

HABITAT AND BIO-DIVERSITY MAPPING OF THE WETLANDS OF
LAKE NAIVASHA, KENYA, USING REMOTE SENSING AND GIS.

A STUDY ON THE DISTRIBUTION OF THE AFRICAN FISH EAGLE
(*Haliaeetus vocifer*) and HIPPOPOTAMUS (*Hippopotamus amphibius*).

MIKE ADU-NSIAH

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Thesis submitted to the International Institute for Aerospace Survey and
Earth Science (ITC) in partial fulfillment of the requirements for the award
of the Degree of Master of Science in Rural and Land Ecology (RLE)

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DISCLAIMER

This is to state that this study is first and intended as an educational exercise in partial fulfillment of the requirement for the degree of Master of Science (MSc) at the Division of Agriculture, Conservation and Environment (ACE), ITC, Enschede, The Netherlands.

The opinions expressed in this thesis do not necessarily represent those of the Kenyan authorities or the International Institute for Aerospace and Earth Sciences (ITC).

DEDICATION

This work is dedicated to my mother and all noble people interested in the conservation of natural resources.

ABSTRACT

The area of Lake Naivasha, the only freshwater lake in the Rift valley of Kenya, is important for its biological diversity and freshwater resources. It was designed a Ramsar site in 1995. Lake Naivasha plays an essential role in the economy of Kenya supporting intensive irrigation based agriculture, geothermal power, fishery and tourism. About 80% of Kenya's horticultural production is found around this lake.

The growing need to support the rapidly increasing human activities around the lake has led to a conflict between economic development and biological diversity conservation. The marginal lake side habitats are lost or modified to fulfill the increasing demand for land.

The main purpose of this research is to study the changes in vegetation cover within the Lake zone and its effect on the habitat and distribution of two selected indicator species, the African fish eagle and hippo.

Aerial photographs of 1984 and Landsat TM imagery of 1995 were used to map the habitat types and their changes in the lake zone.

The nesting and roosting habitat of the African Fish eagle (*Haliaeetus vocifer*), a species at the top of the food chain, is mainly Acacia woodland. An increase of 163 ha (4.1%) of the Acacia woodland was recorded between 1984 and 1995.

Annual Index numbers to measure changes between 1993 and 1997 in the abundance of fish eagle and its prey were calculated and compared.

After a decrease in 1994, the number of fish eagles was stable to date. The distribution of fish eagle seems not to be controlled by the area available for nesting and roosting (woodland). No fish eagles were observed in some sections with an increase in woodland area in 1995. Furthermore, sections with large tracts of woodland have a relative low density of fish eagles or no fish eagle at all, while some sections with a relatively small area of woodland show very high densities. Other factors like loss of open water area, changes in food supply, human disturbance and/or pollution might affect their distribution.

The results of this study show a decrease of 1972.24 ha (13.42%) of open water habitat between 1984 and 1995. Fish, crayfish and coot, the main prey of the fish eagle, are also declining in numbers.

The other causes might be over-fishing and probable pollution from agricultural activities in the lake zone and the catchment, which need further investigation.

The Hippopotamus is a good indicator to monitor the expansion of agricultural areas. The hippopotamus lost 1972.92 ha of its open water habitat and papyrus (995.5 ha), which was mainly converted into agricultural area (763.3 ha) and grassland (1768.6 ha). The declining lake levels and its accompanying land reclamation for agricultural purposes have raised the nocturnal grazing density of Hippopotamus in the area. A nocturnal grazing density of 5.0 km² was estimated taking into consideration the restrictions to agricultural areas by means of electric fences and ditches. Further investigation is needed for possible culling to reduce the "heavy" nocturnal grazing density or to stop a further increase of land reclamation.

Increase in agriculture, deforestation in the catchment area and urbanization are the main human activities affecting the wetland habitats, and therefore species diversity, of the Lake Naivasha ecosystem. Open water and papyrus are the habitats affected most by human activities.

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CHAPTER ONE: INTRODUCTION

Wetlands support high levels of biological diversity, they are, after tropical rainforests, among the richest ecosystems on earth. But, wetlands are also among the most threatened ecosystems in the world. More than half of the world's wetlands may have been destroyed this century as a result of drainage to counteract flooding, land reclamation for agricultural or urban purposes, introduction of alien species and to combat diseases.

There is a growing concern internationally, nationally and locally in the conservation of wetland ecosystems. This led to the promulgation of the Convention on Wetlands of International Importance especially as Waterfowl Habitat, or simply the Ramsar Convention. This international treaty is designed to assist countries in the management and wise use of wetland resources. It is still the only one focused on a single ecosystem.

The term "wetland" appeared when ecologist and resource managers sought to regroup land units such as swamp, marsh, floodplains, peatland, fen and swamp forest (Roggeri 1995). In Kenya wetlands are defined as (Njuguna et al., 1996):

"Areas of land that are permanently, seasonally or occasionally waterlogged with fresh, saline, brackish or marine waters, including both natural and man-made areas that support characteristic biota."

Wetlands in Kenya do not include deep lakes, fast flowing rivers and deep ocean waters.

Lake Naivasha, a shallow freshwater lake located in the Eastern Rift Valley in Kenya, is chosen as fieldwork area for this year study for the following scientific reasons.

First, it is an important freshwater wetland in Kenya, with a high bio-diversity, which was designed a Ramsar Site in 1995 (see below). Secondly, the ecology of the lake has undergone drastic changes over the last decades, partly attributed to natural fluctuations in lake levels, and to the introduction of various exotic plant and animal species. Additionally, the lake system is under pressure of a variety of human activities, including agricultural encroachment, off take of water for irrigation, clearance of papyrus swamps, overfishing and changes in land use and water flow in the catchment area.

