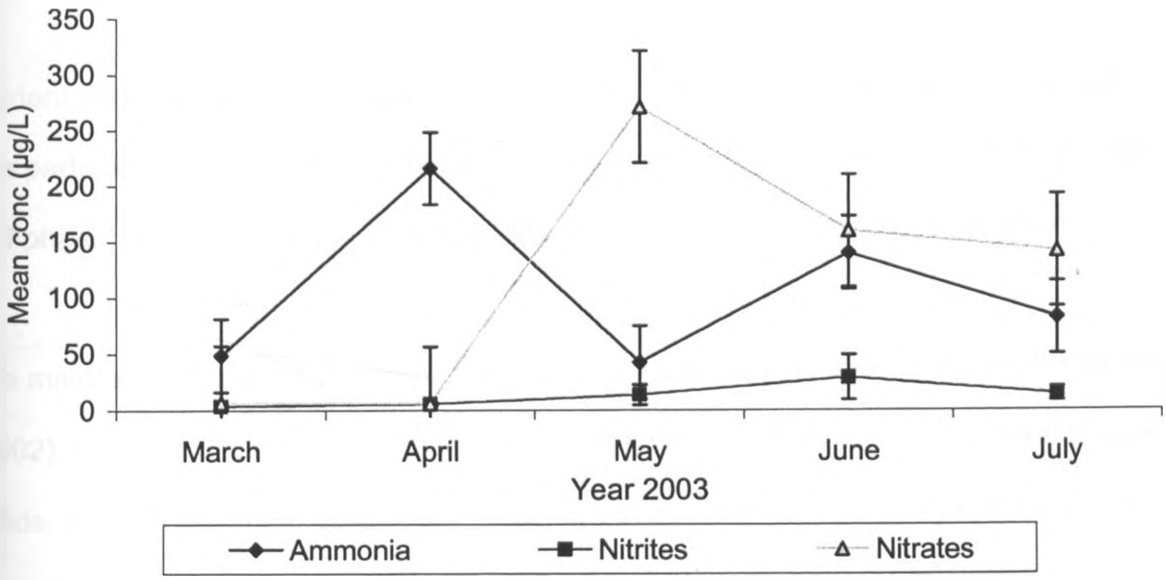

Figure 3.6: Mean monthly concentration of ammonia, nitrites and nitrates in Lake Naivasha (March-July, 2003).

was highest at the Hippo point sampling site whereas Central Landing Beach had the lowest. Mean concentration of nitrites remained generally lower than ammonia and nitrates in all stations. However, there was no significant difference in concentration between the stations for the three forms of nitrogen. Malewa
River Inlet sampling site had on average the highest concentration of nitrates (225±102µg/L) while Crescent Island Lake had the lowest amounts (34±12µg/L).

Substantial temporal changes in the nitrogenous forms were exhibited during the study period. The mean concentration of both nitrites and nitrates increased from the month of May while that of ammonia was reduced in the same month. The concentration of nitrates from the month of May remained above that of both ammonia and nitrites. Both nitrates and nitrites increased significantly over the May-July period (one-way ANOVA, $p<0.05$).

Nutrient availability has a strong influence on the kind and abundance of vegetation found in a particular habitat. Nutrient fractions considered in the present study were nitrogenous and phosphorus compounds which are the most important in aquatic ecosystems.

The main source of allochthonous material to Lake Naivasha is River Malewa. Kitaka *et al.* (2002) reported a strong relationship between total phosphorus and the total suspended solids. In Malewa River, suspended sediment increased with discharge. Most phosphorus was bound into suspended solids because most of the phosphorus is particulate. The loss of phosphorus from the catchment of Lake Naivasha has been reported to be 0.2 $kgha^{-1}$ yr^{-1}, 76% of it particulate in a 'normal' year of wet and dry periods (Kitaka *et al.*, 2002).

Kitaka *et al.* (2002) also noted a strong relationship between suspended solids and total phosphorus, hence, the strong and significant correlation ($p<0.05$, Pears. Corr. =0.447) between the water transparency and total phosphorus in the present study. This relationship can therefore be used to explain the observation that Malewa River Inlet and Central Landing Beach sites which recorded lowest readings had consequently higher concentrations of total phosphorus than the rest of sample sites. Another reason for the occurrence of high total phosphorus concentrations at Central Landing Beach site could be the input of raw sewage/wastewater from Naivasha Municipality into the lake at a point near Central Landing Beach site (Gitahi, pers. comm.).

Phosphorus is low in Kenyan soils and is commonly the primary limiting nutrient (Hinga, 1973; Nyandat, 1981) in farmlands. It is lost from cultivated land mainly in particulate form through run off to find its way into lakes. The phosphate adsorption capacity is dependent on the particles' surface area and on their content of hydrated metal compounds (Fe, AL, Mn). Most particles with these suitable characteristics are clay particles (Viner, 1975). Their iron content depends on particle size and a strong relationship exists between available phosphorus, iron content and the size of different clay fractions (Viner, 1975.). The significant and positive correlation between the proportion of either clay or silt in soil sample and total phosphorus can be as a result of the above explanation. Therefore, sample sites that had high amounts of clay or silt had correspondingly high amounts of total phosphorus. Such sites were Malewa River Inlet, Central Landing Beach and Sher Agencies. On the other hand, sample sites such as Hippo point and Crescent Island Lake with low amounts of clay/silt (or high amounts of sand) had low concentration of total phosphorus.

The amounts of soluble reactive phosphorus during the study remained lower than that of total phosphorus and the two were not significantly correlated. Soluble reactive phosphorus is a form of phosphorus that is readily available for biological utilization. Soluble reactive phosphorus may therefore be assimilated rapidly by the biota, which includes algae and bacteria, hence, the concentration of soluble reactive phosphorus at any given time is usually low in the trophogenic zone of fresh water (Lean, 1973). This may explain lack of correlation between soluble reactive phosphorus and total phosphorus and lack of any significant difference of soluble reactive phosphorus between the eight sample sites. However, the estimations of total phosphorus in aquatic system may give an indication of maximal or potential supply of soluble reactive phosphorus irrespective of its biological utilization (Talling, 1966).

The major nutrient input in Lake Naivasha is due to riverine transport, with flow and nutrient load regulated by season and anthropogenic factors (Kitaka *et al.*, 2002). Both sediment bound and soluble nutrients are transported into the lake by river water. The seasonal rivers (Gilgil and Karati) are also important in transport of the nutrients. However, the amount they contribute may be more than that of Malewa due to concentration of materials in the two rivers. Phosphorus is transported bound to sediment particles with the Malewa River as the main source of sediment input due to upstream erosion especially during high rainfall–erosivity periods. Hence, the increase of soluble reactive phosphorus and total phosphorus concentrations during the rainy seasons.

The riparian farming that takes place around the lake could be contributing to nutrient supply into Lake Naivasha. During the rains it is possible that, run off from the farms which are applied with artificial fertilizers carries nutrients that find their way into the lake. The ditches (pers. observ.) that drain waste water from the residential houses could have nutrient elements hence contributing to the lakes nutrient load. The Sher Agencies sample site was situated next to the area where many farms are located. The site had high amounts of total phosphorus though it experienced minimum or no influence from the rivers. The high amounts of total phosphorus could be an indication that the farms also play a role in supply of nutrients into Lake Naivasha.

Nitrate concentrations were highest at Malewa River Inlet sample site though they were not significantly different ($p>0.05$) among the sample stations. At Malewa River Inlet site, there is much inflow of suspended and dissolved material including runoff from livestock, which have been watered upstream. This is especially relevant during rainy periods when high water levels flush collected material downstream. Kamere site also recorded high concentrations of nitrates. This site was located near a public entry point into the lake. Domestic activities such as washing and watering of animals take place here (pers. observ). These activities could be contributory factors to the elevated amounts of nitrates.

Ammonium is an important source of nitrogen for bacteria, algae, and lager plants in lake and streams. Since nitrate ion (NO_3^-) must be reduced to ammonium ion (NH_4^+) before it can be assimilated by plants, ammonia is an energy-efficient source of nitrogen for plants. Among the blue-green algae, highest growth rates have been reported to occur with NH_4^+ as the nitrogen source at many different light intensities (Ward & Wetzel, 1980a, 1980b). Distribution of ammonia in freshwaters is highly variable regionally, seasonally, and spatially, within lakes and depends upon the level of productivity of the lake, and the extent of pollution from organic matter. While generalizations are difficult to make, the concentrations of NH_4-N are usually low in well oxygenated waters. In the trophogenic zone, NH_4-N is rapidly assimilated by algae and represents the most significant source of nitrogen for the plankton in many lakes (Liao and Lean, 1978).

Nitrites are intermediate products which occur during transformations between more stable compounds such as gaseous nitrogen into nitrates and *vice versa*. The nitrites are liable to physical and heterotrophic oxidation, and are usually found only in significant quantities relative to other forms of combined nitrogen (Baxter, *et al*, 1973). Nitrite is relatively short-lived in water because it is quickly converted to nitrate by bacteria during nitrification process. Amounts of nitrite are further lowered when it is converted into ammonia during the process of denitrification by fungi and bacteria (Wetzel, 1983). These reasons are possible causes that made the amounts of nitrite to be below those of both ammonia and nitrates in almost all instances.

3.1.2.1 Importance of draw-down and littoral zone in nutrient dynamics

The slope of the lake bed and concentration of total phosphorus were observed to be negatively and significantly correlated in the present study. Therefore, higher total phosphorus concentrations were found in the sites where the gradient of the lake bed was low. This observation can be explained partly by the occurrence of a large draw-down in such areas as Central Landing Beach, Malewa River Inlet and Sher Agencies which had low lake bed gradient. Areas with low gradients afford large draw-down as opposed to areas with steep lake bed e.g. Hippo point and Crescent Island Lake sample sites.

The importance of draw-down in relation to nutrients regeneration has been reported in several shallow African lakes (Gaudet & Muthuri, 1981; Howard–Williams & Lenton, 1975; MacLachlan, 1971). Gaudet and Muthuri (1981) noted the mud in the shallow areas of Lake Naivasha to have a large reserve of nutrients. These nutrients are released to the overlaying water after flooding on onset of rains. During the dry season, the hydrosoil in the draw-down area of the lake edge is exposed, resulting in dried, cracked and aerated soil. Within the draw-down, the soil is sometimes enriched by dung deposited by cattle and hippos grazing and trampling the draw-down flora.

During the process of inundation, or rising lake level, the decomposed organic material, dung and previously oxidized aerated soils release large amounts of nutrients. Released nutrients could eventually be transferred from the littoral waters to the open lake by wind, animal migration or drifting of floating macrophytes (plant migration). This phenomenon apart from contributing to may be linked with the observed increase of nutrients during the wet season in Lake Naivasha.

The littoral zone of Lake Naivasha has been described as a very important component of the lake in nutrient studies. According to Gaudet (1977), the littoral zone has a large stock of nutrients, which can be used in replenishment of open waters. The zone was once described as a 'nutrient kitchen' for the lake (Gaudet & Muthuri, 1981). Muthuri (1985) attributed the high amounts of nutrients, for example phosphorus, in the swamp, to mineralization of the large amount of organic matter in the swamp. He further noted that, phosphorus concentration increase in the open waters during high lake levels was partly as a result of flooding of the swamp by rising lake level.

Melack (1976) and Gaudet (1977) reported that, the standing stock of dissolved phosphorus and nitrogen in the Main Lake was larger than the input concentrations from River Malewa. This observation was attributed to inputs through seepage and nitrogen fixation in papyrus swamps. Seepage accounted for about 70% of the nitrogen and 40% of phosphorus inputs to the open waters, even though the North swamp has been described as a 'phosphate pump' (Gaudet, 1978). Atmospheric fallout contributed 2-8% of nitrogen and 7-23% of the phosphorus inputs to the lake (Njuguna, 1982).