General site description

Lake Naivasha is located at an altitude of 1885 m a.m.s.l. between latitude 0 45' South and longitude 36° 21' East in Nakuru District, Rift Valley Province. The Lake ecosystem consists of a main lake (Naivasha), a smaller sometimes separate and more alkaline Lake Oloidien and the strongly alkaline Crater Lake Sonachi (see Figure 3.3.).

Ramsar site

Lake Naivasha was designed as a Ramsar site¹ in April 1995 based on the following reasons:

- its special ecology to the region, being a high altitude Rift Valley freshwater lacustrine system with adjacent sodic wetlands.
- it regularly supports flocks of > 20 000 waterfowls, including as many as 15 000 red-knobbed coots and up to 92 Maccoa ducks (a significant proportion of the world population).
- it is of national value for it is the only freshwater source in the Rift Valley, as a refuge for wildlife in an otherwise dry area , as having the largest number of waterbird species of any wetland in Kenya. More than 350 species of birds are found in Naivasha and 75 of these are regular Wetland inhabitants. With around 60 pairs along the lake, Naivasha also has the highest density of fish eagles in Africa.

The study area covers the Ramsar site area and includes an area of approximately 30,000 ha inside the Moi North Lake Road, the Moi South Lake Road and the railway in between these roads, excluding any high density urban areas or industrial areas of Naivasha town (see Figure 3.3).

1.1 Conceptual framework

A growing need to support a rapidly growing human population has led to a conflict between socio-economic development and habitat and biodiversity conservation. Marginal lake-side habitats are lost or modified to fulfill the need for fertile agricultural land, settlements or recreation.

The causes and effects of the problems of the lake system were identified and a problem tree was constructed (Figure 1.1).

¹ A Ramsar site is a wetland designated for the Ramsar list of Wetlands of International Importance, especially as a Waterfowl Habitat. It is also significant in terms of ecology, botany, zoology, limnology, or hydrology. It is bound by the Ramsar Convention of 1971, which provides a framework for international cooperation for the conservation and wise use of wetlands.

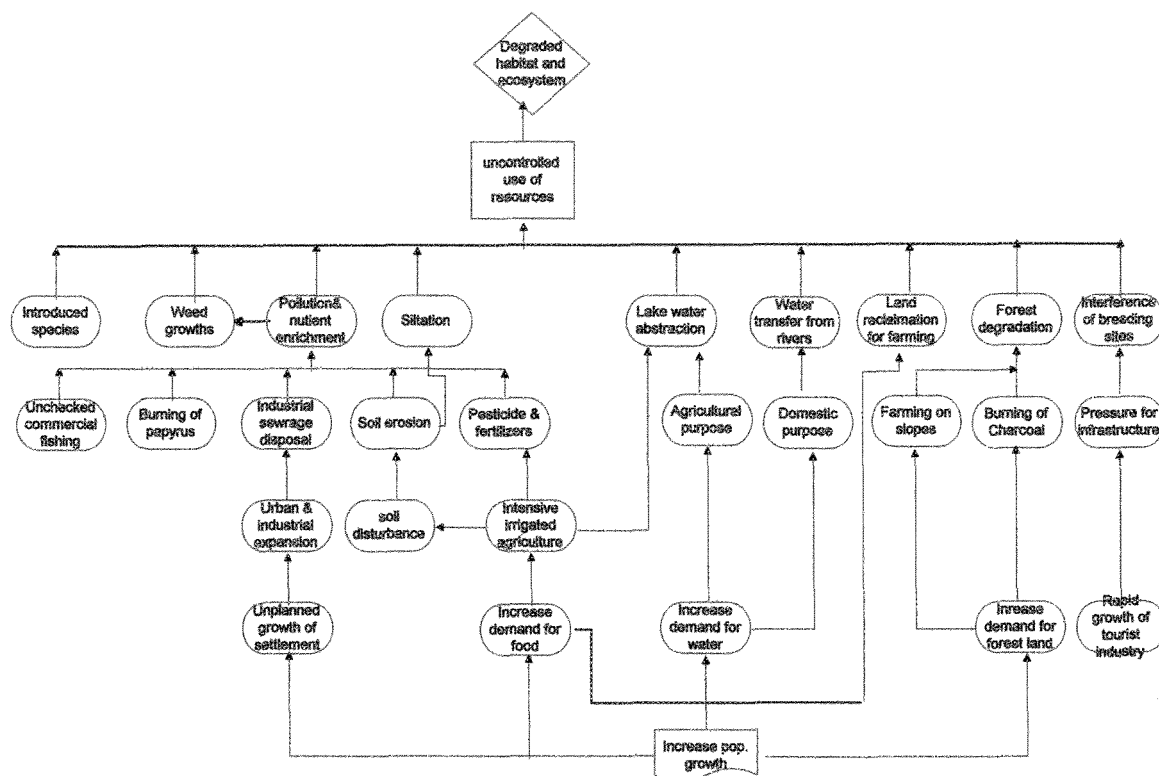


Figure1.1: Flowchart showing identified problems of Lake Naivasha

Out of the general issues, the following key issues affecting the Lake Naivasha ecosystem, were indicated:

- Changes in land use adversely affecting the lake ecosystem and its biodiversity
- Decrease in lake water levels
- Water pollution and nutrient enrichment from increasing urban and agricultural activities, aggravated by reducing water levels
- Potential of lake water to become more sodic in dry spells
- Invasive alien plants and animals which have infested the lake and its surroundings
- Mass tourism may cause disturbance to breeding places and fragile ecosystems

The specific problems currently affecting the lake are:

- Inappropriate activities on the riparian land including construction of permanent buildings
- Drainage of land for cultivation, especially intensive irrigated agriculture
- Destruction of papyrus and conversion of the 50 m buffer zone behind the papyrus fringe
- Loss of habitat for water birds and mammals

This study will mainly focus on the changes in vegetation cover within the lake zone and its effect on biodiversity.