The increase in concentration of phosphorus and decrease of NH_4^+ was observed on onset of rains. Previous studies (Peters & MacIntyre, 1976; Anon, 1978; Njuguna, 1982) on growth of phytoplankton in Lake Naivasha have shown phosphorus to limit the growth of both phytoplankton and macrophytes. The increase of phosphorus in the water medium may have triggered the growth of plants and algae leading to accelerated uptake of NH_4-N as it is the most readily available source of nitrogen, hence, its decrease. NH_4-N is the preferred source of nitrogen by aquatic macrophytes and phytoplankton (Liao and Lean, 1978). The decrease of NH_4-N could have been also due to its enhanced conversion into either nitrogen or nitrates by the de- or nitrifying micro-organisms on availability of more growth resources.

3.1.3 Prevailing ground level winds over Lake Naivasha

The overall wind direction over the period of six months is illustrated in Figure 3.7. The percentage value is equivalent to frequency of wind to each direction. Wind was mostly southeasterly (51%) and southerly (27%) with a proportion of 15% blowing to the west. The prevailing winds over Lake Naivasha have been described as a very important physical factor that influences physical, chemical and biological functions of Lake Naivasha (Nils Tarra's-Wahlberg, 1975). In tropical lakes, circulation is a balance between wind induced mixing and stabilizing action of solar radiation. If temporary stratification

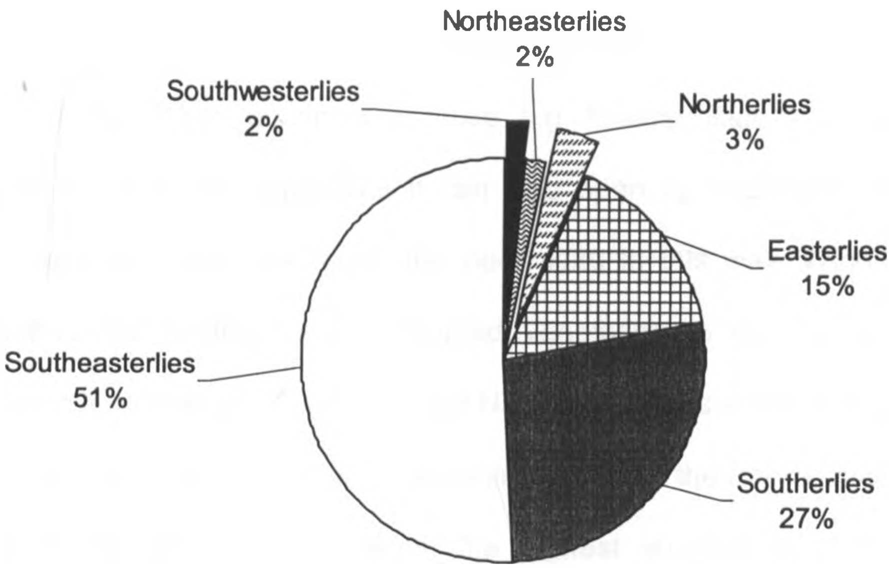

Figure 3.7: Prevailing ground level wind direction over Lake Naivasha (February-July, 2003).

occurs, its stability is proportional to the thermal gradient. In shallow freshwater, a lack of prolonged stratification reduces accumulation of solutes in deeper waters. This decompartmentalization of dissolved material has a possible advantage of availing the submerged macrophytes with a nitrogen source. It is the wind action that may have partly ensured insignificant differences among sampling sites as far as nutrient content was concerned in the lake water.

Wind also causes sediment turbulence leading to sediment water interactions and a daily cycle of change is prevalent for many physical-chemical conditions (e.g. temperature, oxygen and pH) and biological activities. Nutrient resupply from sediments will occur, but is likely to play a secondary role to replenishment of the limnetic nutrient pool by water column circulation as regulated by evaporative cooling and the persistence of monsoon winds (Talling, 1993).

Wind speeds greater than 3m/s with some reaching 11 km/h in the afternoon, are frequent in Lake Naivasha. Wind action can move big floating islands, which are normally composed of a variety of vegetation. It can also open up enclosed lagoons and make *Salvinia* as well as *Eichhornia* reach the open lake in this way. Wind blowing at such speeds pushes the floating and associated vegetation to various parts of the lake. However, since the direction of wind in Lake Naivasha follows a certain pattern as depicted in this study, its net effect would be to concentrate most of the free-floating macrophytes to a particular region of the lake. Hence, the highest abundance of the freely floating macrophytes was found to be the west and northern shores of Lake Naivasha.

The results of the present study on the wind direction were also reported by Hubble (2001). Wind direction is southwesterly to easterly throughout the year, becoming more southeasterly during periods of rain. Southeasterly winds bring rain from Indian Ocean and dominate November and December months. In the present study, southeasterlies, southerlies and easterlies dominated. They all constituted 93% of the total wind measurements carried out. This phenomenon had significant influence on distribution and abundance of floating macrophytes, as it will be demonstrated later.

3.1.4 Sediments

The soil textural characteristic of sediments was investigated for the established stations. Percentage composition of silt, sand and clay in the sediments is shown in Figure 3.8. Highest amounts of sand were found at Hippo point (93-97%) and Crescent Island Lake

(89-91%) while Kasarani site (10-27%) had the lowest proportion. The composition of soil samples was significantly different between the stations. Their proportions are shown in Table 3.1, which also shows ratios between sand, silt and clay for respective stations.

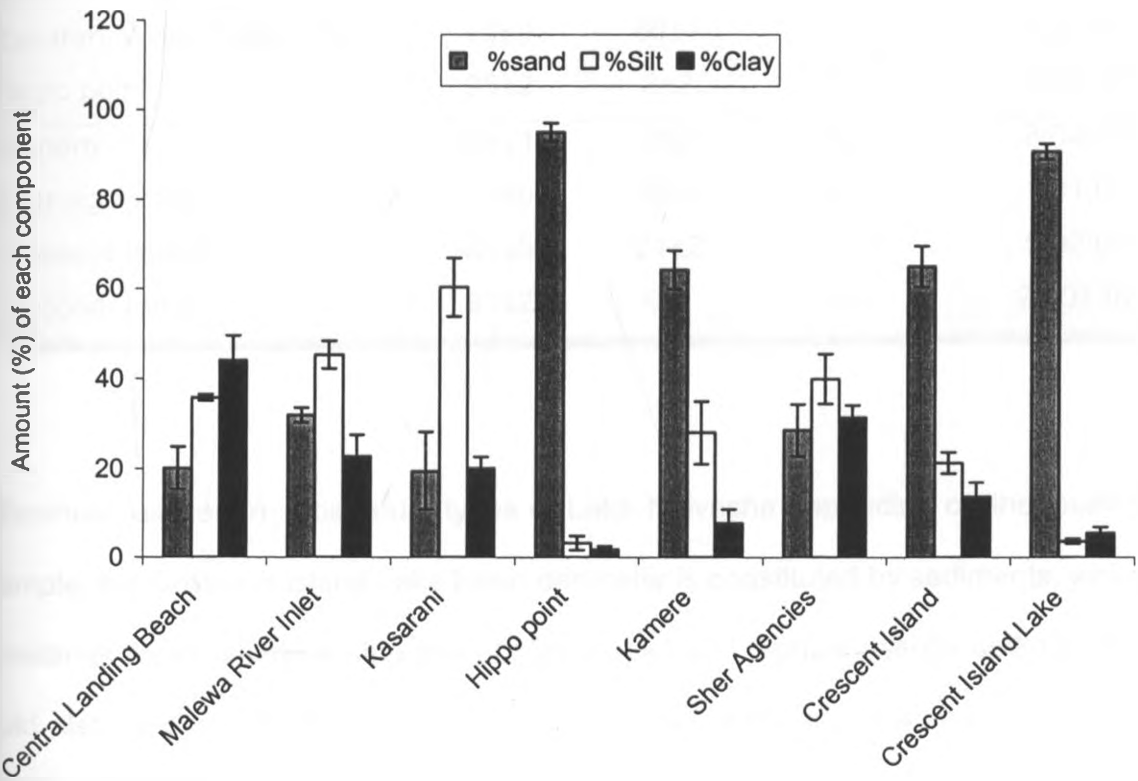

Figure 3.8: Sediment composition in various stations in Lake Naivasha (February-July, 2003).

Table 3.1. Proportions of sand, silt and clay and their ratios in sediments from various stations in Lake Naivasha.

Station	% Sand	%Silt	%Clay	Ratio: Sand:Silt:Clay
Central Landing Beach	20±5	36±1	44±5	1:02:02
Malewa River Inlet	32±2	45±3	23±5	1:02:01
Kasarani Water Intake Point	19±9	60±7	20±3	1:03:01
Hippo point	95±2	3±2	2±1	48:01:01
Kamere	64±4	28±7	8±3	8:04:01
Sher Agencies	29±6	40±6	31±3	1:01:01
Crescent Island	65±5	21±2	14±3	5:02:01
Crescent Lake	91±2	4±1	6±1	23:01:02

Differences existed in substratum types of Lake Naivasha depending on the location. For example, the Crescent Island Lake basin perimeter is constituted by sediments, which are sometimes rocky. Likewise, the site at Hippo point had primarily sandy sediments. Rocks could also be seen in the surrounding areas. Crescent Island Lake and Hippo point sites had the steepest lake bed slope and had sediments where sand was the biggest proportion in soil samples. Hence, sand and slope were positively correlated. The nature of the substratum appears to derive its characteristics from the geological forces that took place to form the steep landscapes. The riparian lands of the Crescent Island Lake and Hippo point sites were similarly steep and sometimes rocky meaning that the trend persisted into the lake.

There was a large difference between sediments in the West and the ones in the East of the Main Lake. Earlier studies (Clark & Baroudy, 1990; Christine, 1995) have shown that the debris of Papyrus and *Salvinia* leaves highly flocculated inorganic material, from North to West of the lake, while the eastern part is predominantly made of sandy and inorganic particles. The present study revealed that Kasarani site which was located in the northwestern part of the lake had loose sediments that were sometimes characterised by odour of decaying matter, an indication of the process of decomposition taking place. The same observation was made at Kasarani and Malewa River Inlet sites and the region between the sites during occasional sampling exercises. Such observations were reported by Clark and Baroudy (1990). Unlike Hippo point and Crescent Island Lake, other sites had a balanced composition of silt, sand and clay especially Sher Agencies site. Sher Agencies site was located in the southeastern part of the lake. The soils were basically muddy as silt was the highest soil textural component. Site Central Landing Beach had silt and clay as the principal textural components. The high amounts of clay were probably responsible for the hard mud that developed cracks during low lake levels. At Malewa River Inlet sample site, the silty fraction dominated the sediments. This was probably so because of the alluvial material brought in by River Malewa. According to Clark and Baroudy (1990) the most common substrate of the lake is mud softened by decomposing papyrus together with submerged macrophytes. The other rare types are the rocks found at Hippo point and some areas of Crescent lake basin and hard mud found in the northern and northeastern parts of the lake.

3.1.5 Conductivity and pH

Electrical conductivity is a readily and widely measured index of ionic concentration in the water. Measurements of conductivity are also used as an approximation of the total dissolved solids (Amarican Public Health Association, APHA, 1971). Lake Naivasha conductivity ranged from 80 to 390μScm^{-1}. Spatial and monthly variations are shown in Figures 3.9 and 3.10. Malewa River Inlet sampling site had the lowest mean conductivity (168±47μS/cm) while Crescent island Lake had the highest (317±15μS/cm). The more dilute water flowing from River Malewa may have contributed to low conductivity at Malewa site. Crescent Island Lake sample site experience little dilution effect from the major rivers hence, its high conductivity when compared to the other sites which were all located in the Main Lake basin. Conductivity was significantly different between the stations (one-way ANOVA: $F_{7, 40}=3.34$; $p<0.05$).

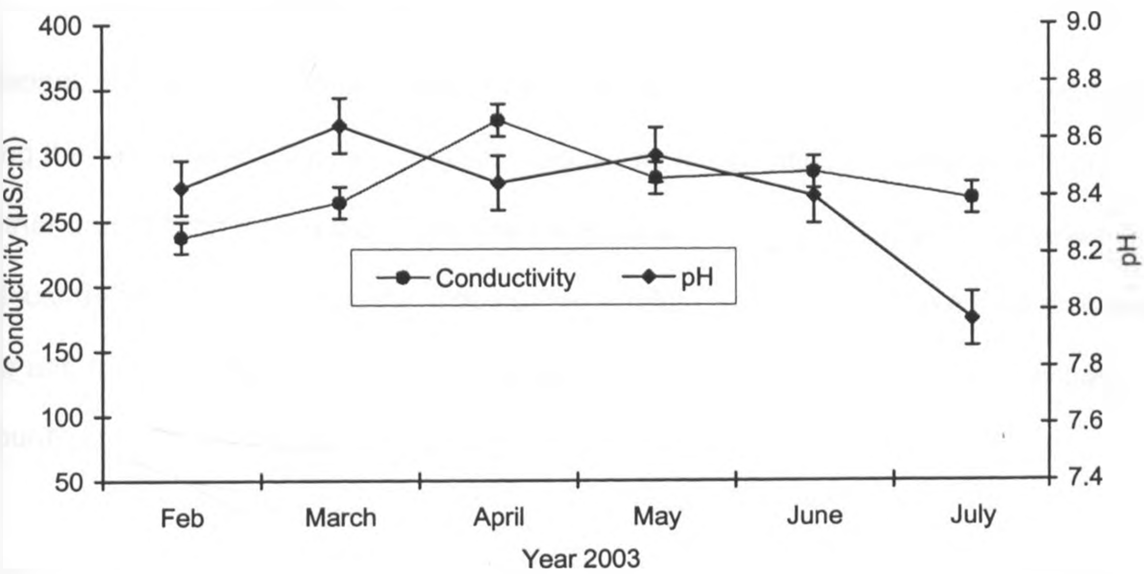

Figure 3.9: Monthly variations of pH and conductivity in Lake Naivasha (February-July, 2003).

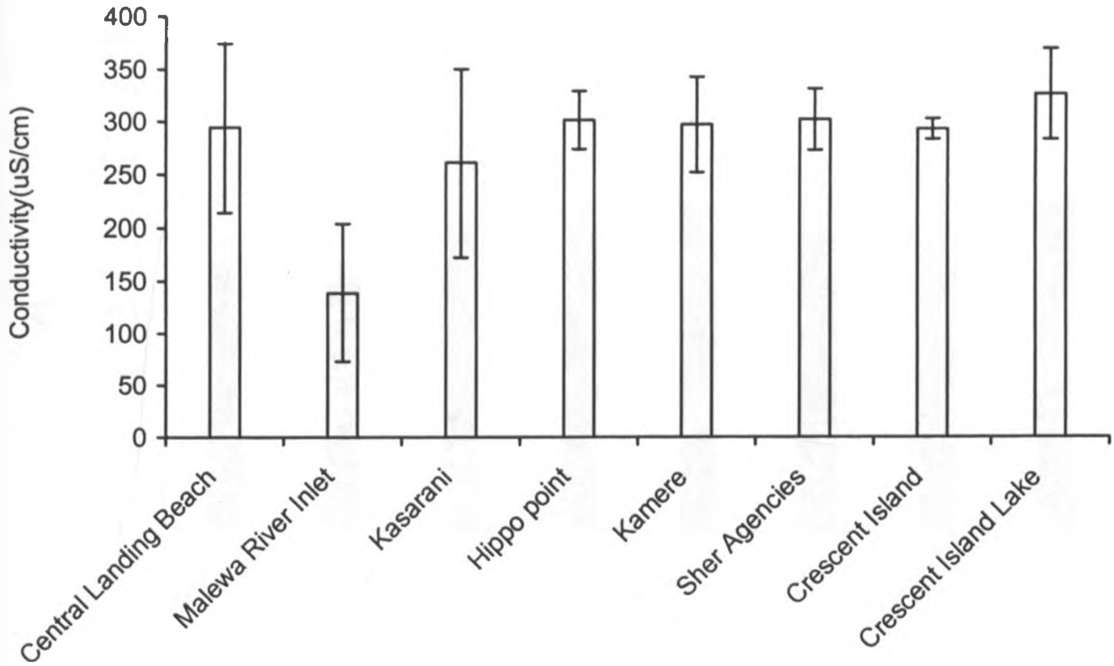

Figure 3.10: Spatial variations of conductivity in various stations in Lake Naivasha (February-July, 2003).

Seasonal changes show an increase in conductivity during the dry period and a decrease during the wet season. This is most likely caused by evaporative concentration in dry weather and dilution during the rains. The peak values of conductivity were observed in April just before the onset of rains. Influx of more dilute water into the lake through Malewa River and the two seasonal streams, Gilgil and Karati and also direct rainfall may have accounted for the low conductivity during the rainy period.

pH varied from 6.8 to 10.2 (Figure 3.11). Minimum pH values were recorded in the month of July when the lake level was the highest during the study period. The waters of Lake Naivasha are well buffered and no marked variation in pH was observed throughout the study period. However, pH at Crescent Island Lake site was significantly different from all

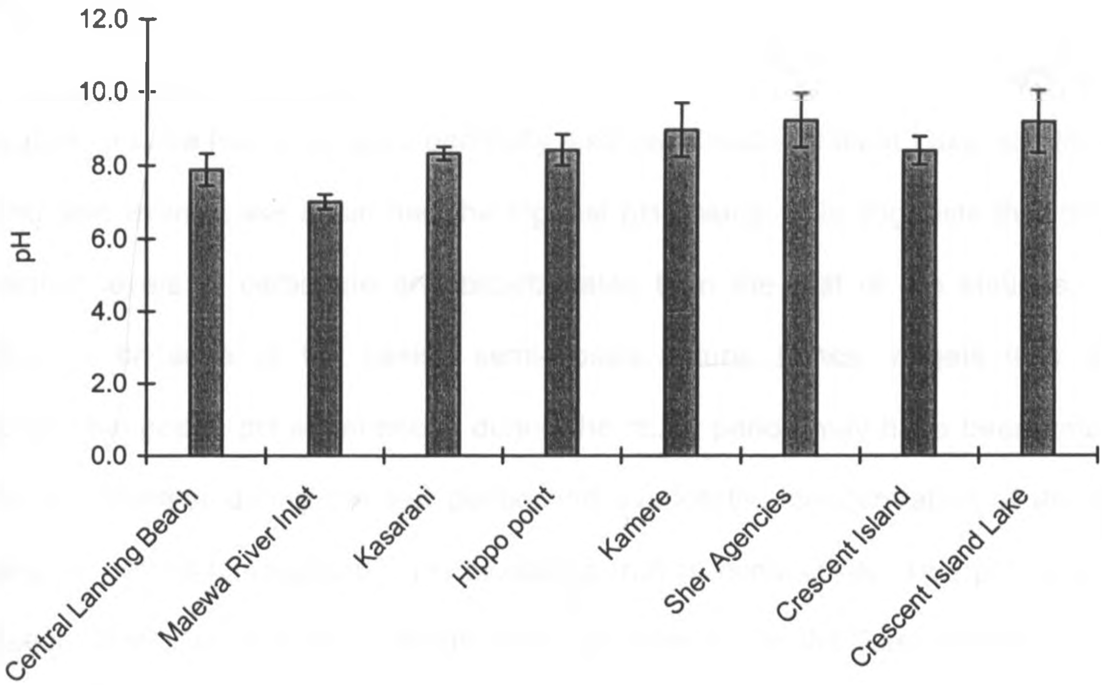

Figure 3.11: Spatial variations of pH in various stations in Lake Naivasha (February-July, 2003).

the other stations. Malewa River Inlet (7.0 ±0.1) sampling site had the lowest mean pH while Crescent Island Lake (10.8 ±1.1) had the highest. This variation may be attributed to the effect of run-off through River Malewa and the fact that the river water has little influence on the almost enclosed basin where Crescent Island Lake site was located.

The waters of Lake Naivasha are well buffered to major pH changes. The buffering capacity is attributed to the high amounts of bicarbonate ions in the waters. The buffering or neutralizing processes are of comparatively greater importance in closed and seepage lakes. Closed and seepage lakes have long periods of water renewal than they are in open drainage lakes. It is for this reason that the drainage lakes face severe problems of acidification (Hongve, 1978).

The waters of Lake Naivasha were generally alkaline. Crescent Island Lake site located in the Crescent Island Lake basin had the highest pH values. This suggests that the basin had higher levels of carbonate and bicarbonates than the rest of the stations. This is possibly so because of the basins semi-closed nature, hence, it gets less dilution. Seasonal changes in pH experienced during the study period may have been caused by dilution of rainwater during the wet period and evaporative concentration of the solutes affecting pH. Monthly variation in pH paralleled that of conductivity. This pH-conductivity correlation ($P=0.001$) has been documented as common in the East African Rift valley lakes and depends upon the predominance of bicarbonate and carbonate anions (Talling, 1965), which account for over 80% of the total anion.

Water conductivity is usually used as an indicator of ionic concentration and as approximate measure of total dissolved solids (APHA, 1971). The average conductivity range 138-303μScm^{-1} observed in the present study for the Main Lake stations compares with 220-297μScm^{-1} (Kitaka, 1992), 250μScm^{-1} (Lind, 1965) 208μScm^{-1} (Hecky & Kilham, 1973) and 259μScm^{-1} (Harper, 1987) which were taken during wet seasons. Studies have shown that conductivity measurements increase with decreasing lake level in Lake Naivasha. For example, 311-353μScm^{-1} (Melack, 1976), 400-445μScm^{-1} (Milbrink, 1977). 200-300μScm^{-1} (Mavuti, 1978), 300-350μScm^{-1} (Njuguna, 1982) and 350μScm^{-1} (Harper, 1987). In the present study, conductivity as high as 375μScm^{-1} in the dry period was observed in the Main Lake. Crescent Island Lake had on average higher conductivity than the Main Lake. Conductivities of 270-369μScm^{-1} were recorded in the Crescent Island

Lake. Harper, (1987) recorded 359 μScm^{-1} for the Crescent Island Lake while Kitaka (1992) observed the conductivity to range between 280 μScm^{-1} and 390 μScm^{-1}. Lind (1965) recorded 250μScm^{-1} in the same locality in 1965.

In general, seasonal changes of conductivity show an increase during the dry seasons and low water levels and decrease during the wet seasons and high water levels. This shows that conductivity is affected by dilution during high water levels owing to influx of dilute water from direct rain water, seepage and run off. This is probably the reason why Malewa River Inlet site recorded the lowest conductivity. Melack, (1976) recorded as low as 88 μScm^{-1} in 1973 and 72μScm^{-1} for Malewa and Karati Rivers respectively.