The following questions were the starting-point for the present research:

1. *What vegetation communities can be distinguished in the Lake Zone and what is their distribution?*
2. *How to link the distribution of vegetation communities with existing census data on birds and mammals?*
3. *Which bird and/or other animal species are good indicators for the quality of the wetland system? What are their habitat requirements?*
4. *What is the effect of changes in vegetation cover on the biodiversity of Lake Naivasha?*
5. *What (human) activities affect the vegetation of Lake Naivasha? Which habitats are affected most?*
6. *Is the present land use conform to the proposed management options?*

Many ecological studies have been conducted on Lake Naivasha in the past. As result of the increasing pressure exerted on the lake during the 1970's and 1980's, water level fluctuations, alien species introductions, disappearing lake margin vegetation, increasing agricultural activities around the lake and lake water extraction for irrigation and geothermal power supply, the Earthwatch/University of Leicester research team initiated in depth ecological studies on the lake ecosystem (LNROA 1996). Ecologically the lake is interesting due to its fluctuating water level as result of irregular rainfall patterns and the change through introduction of alien species either accidental or intentional.

1.1.1 Vegetation

The vegetation of the Lake Zone area supports a high biological diversity of flora and fauna. Guadet (1977) described 108 species of 43 families of plants. He distinguished a clear zonation of vegetation species from the submerged hydrophytes in the lake working towards the Acacia woodlands on dry land. A plant list for the littoral zone can be found in appendix IX of the 1993 report by LNROA, as well as a checklist of the lake edge flora per family (pp. 74-78).

Plant species of interest are:

The world's largest sedge, *Papyrus* (*Cyperus papyrus*), is important in lake Naivasha because of its role in keeping the water of the lake fresh. The role of *Papyrus* in acting as a filter and causing the retention of nutrients in organic particles in the detritus and recycling of nutrients is discussed by several authors (Guadet 1977, 1979, 1980 and Njuguma 1982). Fluctuating lake water levels and salinity are important factors for the distribution of *Papyrus* (Harper et al., 1990). *Papyrus*, but also water-lilies (*Nymphae careulea*) and *Salvinia molesta*, do not occur in Lake Oloidien because of its higher alkalinity. A Presidential order in 1986 to protect *Papyrus* in the ecosystem of Lake Naivasha emphasized its importance (John Goldson Associates, 1986).

The most recent accidental introduction of an alien species is the South American ornamental, the water hyacinth (*Eichhornia crassipes*). Water Hyacinth was noted on the lake in 1988 and is mainly rooted in shallow water, particularly near the *Papyrus*

fringe together with *Salvinia*. The weed is very responsive to high nutrient concentrations, which might be a problem if N and P levels in the water rise (Harper, 1992).

Water lilies (*Nymphae careulea*) were common on the lake up to the early 1970's, but disappeared, probably due to an increase in Crayfish (*Procambrus clarkii*) and Coypus (*Myocaster coypus*) which grazed on the plant.

Salvinia molesta was a problem weed on the lake until 1991 when it was controlled biologically using weevils (Owour 1993).

Harper (1989) listed *Salvinia molesta*, *Pistia stratoites*, *Wolffia arrhiza*, *Eichhornia crassipes* as dominant floating species and *Najas pectinatus*, *N. caerulea*, *Potamogeton schweinfurthii*, *P. pectinatus*, *P. octandrus*, *Utricularia reflexa*, and *U. gibba* as dominant submerged plants.

Many ecological studies have been conducted on lake Naivasha including its vegetation, but most of the maps are sketch maps or old. An up to date and detailed vegetation map of the Lake zone area is essential for management and as a basis for other studies.

This study will therefore focus on surveying and mapping of vegetation communities within the lake zone by using remote sensing techniques and ground truthing.

1.1.2 Indicator species

The range of biological indicators that can be used for monitoring is wide. In this study the description of Keddy (1991), that is as an indicator of environmental conditions, will be used (see also chapter 2, section 2.4)

The following section is a result of literature studies, interviews and field observations.

Mammals

The typical mammalian species around the lake include Hippopotamus (Figure 1.2), Giraffes, Waterbucks, Zebras and Buffaloes.

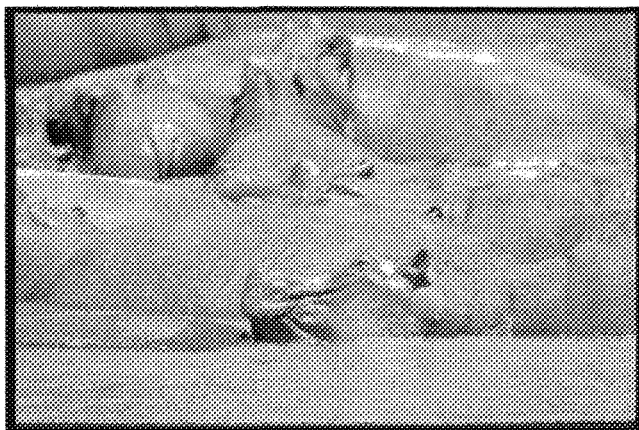


Figure 1.2: *Hippopotamus amphibius* resting in water.