3.1.6 Lake bed slope

The topography at all sampling stations was determined and compared to the already existing information. The results were in strong agreement with available bathymetric maps. The bathymetric map, Figure 1.4 shows that Crescent Island Lake and the region around Hippo point have the steepest lakebeds as depicted by closely packed contours unlike the area where Malewa River enters the lake, for example. Of the eight sample sites, Crescent Island Lake had the highest substratum gradient followed by Hippo point. Figure 3.12 shows a comparison of lakebed gradients among the eight sample stations. Central Landing Beach sample station had an almost flat lakebed. The gradient was significantly different between the stations (One-way ANOVA: F_7, 40=582.67; $p<0.05$) bathymetric studies, for example, (Hubble, 2001; Åse *et al.*, 1986). The most important area as far as this study is concerned, is the littoral zone occupied by the submerged and

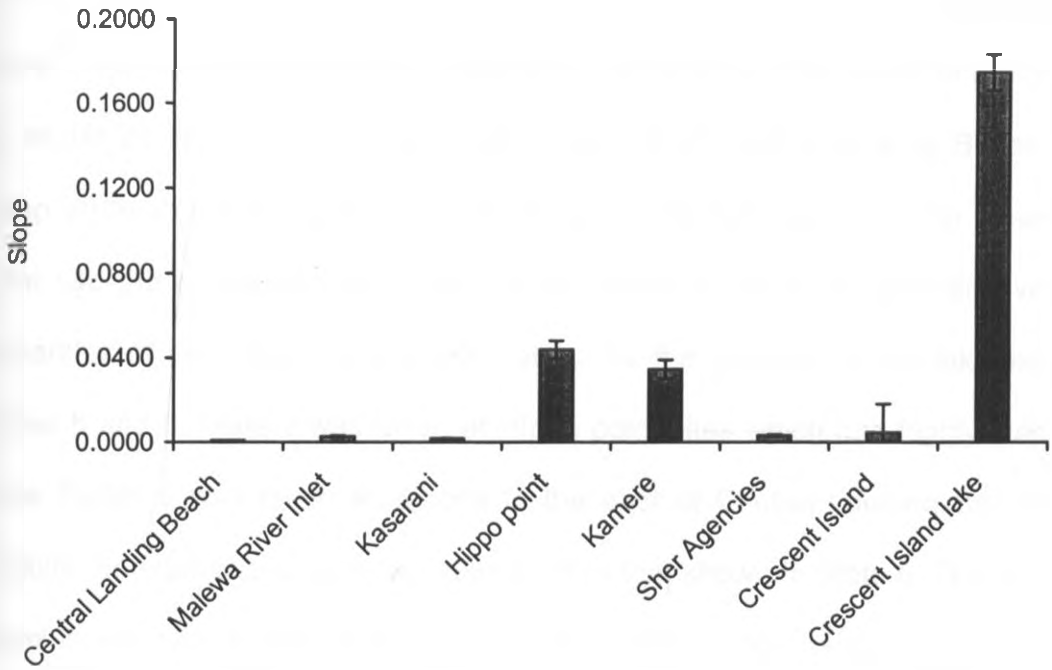

Figure 3.12: Slope of lake bed in relation to the stations in Lake Naivasha (February-July, 2003).

floating macrophytes. The littoral zone of Lake Naivasha is apparently steep unlike the inside regions of the lake, giving it the shape of a basin. However, there were significant differences in the lake bed gradients of the established sampling sites. The difference in gradients at the littoral area has a particular impact on the distribution of the submerged and floating macrophytes.

The manifestation of the importance of slope in Lake Naivasha is demonstrated when the lake water level changes. Lake Naivasha is known to undergo periodic but tremendous changes in lake level. Changes in the range of 8m have been recorded between 1931 and 1952 (Litterick *et al.*, 1979). Seasonal falls in the lake water level have major effects on the sites with gently sloping substrata such as sites Central Landing Beach and Malewa River

Inlet. During the dry seasons such areas have large tracks of dry land (draw-down) in the littoral area exposing any present submerged vegetation. The extent of the draw-down can go as far as 250m (pers. observ.) as measured at Central Landing Beach site, while at steep areas the extent of the draw-down are comparatively small. For example, at Hippo point site the draw-down was found to be about 3m from the shoreline vegetation. The disparities of draw-down are brought about by the gradient of the lakebed as shown in Plates 6 and 8. Plate 6 was taken at Hippo point sites which had highly steep substratum while Plates 8 was taken at a point to the east of Central Landing Beach site. Plate 8 exhibits an extensive draw-down compared to that shown in Plate 6. The size of the draw-down is naturally expected to vary inversely with slope. Hence, sites with low lakebed gradients are expected to have large draw-down and *vice versa*.

3.2 The Abundance and Distribution of Vegetation

Eichhornia crassipes and *Salvinia molesta* were observed to be the most abundant free-floating species in Lake Naivasha from February to July, 2003, when the present study was conducted. The trends of the two species are shown in Figure 3.13. However, it was found out that *E. crassipes* was five times more frequent than *S. molesta* (Figure 3.13) throughout the study period.

There was a reduction in abundance of both species after the onset of the rainy season in the month of May 2003. After the drop, there was a gradual increase of floating species. However, the recovery of *S. molesta* was slower compared to that of *E. crassipes*.

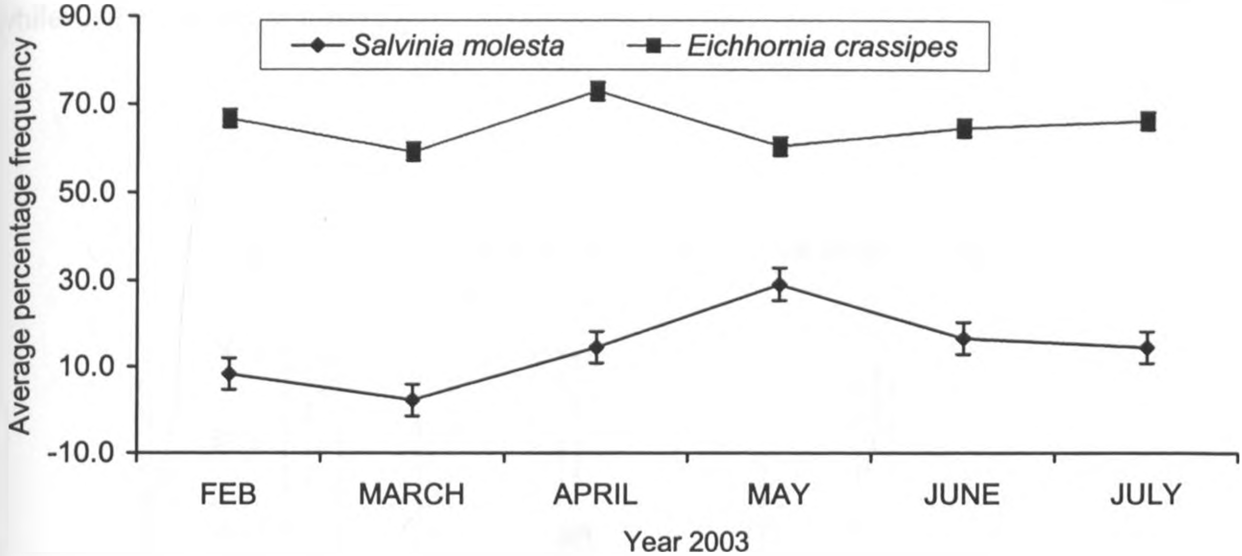

Figure 3.13: Monthly variation in average percentage frequency of the floating species in Lake Naivasha (February-July, 2003).

The abundance of the floating species varied from one sample site to another as shown in Figure 3.14. Sample sites Central Landing Beach, Malewa River Inlet, Sher Agencies, and Kasarani, had the highest abundance of *E. crassipes*. Plates 4 and 5 show *E. crassipes* growing at Kasarani and Malewa River Inlet sites spectively. Kasarani was in the northwestern side of the lake (Figure 2.1). Central Landing Beach and Malewa River Inlet were to the North while Sher Agencies, was in the southeastern side of the lake. Although Hippo point and Crescent Island were almost at the opposing sides of the lake, they had almost the same amounts of *E. crassipes*. This shows that apart from wind being an important factor affecting the distribution and abundance of the floating plants, other factors as well played a significant role. Crescent Island Lake site had the lowest abundance of *E. crassipes*. Kasarani sample site had the highest amount of *S. molesta* while Crescent Island Lake ,

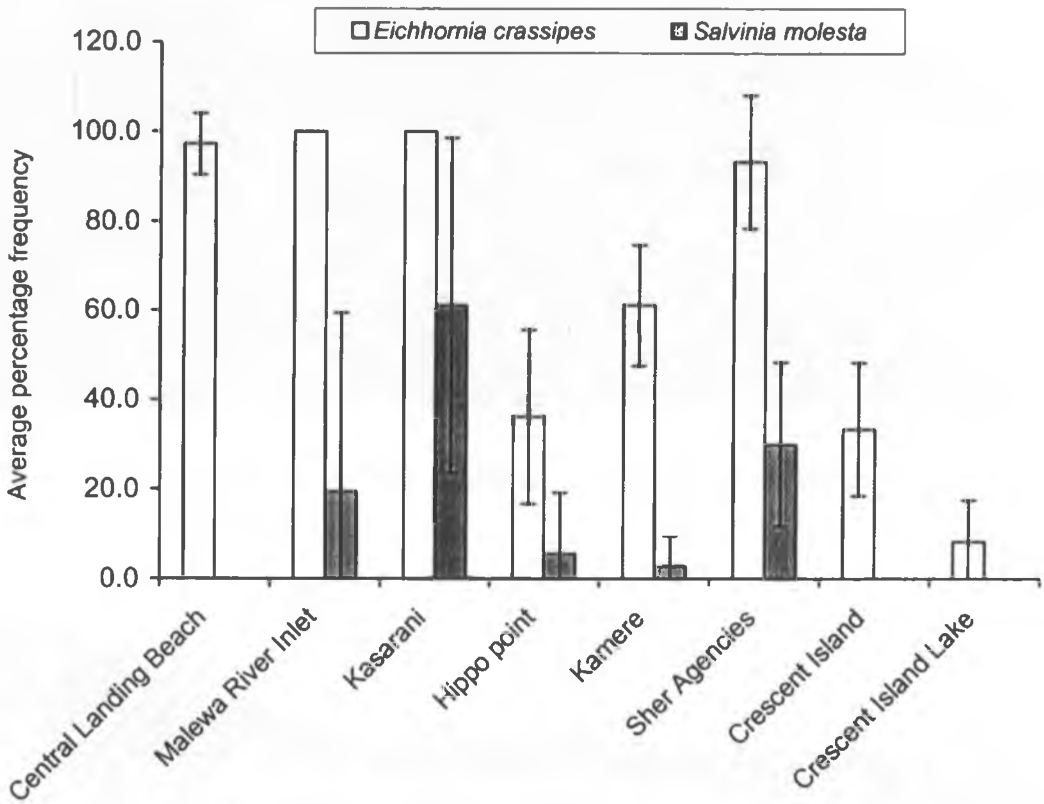

Figure 3.14: Spatial variation in average percentage frequency in floating species of Lake Naivasha (February-July, 2003).

Crescent Island and Central Landing Beach recorded none (Figure 3.14). Hippo point and Kamere had almost the same amount of *S. molesta*. It is apparent that the factors that determined the distribution and abundance of the two free-floating species were similar. This is so because apart from Central Landing Beach, sites which recorded high amounts of *E. crassipes*, also had correspondingly high amounts of *S. molesta* and *vice versa*. This can be confirmed by the fact that the correlation of the two species was highly significant as shown in Table 3.3.

Plate 4. *E. crassipes* growing at site Kasarani in Lake Naivasha. Kasarani was in the western side of Lake Naivasha.

Plate 5. A lush vegetation of *E. crassipes* growing at Malewa River Inlet site in Lake Naivasha during dry season *(Photos by the author, 2003).*

Unlike the floating vegetation, submerged aquatic vegetation was found to occur only in some sites. The distribution and the average abundance of submerged vegetation within Lake Naivasha is shown in Figure 3.15. No submerged aquatic vegetation was recorded in sites Central Landing Beach, Malewa River Inlet and Kasarani. Crescent Island Lake site had the highest abundance of the submerged aquatic vegetation followed by Sher Agencies. A small amount of emaciated submerged aquatic vegetation was found at Kamere site and only at the commencement of this study.

Sampling of submerged aquatic vegetation revealed four species of plants. These were *Najas horrida*, *Potamogeton schweinfurthii*, *Potamogeton octandrus*, *Potamogeton pectinatus*, *Nitella* spp. and *Ceratophyllum demersum*. These species were coded as NH, PS, PO, PP, NI, and CE respectively for easy reference. Of the six species, the most abundant was *P. octandrus* while *Nitella* sp. and *C. demersum* were the least abundant as shown in Figure 3.16. *Nitella* sp. and *C. demersum* were only recorded during the wet season.

P. octandrus was recorded in all stations where submerged aquatic vegetation was found with most of it found at Crescent Island Lake site. *P. pectinatus* was the second most abundant species with most of it found at Crescent Island Lake and Crescent Island sites. *P. pectinatus* was recorded in all stations except Kamere. No *N. horrida* was found at Hippo point and Kamere stations, however, it was the third most frequent species. *P. schweinfurthii* was the most abundant submerged aquatic species at Hippo point site and

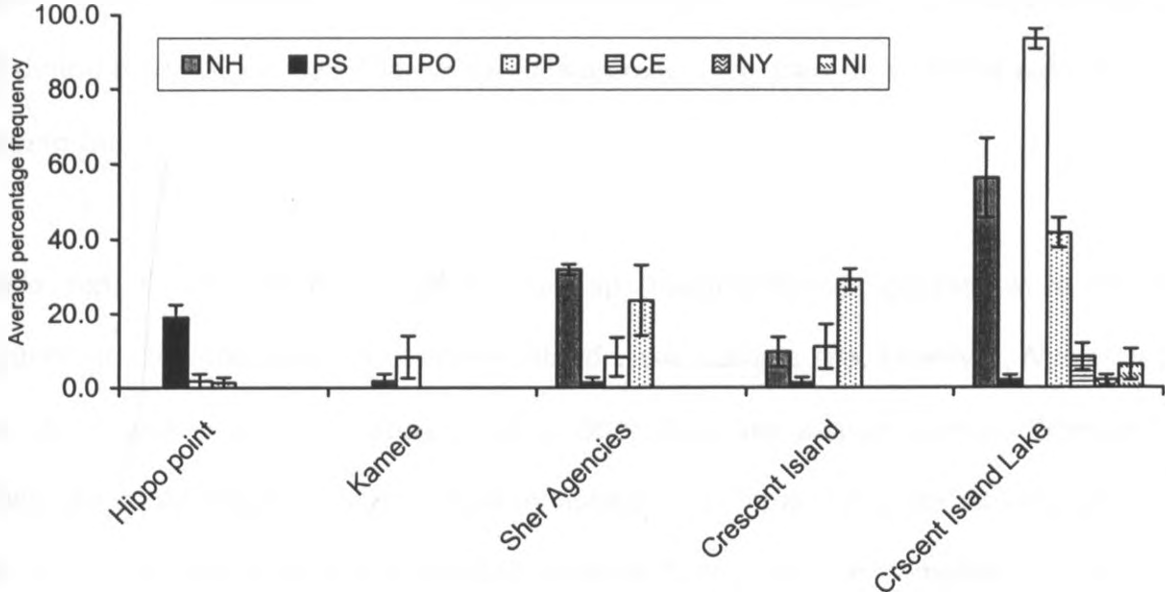

Figure 3.15. Spatial variation in average percentage frequency of submerged aquatic plant species in various stations in Lake Naivasha, (February-July 2003). (NH=*Najas horrida*, PS=*Potamogeton schweinfurthii*, PO=*Potamogeton octandrus*, PP=*Potamogeton pectinatus*, CE=*Ceratophyllum demersum*, NY=*Nymphaea*, NI=*Nitella* sp.)

Note: *Nymphaea* is a floating-leaved species. It has been put together with submerged species because the same sampling procedure (raking) was applied to both groups of macrophytes.

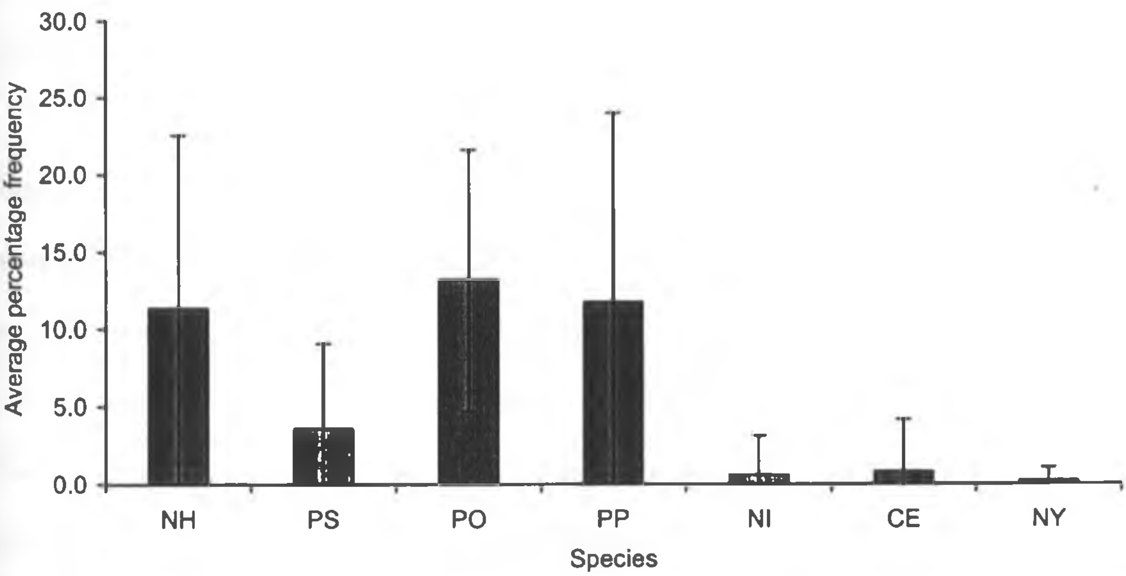

Figure 3.16: Average percentage frequency of submerged aquatic species in Lake Naivasha (February-July, 2003).

only found in small quantities in the other stations. Plate 6 shows a stand of *P. schweinfurthii* at Hippo point site during the dry season while Plate 7 is a view of the same site during the rainy season. Plate 8 exhibits an extensive draw-down to the east of Central Landing Beach site.

Nitella spp, *C. demersum* and *Nymphaea* sp (floating-leaved species) were the least frequent species and found at Crescent Island Lake sample site. However, *Nymphaea* sp was also found to occur in areas close to Sher Agencies sample station. Fragments of *Nitella* spp could also be found trapped by fishermen's net and at different locations of the lake away from the established sample stations during random sampling occasions. *C. demersum* was only observed at Crescent Island Lake site during the present study.

Sampling of the submerged aquatic vegetation was also done according to the depth zones. The littoral zone from the shore to 4.5m depth was divided into 3 zones. These were zone 1 (0-1.5 m), zone 2 (1.5-3.0 m) and zone 3 (3.0-4.5 m). The average frequency of submerged aquatic vegetation in relation to the depth zones is shown in Figure 3.17.

There was a significant difference of the submerged aquatic vegetation abundance between the zones (One-way ANOVA: F_2, 18=4.28; $p<0.05$). Most of the submerged aquatic vegetation was found in the first zone and represented 70.3% of vegetation found in the three zones. The least was found in the third zone, which accounted for 9.6% only. The other proportion was found in the intermediate zone. It was observed that although most of the submerged species were limited to zone 1, some species were well

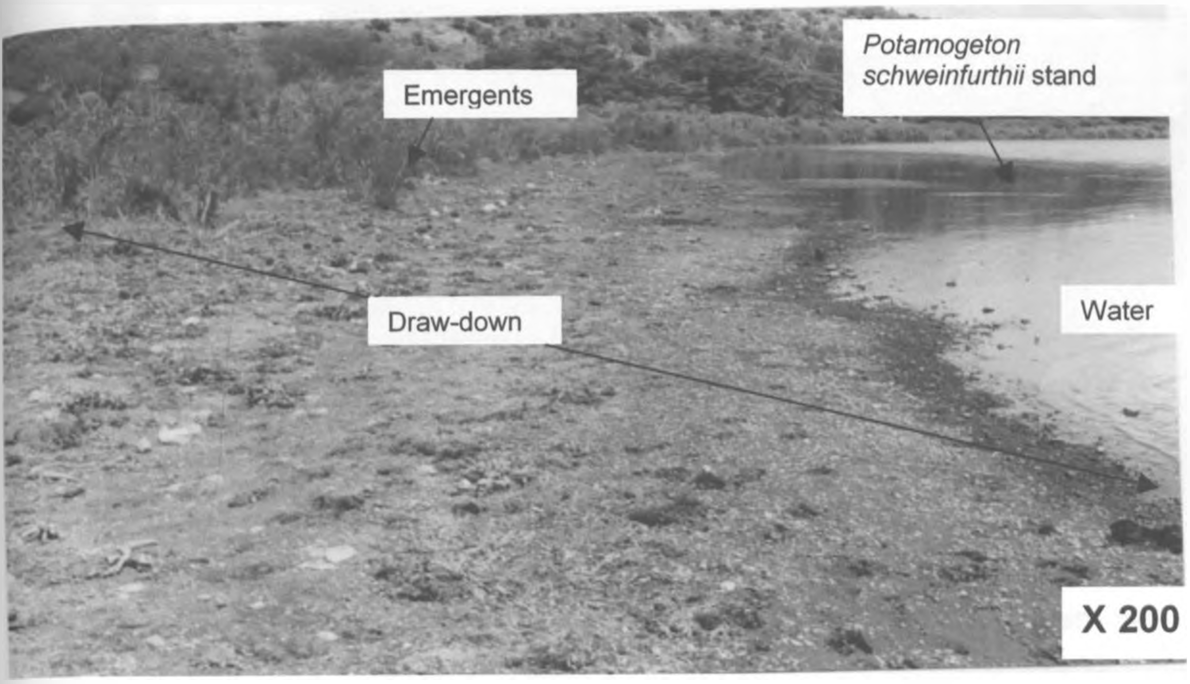

Plate 6. Hippo point sample site during the dry season. Note a stand of *P. schweinfurthii*

Plate 7. Hippo point sample site during the rainy season. *(photos by the author, 2003).*

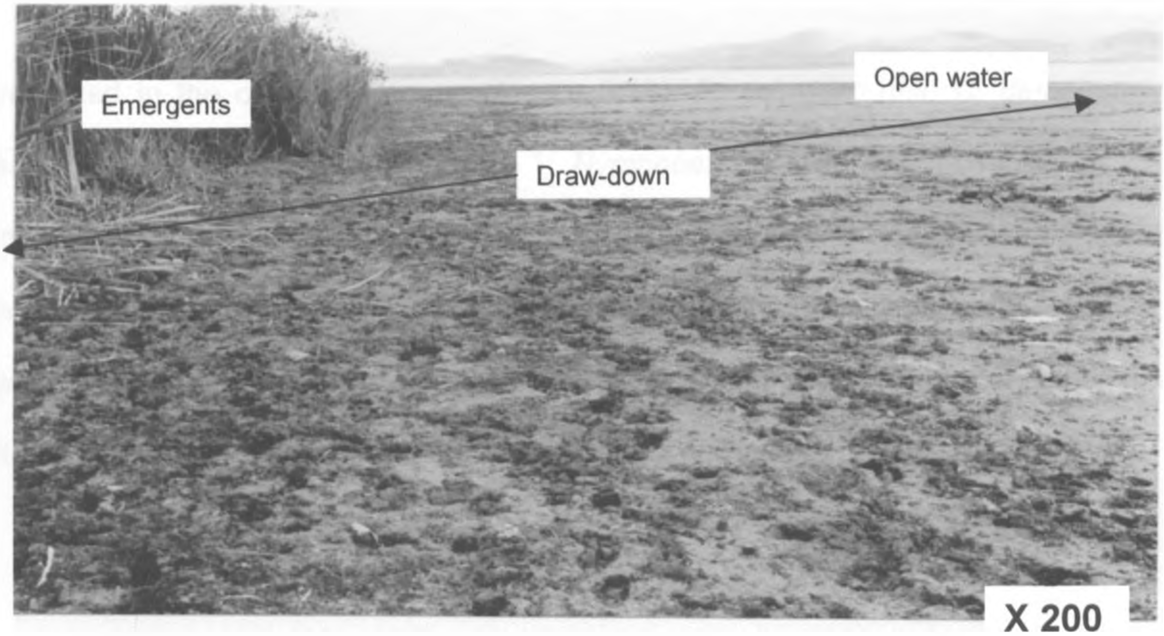

Plate 8. A photograph showing an extensive draw-down at the northeastern part of Lake Naivasha *(photo by the author, 2003).*