The hippo (*Hippopotamus amphibius*) population at Lake Naivasha is of particular interest. Hippos prefer to stay in the water during the day and come out of the water to graze at the surrounding grasslands by the evening.

Access to their nocturnal grazing areas is more and more restricted due to a rapid agricultural expansion and swamp clearance during the present phase of declining Lake levels. The construction of 'hippo fences' and walls is likely to concentrate hippos in areas where grazing is still possible. Loss of grazing may be compensated by eating macrophytes in the lake.

The total numbers of hippos is under debate, but a reliable estimate seems to be 200-300, though farmers around the lake mention figures ranging from 500-1000 (Harper, 1989). During a boat and aerial survey carried out in 1987 around the lake, including Lake Oloidien, 228 hippos were recorded. The nocturnal grazing density of the hippo population calculated based on actual shoreline availability was estimated at 1.1 km². Overgrazing is no problem at present. However, as more land is reclaimed for agriculture and hippos are limited to graze in particular areas, local nocturnal densities may increase leading to overgrazing. Lack of forage might force the hippos to enter agricultural lands and hence damage the crops.

In this study an attempt will be made to map and assess the nocturnal grazing areas of the hippos.

Birds

The lake supports numerous birds species. Henderson (1987) in his survey of bird habitat use and abundance, counted 350 species with 90 of them being aquatic birds. He further reported the use of papyrus as an important habitat for birds and that the destruction of papyrus will not only affect the water quality of the lake but also bird populations. A study of the distribution and abundance of bird species with respect to seven identified habitat types around Lake Naivasha and Oloidien, revealed the highest numbers of bird species and abundance in habitats supporting submerged or emergent vegetation (Henderson and Harper, 1992). Habitat complexity seems also to enhance species richness. Open shallow shorelines accommodate a relative lower number of species but they attract especially 'unique' species, mainly members of the Charadriidae and Scolopacidae.

The African fish eagle (*Haliaeetus vocifer*), being at the top of the food chain, is one of the most important predators of the Lake Naivasha ecosystem and as such is a good indicator for the health of its ecosystem (Figure 1.3).

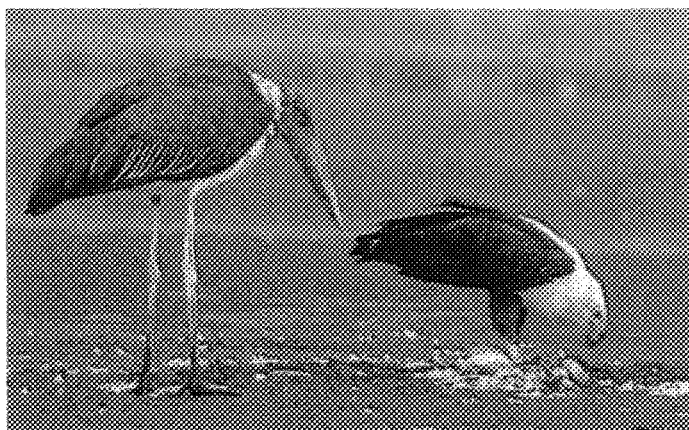


Figure 1.3: African Fish eagle (right) feeding, whilst the Marabou stork waits for its turn.

Along the lake shores of Lake Naivasha between 55 and 60 pairs of fish eagles are observed. Lake Ololdien has about 5 pairs and Lake Sonachi 1 pair. Fish eagles are territorial. Their main prey is fish, but they also feed on small birds like coots, cormorants and tails, and on crayfish.

Preliminary results of a monitoring study on the fish eagle population in Lake Naivasha indicate that, although the adult population appears to be stable, the annual productivity is very low (very few pairs are breeding). Also, there is a conspicuous lack of immature and juvenile fish eagles (Elsamere, unpubl).

Fish eagles are very vulnerable to poisons and pollutants entering the lake. A number has been killed by eating fish which carry lethal doses of organo-chlorines while many have been affected by fish contaminated with pesticides. One of the consequences of this contamination is that the shells of their eggs become thinner than usual and break before they hatch.

Loss of suitable nesting habitats by cutting of the Acacia woodlands for agriculture or other developments, is another factor threatening fish eagles. Fish eagles prefer mature (Acacia or Ficus) trees near the water, as nesting sites and for territorial display. As a consequence, particularly the immature birds are forced to move to less suitable habitats, as was observed by a survey carried out in 1986 (Johnson et al., 1986). The importance of the Acacia woodland habitat is recognized in Naivasha, that there is a Presidential ban on its destruction (John Goldson Associates 1993).

Change in food composition might also play a role. Over fishing by illegal fishing has reduced the fish population in the lake. Coot, another important source of (protein rich) food, depend on macrophytes. Overgrazing (by crayfish) of the submerged vegetation causes coots to migrate to other areas. Though fish eagles eat crayfish, a diet of mainly crayfish (which has less protein), is not enough. Many fish eagles show very low body weight at present (Munir Virani, pers. comm.)

The spatial distribution and habitat of the fish eagle will be studied with emphasis on (Acacia) woodlands and papyrus.

Fish

Prior to 1925, only one species of fish, *Aplocheilichitys antinorii*, a carp, was observed in the lake. The present fish population in the lake is all introduced by man and has an effect on the underwater vegetation and bird life. Over the last 20-30

decades the number of fish eating birds increased, including the white and pink backed pelicans, white necked and long tailed cormorants, herons and fish eagles (LNROA, 1993).