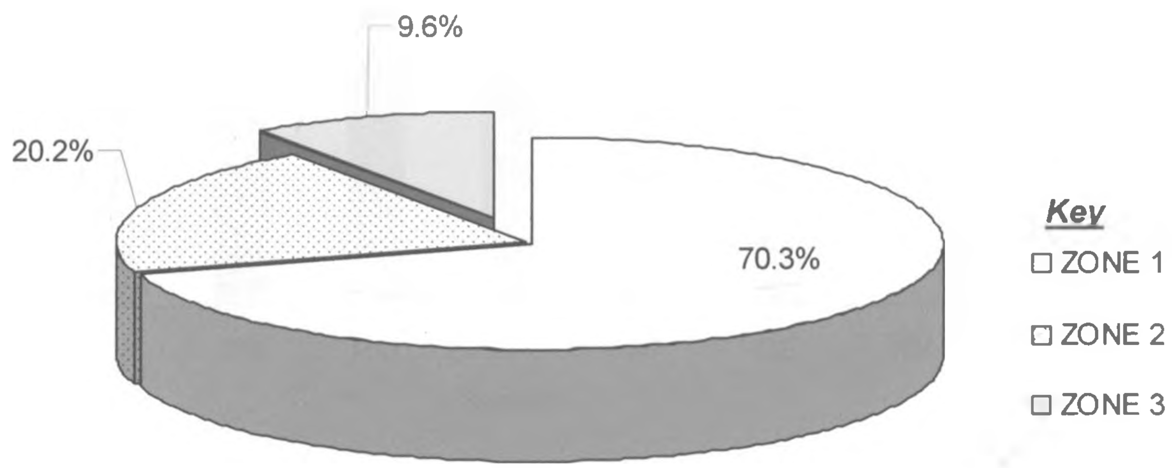

Figure 3.17: Mean percentage frequency of submerged vegetation in relation to the depth zones in Lake Naivasha (February-July, 2003).

represented in the other two zones (Figure 3.18). *P. schweinfurthii*, *C. demersum* and *Nitella* sp. were only recorded in zone 1. *Nymphaea* sp. was only observed as young germinating plants in zone 2. *N. horrida, P. octandrus* and *P. pectinatus*, the most abundant submerged species of the lake, were observed in all zones. However, *P. octandrus* was better represented in all zones than other species with zone one having 53%, zone two 24% and zone three 23% of the total abundance.

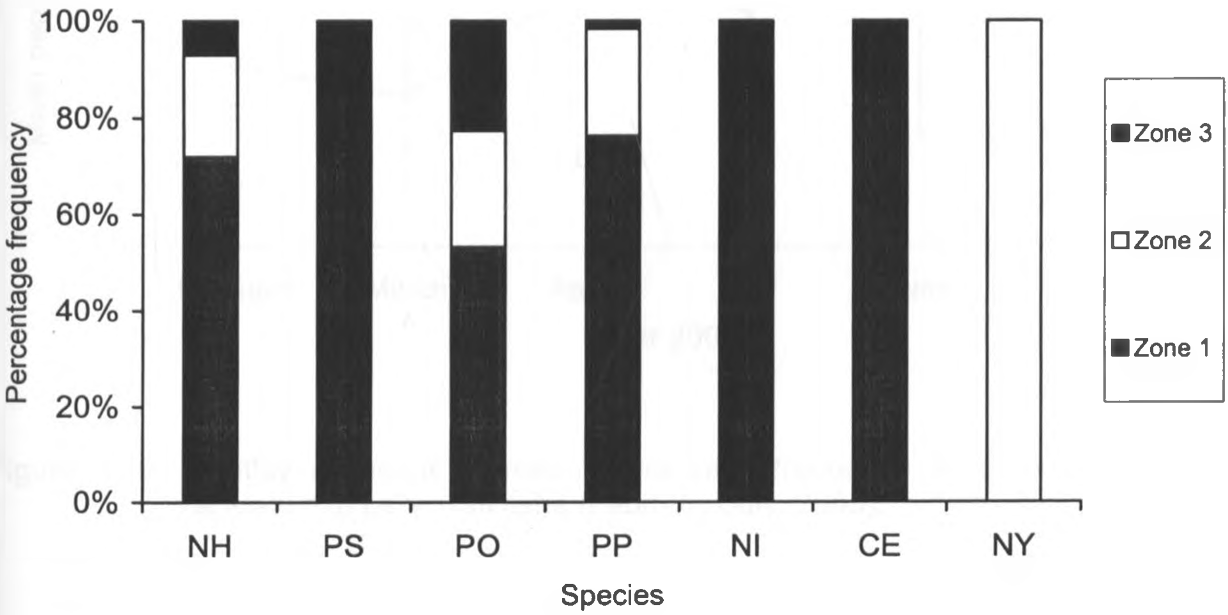

Figure 3.18: The percentage frequency and distribution of submerged aquatic species in relation to depth zones in Lake Naivasha (February-July, 2003).

Temporal variations of the submerged aquatic vegetation in Lake Naivasha are shown in Figure 3.19. The abundance of the vegetation is apparently affected by the season as for the case of the floating species. However, there was no apparent drop in abundance of submerged aquatic vegetation as opposed to the floating vegetation. Abundance of submerged aquatic vegetation instead increased with commencement of the rainy season in May. The submerged aquatic vegetation was 1.5 times more abundant during the rainy season than dry season.

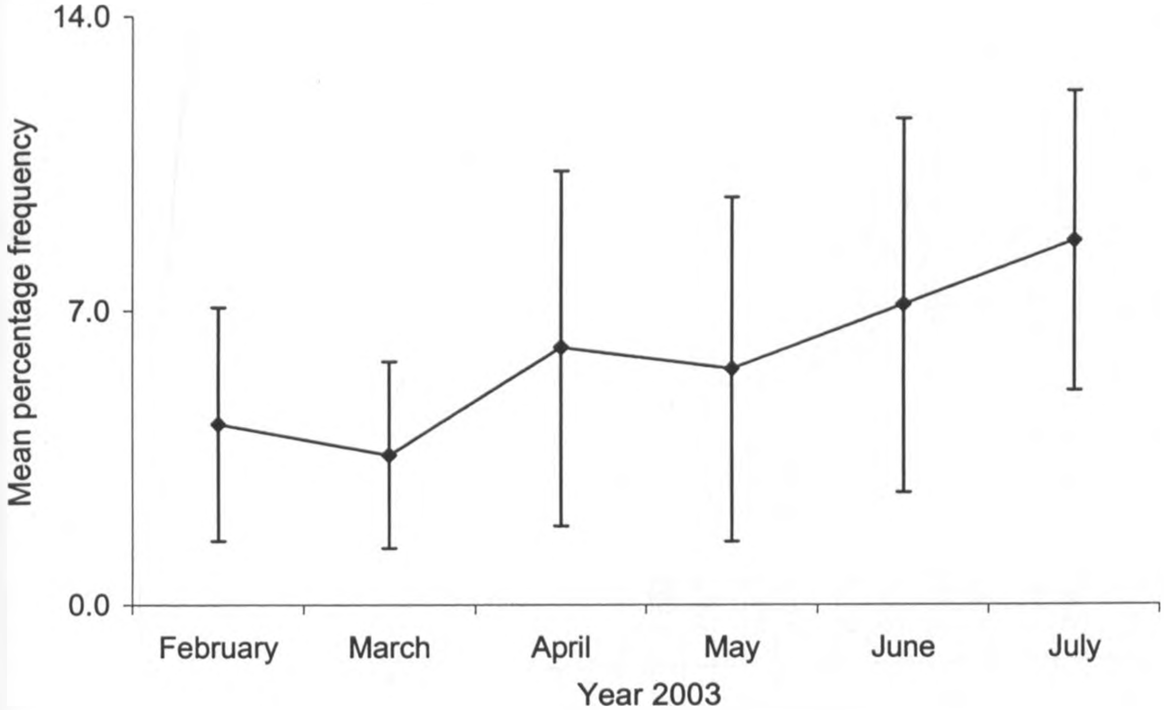

Figure 3.19: Monthly variations in mean percentage frequency of submerged aquatic vegetation in Lake Naivasha (February-July, 2003).

3.3 Correlation Analyses of Environmental Variables

Table 3.2 shows correlations between a range of chemical and physical factors. As expected, clay and silt were significantly and inversely correlated with sand. This means that, as both clay and silt increased, sand on the hand, decreased in the sampled areas of the lake. Clay and silt fractions were significantly and positively correlated. Secchi depth

Table 3.2. Correlations between various chemical and physical factors in Lake Naivasha. **Cell Contents:** Pearson correlation (Pears corr.)
P-Value

Variable	Sechhi depth	%Clay	%Silt	%Sand	SRP	TP	NO_2^-	NH_4^+	NO_3^-	pH	Conductivity
%Clay	-0.517										
	0.000										
%Silt	-0.643	0.611									
	0.000	0.000									
%Sand	0.656	-0.865	-0.926								
	0.000	0.000	0.000								
SRP	-0.181	-0.042	0.177	-0.090							
	0.271	0.799	0.274	0.582							
TP	-0.447	0.497	0.367	-0.472	0.059						
	0.004	0.001	0.020	0.002	0.720						
NO_2-	0.253	-0.133	-0.092	0.123	0.059	-0.086					
	0.126	0.419	0.578	0.454	0.720	0.604					
NH_4^+	0.338	-0.291	-0.302	0.332	-0.145	-0.411	0.273				
	0.038	0.072	0.062	0.039	0.377	0.009	0.093				
NO_3^-	-0.121	-0.006	0.100	-0.059	-0.109	0.470	0.231	-0.352			
	0.468	0.973	0.546	0.720	0.508	0.003	0.157	0.028			
pH	0.512	-0.191	-0.285	0.273	-0.133	-0.448	0.347	0.058	-0.184		
	0.000	0.204	0.055	0.067	0.413	0.004	0.030	0.726	0.262		
Conductivity	0.273	-0.158	-0.327	0.281	0.258	-0.482	0.160	0.229	-0.489	0.482	
	0.070	0.295	0.026	0.058	0.109	0.002	0.329	0.160	0.002	0.001	
Slope	0.908	-0.506	-0.681	0.673	-0.149	-0.477	0.126	0.414	-0.163	0.362	0.263
	0.000	0.000	0.000	0.000	0.358	0.002	0.446	0.009	0.322	0.014	0.077

was also significantly correlated with all sediment textural fractions particularly sand. The negative correlation between either clay or silt with Secchi depth implies that these particles tend to take a longer time to settle when suspended in the lake water unlike the sandy ones.

Soluble reactive phosphorus was not significantly correlated with the investigated physical factors suggesting instability in concentration of this nutrient fraction lake system. It may also imply that the amount of total phosphorus within a system does not necessarily mean presence of high amounts of soluble reactive phosphorus but the potential that a system has as far as the release of the biologically utilizable phosphorus is concerned.

The significant and negative correlation between total phosphorus and sand (Pears. corr.=-0.472; $\alpha<0.05$) suggest that areas with large proportions of sand would tend to be poor in this fraction of phosphorus. However, total phosphorus was significantly and positively correlated with clay and silt. Sites where Secchi depth was low apparently had high concentration of total phosphorus and vice versa. High water transparency may therefore indicate low quantities of total phosphorus since Secchi depth and sand were strongly and positively correlated (Pears. corr.=0.656; $\alpha<0.05$). Secchi depth and conductivity were not significantly correlated indicating little effect of dissolved material on transparency.