Oreochromis leucosticta is at present the most numerous fish, outnumbering the wide mouthed Black Bass (*Micropterus salmoides*), *Tilapia zillii*, *Barbus amphigramma* and *Lebistes reticulata*.

The Louisiana red swamp crayfish (*Procambarus clarkii*) was introduced to the lake in 1970 (Parker 1974) and has since increased rapidly with most of the catch being exported. Crayfish heavily graze the submerged vegetation which is vital to the feeding grounds for species as diverse as coots and hippos. Once the plants have been depleted, the crayfish population crashes and the plants start to re-colonize from the seeds stored in the lake sediments. The crayfish gradually respond and the cycle continues (Harper, Unpubl.) However, crayfish are eaten by bass, which limits the rate of plants damage. Bass feed by night. Phytoplankton blooms occur in wet years when nutrients are flushed out of flooded sails and so the bass cannot see their prey clearly. This then allows the crayfish to expand more rapidly.

Crayfish, as mentioned above, are also preyed on by fish eagles, cormorants (Figure 1.4), herons and other fish eating birds on the lake.

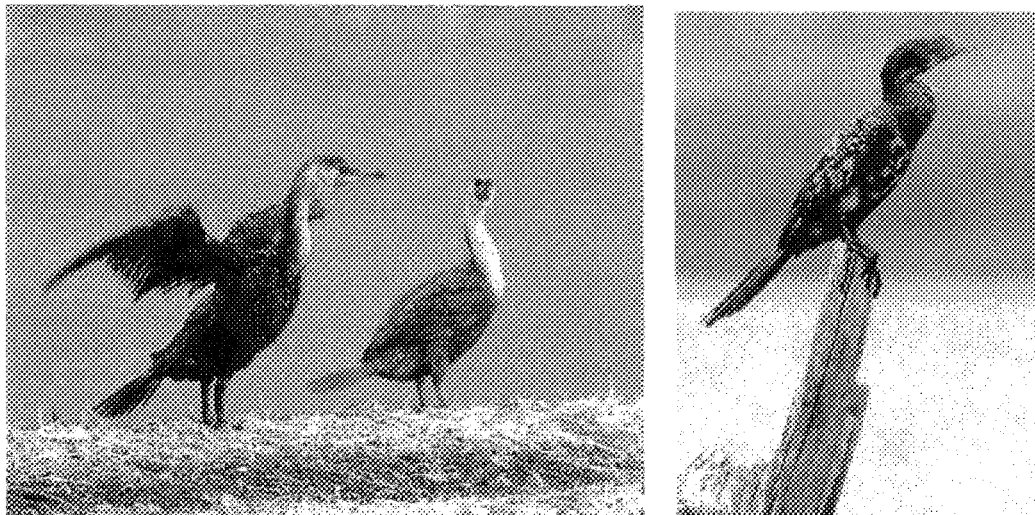


Figure 1.4: Two species of cormorants *Phalacrocorax carbo* (left) and *Phalacrocorax africanus* (right) in Lake Naivasha

Harper (1992) has indicated that the lake edge vegetation is very much responsible for the bird species richness of the lake. These edge plants also play a big role in the feeding and reproduction of *Tilapia* (Muchiri and Hickley 1991).

The relation between vegetation and indicator species as described above, is schematically presented in Figure 1.5.

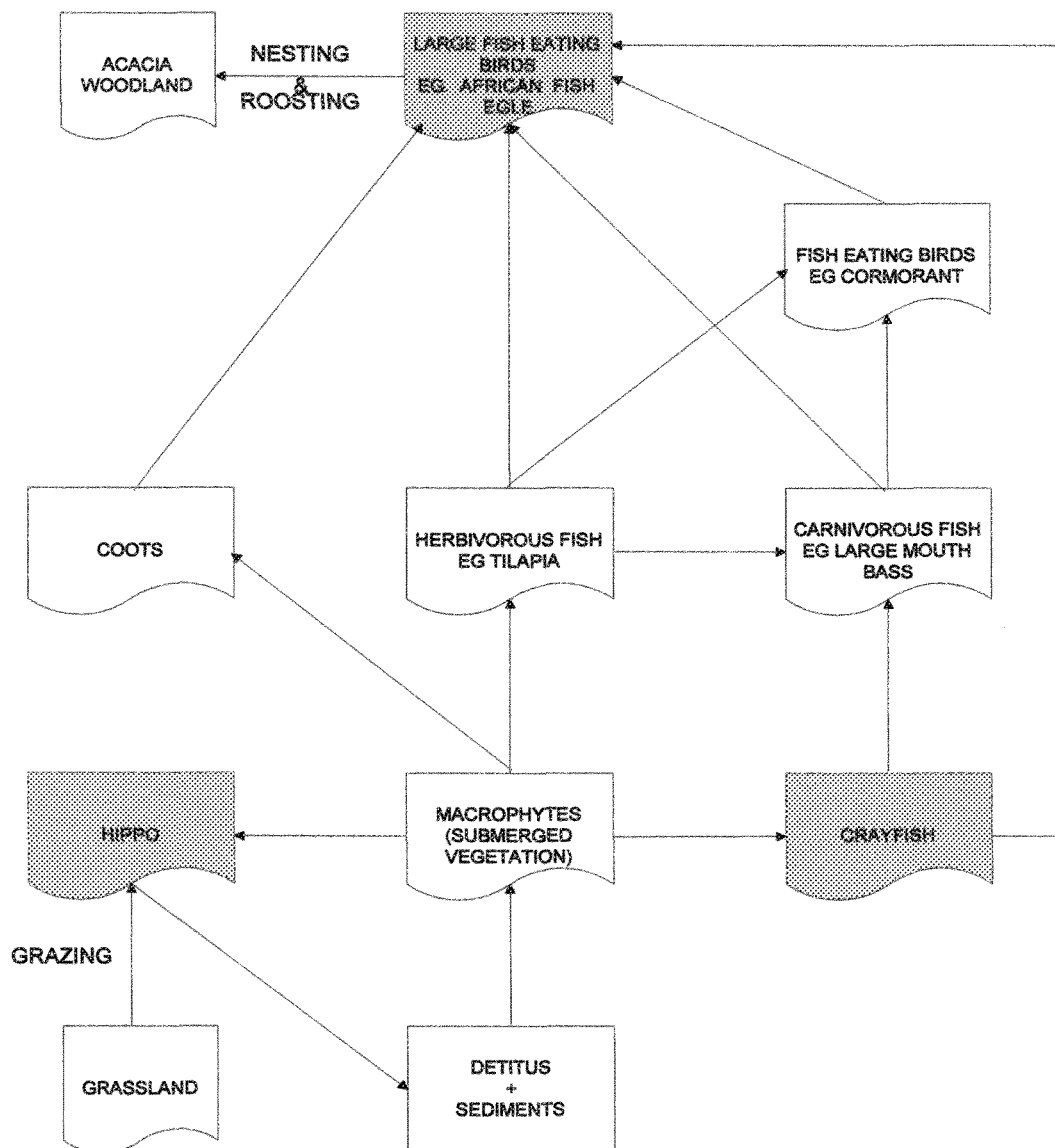


Figure1.5: The Relationship between vegetation and indicator species at Lake Naivasha

1.2 Scope of the study

Attention must be given to the conservation of biological diversity in the Lake Naivasha area. The two circumstances that conspire to give this matter an unprecedented urgency are:

- the exploding human population that are degrading the Naivasha ecosystem at an increasing rate

- the irreversible loss of diversity by the destruction of natural habitats (Acacia woodland, Papyrus etc.)

The primary cause of the loss of biological diversity is not the direct human exploitation but rather the habitat destruction that results from the expansion of human population and human activities. Brady (1988) stated that although pollution and over exploitation are serious threats to many wild plants and animals species, the continuing loss of habitat is the major cause of current and projected rates of species extinction. The lack of full knowledge of the identity and number of all species, their distribution and habitat requirement limit our effort to achieve systematic conservation to higher levels of organization such as habitat or ecosystem.

Based on the above mentioned (literature) review, the following statements can be formulated:

- Loss and/or degradation of habitats has a negative impact on biological diversity
- The African fish eagle, being at the top of the food chain, is a good indicator for the quality of the Lake Naivasha area. Loss and or degradation of woodlands, changes in food supply, and/or pollution might influence their distribution.
- The hippo is a good indicator to monitor the expansion of agricultural areas in relation to their densities.

-

1.3 Hypothesis

In Lake Naivasha increasing human activities are changing the plant communities and habitat of animals in the lake zone. To ascertain this, the study will be based on the following hypothesis.

1. Changes in the habitat of the African Fish Eagle are related to changes in species numbers.
2. Expansion of agricultural areas will increase the density of the hippo population. This will increase the grazing pressure on agricultural land.

1.4 Objectives

This study will mainly focus on the changes in vegetation cover within the lake zone and its effect on biodiversity.

To achieve the primary objective of this study the following secondary objectives are proposed:

- To map the present vegetation cover and general land use within the lake zone (together with Jane Bemigisha)
- To identify indicator species for Lake Naivasha
- To map the distribution of plants and habitats of selected mammals and birds
- To investigate the impact of human activities on community diversity.

1.5 Research questions

The study will be concentrated in the lake zone and particularly at what is happening in the following subzones:

- Papyrus fringe
- Acacia woodland areas.
- Grasslands
- Agricultural land

The following research questions will be addressed:

1. What is the present vegetation cover and land use in the Lake Zone and what is their distribution?
2. Which bird and/or animal species are good indicators for the quality of the wetland system? What are their habitat requirements?
3. What (human) activities affect the vegetation of Lake Naivasha? Which habitats are affected most?
4. What is the effect of changes in vegetation cover on the biodiversity of Lake Naivasha?

The primary objective written in the management plan of lake Naivasha (see chapter 3, section 3.8) is to manage the existing activities in the lake ecosystem through voluntarily adopted sustainable wise use principles to ensure its conservation (LNROA 1996). A further secondary objective is to maintain, conserve and where necessary restore the natural beauty and biodiversity of the lake. These objectives can be achieved by adopting human activities that ensure the conservation of different and unique habitats.

This study will focus on the identification and mapping of vegetation communities within the Lake zone, and of the habitat of the African Fish eagle and the hippo as indicator species in the assessment of the health of the Naivasha ecosystem. The output will assist in the conservation of wetland habitat for biological diversity of the Lake Naivasha system.

At the end of the study an attempt will be made to come up with recommendations for sustainable management and suggestions for further research.

CHAPTER TWO: LITERATURE REVIEW

This chapter presents a review of available literature on wetland, habitat and biodiversity mapping.