Lake bed slope was significantly correlated with the sediment textural types. Slope of lake bed was significantly and positively correlated with sand and negatively with clay and silt.

This observation suggests that locations in Lake Naivasha with gently sloping lakebeds tend to have much clay or silt and less sand. The negative and significant correlation between slope and total phosphorus can be attributed to the correlation between sand and total phosphorus. Sand apparently increases with increasing slope of lake bed in Lake Naivasha.

Ammonia and sand were significantly and positively correlated meaning that whenever sand was the major textural component, high amounts of ammonia were recorded. On the other hand, sand and phosphorus were significantly and negatively correlated. Therefore, the positive correlation between sand and ammonia may suggest that the low amount of phosphorus inhibited growth of biota in the sandy sites like Crescent Island Lake and Hippo point sites. This possibly resulted to reduced uptake of ammonia, hence, its higher concentration in sandy areas than the less sandy sites.

3.4 Correlation Analyses of Vegetation

To find out the plant species that had possibly common environmental parameters affecting their abundance and distribution, a correlation analysis was carried out. Table 3.3 shows Spearman's Correlation coefficients between various aquatic macrophytes. The floating and submerged species were considered separately since environmental factors affecting the two groups of plants can differ significantly.

Table 3.3: Spearman's Correlation Coefficients between abundance of various aquatic macrophytes.

Floating species	*Eichhornia crassipes*					
Salvinia molesta (**Sal**)	0.493**					
Submerged species	*Ceratophyllum demersum*					
Najas horrida (**NH**)	0.258	**NH**				
Nitella sp (**NI**)	1**	0.258	**NI**			
Nymphaea caerulea (**NY**)	1**	0.258	1**	**NY**		
Potamogeton octandrus (**PO**)	0.269	0.675**	0.269	0.269	**PO**	
Potamogeton pectinatus (**PP**)	0.249	0.819**	0.249	0.249	0.641**	**PP**
Potamogeton schweinfurthii (**PS**)	0.083	0.062	0.083	0.083	0.312*	0.081

**Indicates significance at 0.05 significance level*
***Indicates significance at 0.01 significance level*

3.5 Delineation of Important Environmental Variables

The analysis of variance was used to identify variables that differed significantly among the sampling locations. Environmental parameters that differed significantly were considered to consequently have significant effect on distribution and abundance of aquatic vegetation in the lake. The environmental variables that differed significantly were: percentage silt, sand, and clay, total phosphorus, lake bed slope, pH and conductivity.

3.6 Regression Analyses

The vegetation population was regressed against these variables as per sampling station. Table 3.3 shows the regression and significance results for aquatic vegetation versus the environmental variables. R^2 is the coefficient of multiple regression drawn from the standard partial regression coefficients shown in bold. The coefficients in bold were most important in contributing to variation of the corresponding aquatic plant species and were extracted from the Best Subset Regression.

From the correlation results between abundance of aquatic plants, all the major submerged species in Lake Naivasha namely *P. octandrus* and *P. pectinatus* were apparently influenced by similar environmental variables because their distribution and abundance were significantly correlated. Similarly, the species *Nitella sp.*, *Nymphaea sp.*, and *C. demersum* were affected by similar factors. *P. schweinfurthii* was not significantly correlated with the other submerged macrophytes. This is possible due to the significant and negative influence that the slope appears to have on *P. schweinfurthii* unlike other species (Table 3.4). Floating species were significantly correlated in abundance and the way they were dispersed.

The slope of lake bed appears to importantly influence the distribution and abundance of most aquatic vegetation in Lake Naivasha. All plant species except *N. horrida* were substantially influenced either negatively or positively by slope. Distribution and abundance of *P. octandrus* was positively and significantly influenced by slope. From the Best Subset of regression of variables on *P. octandrus* abundance, slope accounted for

Table 3.4. The regression and significance results for aquatic vegetation abundance versus the environmental variables.

Aquatic plant species	Standardized coefficients from regression equation								
	Secchi depth	% Silt	%Sand	Total phos-phorus	Slope	pH	Cond-uctivity	R^2	P
Potamogeton schweinfurthii	**0.479**	**-0.466**	**0.363***	-0.102	**-0.816***	-0.150	-0.064	38.3	0.001
Najas horrida	**1.030***	**-0.346**	**-0.746***	0.012	-0.095	0.126	0.074	69.3	0.000
Potamogeton octandrus	0.104	0.035	**-0.190**	-0.022	**0.966***	-0.017	0.049	86.3	0.000
Potamogeton pectinatus	0.158	-0.274	-0.301	-0.085	**0.334**	0.113	0.030	32.4	0.006
Ceratophyllum demersum	-0.009	0.148	-0.039	0.123	**0.811***	**-0.491***	**0.219**	23.3	0.029
Nymphaea sp.	-0.009	0.148	-0.039	0.123	**0.811***	**-0.491***	**0.219**	23.3	0.029
Nitella sp.	-0.009	0.148	-0.039	0.123	**0.811***	**-0.491***	**0.219**	23.3	0.029
Eichhornia crassipes	N/A	0.030	**-0.749***	-0.072	**-0.178**	-0.077	-0.052	84.2	0.000
Salvinia molesta	N/A	**1.136***	**0.551**	0.024	**0.094**	**0.149**	**-0.085**	37.4	0.000

**Indicates significance at 0.05 significance level*
Figures in bold are the most important standard partial regression coefficients after Best subset of regression of variables and contributing to R^2
N/A = not applicable

85.4% of total variation of the species. The proportion of sand in the sediments together with slope explained 86.3% of the total plant variation. However, increase in sand did not favour increase in abundance of the *P. octandrus*. Hence, it would be expected that with all other factors held constant, the areas with decreasing sand and steep lakebed would have higher abundance of *P. octandrus.*

The slope of the lake bed significantly ($p<0.05$, $R^2=11.5$) affected the distribution and abundance of the least frequent aquatic species. These species were *Nitella sp.*, *Nymphaea sp.*, and *C. demersum*. The species were also significantly and negatively affected by pH. A combination of lake bed slope and pH contributed 23.3% of the variation in each of species after Best Subset regression.

The lake topography had also an apparently significant and negative [$p<0.05$, regression coefficient (Regr. coeff.) =-0.816] influence on distribution and abundance of *P. schweinfurthii*. It is also apparent that this species was the only one positively and significantly ($p<0.05$, Regr. coeff. = 0.363) affected by increasing proportions of sand. Other important environmental factors affecting P. *schweinfurthii* were water transparency and sand. These two factors substantially affected P. *schweinfurthii* and both explained 38.3% of total variation encountered in the species.

Water transparency and soil texture could explain a total of 69.3% variation that occurred in abundance and distribution of *N. horrida* in Lake Naivasha. Of these two variables, water transparency was the most significant and important suggesting that among the submerged aquatic species found in Lake Naivasha, *N. horrida*, is probably the most sensitive to water clarity. Silt/clay and sand were both apparently important factors that influenced distribution and abundance of *N. horrida* in Lake Naivasha. However, sand was comparatively more important than either silt or clay. Sand had a significant and negative ($p<0.05$, Regr. coeff. = -0.746) impact on *N. horrida. P. pectinatus,* the second most abundant species after *P. octandrus,* was importantly affected by slope which accounted for 32.4% of total variation encountered in the species.

Among the environmental variables regressed against *E. crassipes* abundance and distribution, the percentage sand was significant ($p<0.05$, Regr. coeff. = -0.749) and most important. Hence, it is apparent that areas with a lot of sand had the lowest amount of *E. crassipes*. The other important factor was the site topography ($p<0.05$, Regr. coeff. = -0.178), which also negatively impacted on the distribution and abundance of *E. crassipes.* Both sand and slope accounted for 84.2% of the variation encountered in *E. crassipes.* The proportion of silt in the soil, on the other hand, positively and significantly affected *S. molesta*. Other factors that were apparently important were percentage sand, slope, pH, and conductivity. About 37.4% of variation in *S. molesta* could be explained by the five environmental factors. However, soil textural characteristics were the most important.

3.7 The Distribution and Abundance of Floating and Submerged Macrophytes in Relation to the Environmental Factors

3.7.1 The floating macrophytes

The present study revealed *E. crassipes* and *S. molesta* free-floating species to be the most abundant in Lake Naivasha. Of the two species, the most frequent was *E. crassipes.* Most of the floating species were found to occupy the region between the northeastern and western parts of the lake including Kasarani, Malewa River Inlet and Central Landing Beach sites. The water hyacinth mats and associated macrophytes especially semi aquatic types, are driven by wind from one point to another within the lake. This is particularly the case during high water levels when the stranded plants are detached from the substratum. Water hyacinth forms an important component of the floating islands of Lake Naivasha since it found its way in the lake in 1989 (Adams *et al.*, 2002). . Depending on the general directions of the wind, water hyacinth mats can be found in different areas of the lake in large quantities making wind the most important physical factor determining the abundance and distribution of the plant. The present and previous studies (Njuguna, 1982; Hubble, 2001) have indicated that the general direction of the ground level wind is fundamentally southeasterly, hence, most of the floating species were found in the region in northeastern and western parts of Lake Naivasha. Wind direction pattern can therefore be used to predict where one would find the highest population of the free-floating species in Lake Naivasha.

Central Landing Beach, Malewa River Inlet and Kasarani sample sites were all located in the direction the wind mostly blows. Consequently, these sites had the highest frequency of *E. crassipes*. *S. molesta* was correspondingly high in these stations except at Central Landing Beach site. This discrepancy at Central Landing Beach can be explained from the adaptive features of the individual species to the various environmental constraints. Although Sher Agencies is located to the direction the wind mostly comes from, it had high frequency of floating species. It is, therefore, apparent that other factors may play a secondary role in the distribution and frequency of the plants within the lake in various locations. The tall stands of *Sesbania sesban* (L) trees forming a fringe at the shoreline at Sher Agencies sampling site may act as a wind break, hence, protecting water hyacinth and *Salvinia* growing in the immediate environment against the effect of wind. Although *E.*

crassipes was found in all sites sampled, the abundance of the plant was lowest at Crescent Island Lake site.

From the regression of *E. crassipes* frequency on the environmental variables, sandy substrata played an important role in explaining the variation observed within water hyacinth. Although *E. crassipes* is a free-floating species, it is adapted to surviving low water levels by attaching itself onto the substratum (Gopal, 1987). This adaptation enables the plant to stay for a long time in the damp conditions without dying. Soil texture is the key determinant in retention of soil water (Okalebo *et al.*, 2002). Water retention in sandy soils is low compared to that of either silty or clayey soils. During low water level periods, the soils at the shoreline, where most of the floating plants are found in Lake Naivasha, are left exposed. This means that the floating plants are left on bare soil and hence attach themselves there until the following rainy season when the water level rises. This implies that plants attached to sandy soils are affected adversely more than the ones attached on clayey or silty soils which better retain soil moisture. Therefore, this can be the reason as to why such sites, e.g. Crsecent Island Lake, with sandy substratum had low abundance of either *E. crassipes* or *S. molesta,* while Sher Agencies had high abundance of both floating species though the site was in the direction the wind generally comes from.

Central Landing Beach and Crescent Island sites also recorded low amounts of *Salvinia.* Although its low abundance at Crescent Island site could be explained by the location of the site in relation to the wind, Central Landing Beach site should have recorded high amounts of *Salvinia* in this context. Central Landing Beach had the lowest lake gradient. This implies that this site is left exposed and dry most of the time during low lake water levels. *Salvinia* plants are poorly adapted to dry conditions since they have poorly developed anchorage structures unlike *E. crassipes.* Though Malewa River Inlet site also had a gentle gradient, the higher abundance of *Salvinia* observed at this site than that at Central Landing Beach can be explained by the fact that water from River Malewa helped to moisten the exposed soils where *Salvinia* had been stranded, hence, make it live for longer periods.

Kasarani site had the highest population of *Salvinia* plants. This observation could have been attributed to several factors, for example wind. Since *Salvinia* plant is a free floating plant the direction of the prevailing wind greatly affects its dispersal. From the data collected on wind, it was found out that the prevailing wind direction was mostly southeasterly. Kasarani site was positioned in the northwestern part of the lake hence being in the direction the wind blew. Therefore, the site was best placed to have the most *Salvinia* plants in relation to the wind direction. The other factor that favoured the presence of *Salvinia* at Kasarani site was the lake bed substratum. The topography of the site was such that it was inundated most of the time. Therefore, the *Salvinia* plants at this site were not subjected to dry weather conditions as was the case for Central Landing Beach which had the lowest lake bed gradient.

There was a general decrease of floating species population after the onset of the rainy season. This was probably caused by the submergence of the stranded (rooted) plants after the rise of the lake level. This phenomenon was followed by a gradual rise in population of both *Eichhornia* and *Salvinia*. This implied that dry weather conditions and decrease in lake level, impacted negatively on the floating vegetation of Lake Naivasha. However, the lake-level fluctuations notwithstanding, the wind direction and the nature of the substratum were apparently the most important factors affecting the distribution of floating macrophytes in the lake, where clayey/silty soils were favourable. Such findings were reported for Lake Victoria by Twongo (1995).

3.7.2 Submerged macrophytes

The distribution of the submerged vegetation seems to be skewed to the eastern region of Lake Naivasha. Sites that harboured most of submerged macrophytes were Crescent Island Lake, Crescent Island and Sher Agencies. Hippo point sample site was located in the south west of the lake and had substantial amount of vegetation but diversity was lower than the sites located to the east of the lake.

Zone 1 which was the region from the shoreline to 1.5m depth of littoral zone carried about 70% of the total plant population in Lake Naivasha. Zone 2 carried about 20% of the total population while the third zone had only the remaining 10%. The thin fringe occupied by the submerged vegetation can be attributed to the low water clarity of Lake Naivasha. At Crescent Island Lake site where water was most clear, submerged vegetation could appear beyond a depth of 4.5m but in small quantities.

Regression analysis on abundance of the major submerged species of Lake Naivasha indicate that the nature of substratum, slope and water transparency played an important role in determining distribution and abundance of the plants. As demonstrated in the present study, most of the submerged plants are located in the eastern side of the lake, it follows that the eastern and western regions differ in their constitution of their substrata. The stability of the substratum is of particular importance, in attachment of the plants. Previous studies, for example Clark and Baroudy (1990), have shown that western-northern soils of Lake Naivasha are loose and the process of substantial decomposition exists to the extent that they produce some odour. This observation coupled with the flocculation of sediments by organic matter, makes the soil unsuitable for plants growth. It has been found out in the present study that most of the floating macrophytes, are found in western-northwestern parts of the lake due to the effect of wind. The floating mats and islands are probably responsible for the loose substrata since when the plants die the detritus sink to the bottom where the process of decomposition continues with a net effect an unstable substratum, due to continued addition of the organic matter (Clark & Baroudy, 1990). Therefore, this region can be looked at as a sink while the eastern region as basically sources or production sites of the floating vegetation. The eastern regions export, by way of prevailing wind, vegetation to the western regions of Lake Naivasha. Sandy soils provided more stable substrata and that's why apparently Crescent Island Lake site had most of the submerged plants.

The observation that *P. schweinfurthii* species occurred in sites where the other species existed in low quantities, may suggest that the species is a poor competitor or a pioneer species. Lisowski *et al.* (1978) reported members of Potamogetonaceae as pioneer species plants that disappeared when stronger competitors appeared. This may explain the reason that Hippo point site, which had low quantities of species, had the highest frequency of *P. schweinfurthii.* Conversely, other sites e.g. Crescent Island Lake , had the highest population of submerged species, hence, lowest population of *P. schweinfurthii.* In the present study, among the members of Potamogetonaceae, *P. schweinfurthii* could be the weakest species compared to *P. octandrus* and *P. pectinatus.* Consequently, *P. schweinfurthii* may be regarded as a pioneer species.

Another observation made was that *P. schweinfurthii* favoured areas with low gradient. Almost pure stands of this species could be seen exposed during the times of dry season when water had substantially receded. This could have been attributed to the adaptation of *P. schweinfurthii* to exposure. Lisowski *et al.* (1978) indicated that, members of Potamogetonaceae show adaptation to adverse conditions by having tougher leaves when exposed as water recedes. *P. schweinfurthii* could apparently therefore be able to coupe with low water levels through such adaptation. Such tough leaves could enhance reduction in loss of body water. However, this study did not test this observation made by earlier researchers.

The distribution and abundance of *N. horrida*, was significantly influenced by the nature of the substratum ($p<0.05$, Regr. coeff. = -0.746) and water transparency ($p<0.05$, Regr. coeff. = 1.030). It is apparent that sites that had less sand with high water clarity favoured the establishment of *N. horrida*. This could be the reason as to why Sher Agencies site had the highest abundance of the species.

The slope of the lake bed was the most significant factor that impacted upon the abundance and distribution of *P. octandrus*. Hence, their dominance at Crescent Island Lake and Kamere sites which were substantially steep. The explanation that can be attributed to this observation is that unlike for example, *P. schweinfurthii, P. octandrus* does not tolerate exposure by receding water. Sand is also an important factor affecting the distribution and abundance of *P. octandrus.* Both the lake topography and sand could explain 86.3% of the variation encountered in this species.

The environmental factors considered in the present study had a cumulative significant (p=0.006) effect in determining the distribution and abundance of *P. pectinatus.* The lake bed slope, the most important factor, only explained 32.4% of the total variation experienced in the distribution of this plant species, hence, its effect was apparently not significant.

C. demersum, Nitella sp. and the floating leaved *Nymphaea* sp. were least abundant and significantly affected by the slope of lake bed and pH. However, these two parameters plus conductivity could only explain 23.3% of the variation encountered in these species.

3.7.2.1 Effect of increase of water level on submerged macrophytes

In a follow up to the sampling activities carried out in the year 2003 a visit to the lake was made in the month of March 2004. The Lake Naivasha water level had substantially increased with water covering the entire draw down observed during the sampling period (February to July 2003). During the visit, Hippo point and Sher Agencies sample sites were both sampled for submerged aquatic macrophytes. These two sites had submerged macrophytes present during the study period. However, during this later visit, it was found out that the submerged macrophytes had disappeared from the two localities.

This observation can be linked to the attenuation of light within the increased column of water above the macrophytes. Wetzel (1983) has indicated that the wavelengths under which the photosynthetic active radiation falls on the visible spectrum are greatly attenuated as light travels through a water column. The red (720nm) and the orange (620nm) bands are depleted within the first 20 m of distilled water. However, the attenuation effect is quite significant especially at lower wavelengths of the visible spectrum with increased turbidity

The impact of enhanced light attenuation combined with elevated hydrostatic pressure brought about by increased water column, for example, could have contributed to disappearance or death of submergents from the two localities. Wetzel (1983) observes that hydrostatic pressure interacting with other parameters especially light restrict the distribution of most fresh water angiosperms to depths of less than 10 m. It is apparent that increased lake level could also be responsible for adversely affecting the abundance of the submergents as per the present observations. The fluctuations that occur in abundance of submergents in Lake Naivasha have also been associated with changes in cray fish populations (Harper *et al.*, 1998).

CHAPTER 5: CONCLUSIONS AND RECOMMEDATIONS

5.1 Conclusions

In the present study, a total of six aquatic submerged plants were observed. These were: *Potamogeton schweinfurthii, Potamogeton pectinatus, Potamogeton octandrus, Najas horrida*, *Nitella sp.* (an algae) and *Ceratophyllum demersum*. Free-floating species encountered were *Eichhornia crassipes* and *Salvinia molesta* while small quantities of *Nymphaea* sp., a floating leaved species was also found. Among the submerged aquatic plants, the most abundant was *P. octandrus* followed by *P. pectinatus* while *N. horrida* came third followed by *P. schweinfurthii.* Both *C. demersum* and *Nitella sp.* were found in very small quantities. In the floating group, *E. crassipes* was the most dominant and was five times more than *S. molesta*. *E. crassipes* was found all over the lake and *S. molesta* was only found in the Main Lake basin and none in the Crescent Island Lake basin.

While most of the floating macrophytes were found in the west-northwestern parts of the lake, no submerged macrophytes were found in these regions and most of them were found to be concentrated in the eastern region and particularly in the Crescent Island Lake basin.

The most important factor that apparently affected the distribution and abundance of free-floating group of macrophytes was wind. The ground level wind that blows over Lake Naivasha is principally southeasterly. Consequently, most of the free-floating vegetation is found in the western-northwestern portion of Lake Naivasha. The other important factor was the nature of the substratum. Sites of the lake that had more silt/clay favoured the establishment of the floating plants compared to those that were sandy.

As far as submerged macrophytes were concerned, the lake bed topography, nature of the sediments and water clarity were apparently the major factors that influenced the distribution and abundance of these plants. Stable/hard substratum that was characterized by having more sand than clay or silt favoured the establishment of the submerged species. Steep lakebed as well favoured the growth of the submerged plants, hence, the highest abundance was recorded in sites with high lake bed gradient such as Crescent Island Lake site. The study also shows that among the submerged plants encountered, *N. horrida* was strongly influenced by water clarity.

5.2 Recommendations

The following recommendations can be made from the present study:

1. There is need to include more environmental factors in future research so as to be able to come up with the most informed conclusion on the factors that affect distribution and abundance of aquatic vegetation in Lake Naivasha. Some of the additional factors that may be considered in future related studies are: the effective fetch, water pollution, amount of fluorides and calcium in water column and the sediments, the current strength, amount of organic matter in the substrate and substrate penetrability.

2. There is need to strengthen the existing policies aimed at reversing the deteriorating trend in water quality, e.g. water transparency, and lake siltation which is a result of

erosional processes within the lake catchment. For example, the Environmental Management and Coordination Act, 1999, recognize the major activities that are likely to cause substantial ecological disturbances in a lake (EMCA, 1999), however, it does not emphasize the importance of conserving littoral vegetation in a lake ecosystem. There should be clear guidelines on how to manage this vegetation that acts as buffer zone, hence, mitigating impacts on the lake that emanate from external processes. Further, the feeder rivers and streams should be viewed as an integral part of a lake system. Subsequently, activities aimed at conservation of the vegetation buffer strip, for example, should be made clear.

3. The decomposing detritus of the dead floating macrophytes has the affect of flocculating the lake substrata. This has an impact of loosening and therefore, making the substrata unsuitable for growth of submerged macrophytes. Hence, there is need for the control of floating macrophytes to minimum levels within the lake. Maps (Christine, 1995) show that before the arrival of *Eichhornia*, which is the principal floating macrophyte in the lake, submerged macrophytes occurred round the lake. Unlike today, the submerged plant species occupied the nothwestern part of the lake as well, which is now dominated by *Eichhornia*. Floating macrophytes can be controlled mechanically, biologically or chemically. Although *Eichhornia* weevil was introduced in the lake for biocontrol purposes, there is need to explore an integrated approach to achieve better results. The success of the weevil has been a matter of debate. Some researchers argue that the weevil has not been able to perform well due to low night temperatures in the region which has hampered its establishment.

4. There is need to institute long term sustainable programmes to monitor the dynamics of both floating and submerged aquatic plants for the purpose of formulation of effective policies to guide their management.

5. Future management efforts need to be consolidated and executed from a landscape standpoint where both the catchment and the water body are well taken care of. Guidelines provided for in the Environmental Coordination and Management Act, 1999, needs to be applied in order to avoid future introductions that are likely to cause detrimental ecological changes in the lake ecosystem.

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