2.1 General information on wetlands

According to records from the World Conservation Monitoring, it is estimated that Wetlands occupy about 5.7 million km², roughly 6% of the earth's land surface (WCMC 1992). The highest proportion is made up of bogs (30%), swamps (20%), and floodplains (15%) with lakes occupying only 2% of the total. It is believed that more than half of the world's wetlands may have been destroyed in the current century as result of drainage to counteract flooding , reclaim land to increase food production and combat of diseases

The term "wetland" recently appeared when ecologist and resource managers sought to regroup land units such as swamp, marsh, floodplains, peatland, fen and swamp forest (Roggeri 1995). The two most frequently used definitions of wetlands are those proposed by the Ramsar Convention and the United States Fish and wildlife service shown in Box 2.1

The Ramsar convention:

defined wetlands as areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas or marine water the depth of which at low tide does not exceed six meters (Ramsar convention 1971).

Fish and Wildlife Service (United States):

Wetlands are land transitional between terrestrial and aquatic systems where the water table is usually at or near the surface of the land or the land is covered by shallow water (Cowardin et al, 1979).

Box 2.1 Definitions of Wetland

2.2 Lake Naivasha: values, functions and attributes of wetlands.

Roggeri, (1995) demonstrated that Wetlands are of great significance to man by their resources, functions and attributes. These functions, attributes (or qualities) and resources are goods and services which have a value for human beings.

The values of lake Naivasha are the direct use of its resources for the satisfaction of human needs. These include:

- Freshwater supply- maintenance of quantity and quality for Naivasha and Nakuru townships.
- Fisheries - Freshwater fish, markets at Nairobi, Naivasha and Nakuru.
- Agriculture - Irrigation-based agriculture particularly Flower cultivation.
- Grazing.- Livestock
- Wildlife resources.- mammals and birds like Hippo, Waterbirds
- Tourism and recreation - Boating
- Geothermal power- Olkaria Geothermal power station.
- Education activities- Elsamere Education center.
- Research and monitoring -
- Urbanization - Activities in the lake promotes the growth of Naivasha town.

Wetlands are capable of performing various functions as a result of the interactions of physical, biological and chemical components, such as soils, water, plants and animals. These functions are the indirect use that the wetland provides. Abbruzzese and Leibowitz (1997) divided these functions into three general categories (Box 2.2).

<ul style="list-style-type: none"> • habitat functions, that is providing support for wetland dependent species, including food, shelter, and breeding sites for hippos, waterfowls waterbucks etc.,
<ul style="list-style-type: none"> • water-quality functions, such as water-quality improvements (water purification, retention of sediments and pollutants) and nutrient cycling and supply (nutrient retention and export) and
<ul style="list-style-type: none"> • hydrologic functions such as Water storage, Groundwater recharge, Groundwater discharge, storm protection and flood mitigation.

Box 2.2 Functions of Wetland

In addition, lake Naivasha has the following special attributes :

- Biological diversity - The lake supports more than 350 species of birds including 74 species of water birds, mammals, fish, amphibians, reptiles and invertebrates, as well as countless number of plant species (LNROA 1996).
- Naturalness, uniqueness and rarity - Lake Naivasha has natural beauty and mild climate including nearby Hell's Gate National Park, with access corridors to the lake which is a home to many wildlife species and Mt. Longonot (2777 m). It is the only freshwater lake in the Rift Valley in Kenya with good water quality.

2.3 Habitat and Biodiversity mapping

Biodiversity is broadly defined as “the variety and variability among living organisms, and the ecological complexes in which they live” encompassing genetic, species, ecosystem, and landscape levels (U.S. Congress Office of Technology Assessment 1987, pg. 3). The concept of biological diversity has been subdivided into two main components: (1) Local richness or inventory diversity and (2) differentiation or β -diversity also known as replacement or turnover between species assemblages. Both components apply to a wide range of scales. The first concept has been commonly labeled as α -diversity, when applied within a community or a homogeneous habitat but has also been defined as γ -diversity when applied to the landscape level and a ε -diversity at a regional level (Whittaker 1977). The second sub concept has received a large array of names from many authors such as (1) internal β -diversity or pattern diversity, (2) β -diversity, between habitat diversity or between site diversity and (3) γ -diversity, geographic or δ -diversity (Whittaker 1977).

In this study the variety and variability among species and habitats in the Lake Naivasha Ramsar site will be considered.

Inventories of vertebrates and flowering plants are frequently used as surrogates for estimates of total biodiversity. The reasons given are that the inclusion of invertebrates and non flowering plants can be time consuming, difficult with the shortage of taxonomists and costly Oliver and Beattie (1994).

Reid et. al (1993) outlined reasons why species richness measurements focus on better known taxa, particularly plants and vertebrates. These reasons are because:

- plants and vertebrates tend to be of considerable direct importance to humanity
- areas with high species richness in these groups tend to have high species richness in other groups
- data on these taxa within a country are often available (estimates of population size have been made for some taxa)
- the diversity of plants in a region does not fluctuate significantly over short time intervals.

The dictionary of biology simply defines *habitat* as a place with particular kind of environment inhabited by organism(s). This means home area of a free living creature where it can find food, shelter and in breeding condition the circumstances in which to reproduce. A habitat can be described as a combination of environmental factors like climate, altitude, soil type, humidity, vegetation and human influence.

The terms environment and habitat have different concepts in ecology and very often some of these concepts are corresponding to each other. In his survey of ecological literature to resolve the ambiguity surrounding these terms Looijen (1995) came out with a set of definitions for *environment* and *habitat* summarized in Boxes 2.3, 2.4 and 2.5.

E1: the sum total of abiotic and biotic factors surrounding and in some way affecting an organism or a group of organisms.
E2: the set of biotic and/or abiotic factors occurring at a certain place.
E3: an area characterized by distinct, more or less uniform , biotic and/or abiotic conditions.

Box 2.3 Different concepts of environment in the ecological literature.

H1: the set of (E2 or E3) environments in which a species lives.
H2: the set of (E2 or E3) environments meeting a species' ecological requirements and tolerances.
H3: an E3 environment within which many species may live.
H4: the (E3?) environment of a community.

Box 2.4 Different concepts of habitat in the ecological literature.

Environment: the set , or combination, of (values of) biotic and or abiotic variables occurring at a certain place (E2).
Potential habitat: the set of environments meeting a species' ecological requirements and tolerances (H2)
Realized habitat: the set of environments in which a species lives (H1)

Box 2.5 Recommended definitions of environment and habitat.

In this study habitat is defined as an E3 environment within which many species live.

Research programs in ecology (Lubcheno et al. 1991) and conservation biology (Soule and Kohm 1989) identified biological diversity (biodiversity), as an important topic worthy of further studies. Both reports acknowledged that remote sensing could be a

valuable tool to support studies on biodiversity. The approach to integrate existing data on species distribution and habitat characteristics in using geographical information systems (GIS), supported by remote sensing inputs in biodiversity assessments was proposed by Davis et al. (1990).

Measurements of diversity and debates about their meaning filled the ecological literature as far back as 1950, with no clear resolution emerging (Goodman 1975). It is therefore not surprising that there is no consensus yet on how biodiversity should be measured. Measuring species diversity is often equated to species richness (the number of species in a given area or sample) but a more informative measure of diversity would include the relatedness of the species involved.

A report by Reid et. al. (1993) provides a set of 22 indicators that can be used to assess long term trends in the conservation of biodiversity. Thirteen of the indicators deal with wild species and genetic diversity, four with community diversity, and five with domesticated species. These indicators together comprise a basic set of indicators that can be used to understand better biodiversity conservation at local, national, regional and global levels.

To maintain the benefits that humanity obtains from healthy ecosystems, the concern is not the preservation of specific attributes of the community but, rather, the management of the system to meet human needs, support species and genetic diversity, and enable the system to adapt to changing conditions. There is therefore the need for indicators that can be used to provide decision makers with useful information on status of and trends in biodiversity. Other uses of indicators include ascertaining the effectiveness of existing policies and management objectives, and forecasting and projecting trends. Indicators therefore help determine priorities for action in the management of resources.

2.4 Indicator species for monitoring

To reduce the erosion of biodiversity conservation biologists urge us to focus on identifying and sustaining indicator species which provide early warning that a community or an ecosystem is being damaged.

Indicators are measurable variables for characteristics of an ecosystem that are assumed to be of importance for its values and their magnitude indicates divergence from a certain environmental objectives (Vives 1996). Noss (1990) identified three categories of variables - compositional, structural and functional - in ecosystems that can be affected by stress and can be measured by indicators. The compositional indicators involve types of landscapes, communities, population, and species items found in an ecosystem. The physical assemblage of the elements in the system is what structural indicators describe whiles functional indicators address processes in the ecosystem. Indicators can be non biological or biological.

Non biological indicators provide precise information on the management implemented and on selected possible causes of stress. The limitations are they can be costly and their impact on the biological components may be difficult to assess.

The range of biological indicators that can be used for monitoring is enormous. In addition to their indicative value, biological indicators may have an intrinsic value (conservation and economic values). In the use of species for monitoring Keddy (1991) assigned three motivating reasons for monitoring a species which are (1) because of the rarity of the species, (2) because it is undesirable (alien species) and (3) because it is an indicator of environmental conditions.

The basic assumption in the selection of indicator species is that the biological diversity and individual species will persist if the quality of habitat is maintained. Birds and their eggs have been widely used for the analysis of the residues of organochlorine insecticides (Ormerod and Tyler 1993)

To be effective for monitoring, a potential bio-indicator should have a number of desirable qualities (Box 2.6) as proposed by Hellawell (1986). The use of biological indicators however have a number of draw backs including mobility and late warning.

1. are readily identified - taxonomic uncertainties can confuse data interpretation;
2. may be sampled easily, that is, without the need for several operators or expensive equipment, and quantitatively;
3. have cosmopolitan distribution - the absence of species with very narrow ecological requirements and limited distribution may not be associated with pollution, etc.;
4. are associated with abundant autecological requirements this is of considerable assistance in analyzing survey results and devising pollution, or biotic indices;
5. have economic importance as a resource or nuisance or pest; species which is economically important (fish) or are a nuisance (some algae) have intrinsic interest;
6. readily accumulate pollutants - especially so as to reflect environmental levels since this facilitates understanding of their distribution in relation to pollution levels;
7. are easily cultured in the laboratory, which also assists in relating experimental studies of their responses to pollutants and field observations;
8. have low variability, both genetic and in their role (niche) in the biological community.

BOX 2.6: Desirable attributes of bio-indicators (Hellawell 1986)

In this study the term biological indicator is used as an indicator of environmental conditions.

2.5 Calculation of Index Numbers from monitoring data

Index numbers (Indices) are used to measure changes between different circumstances in the values of some quantity or quantities. The circumstances may be temporal for example a series of annual index numbers. Wildlife monitoring index numbers are often temporal. Index numbers are ratio as such they have no dimensions. This is a useful property because it means that relative changes in a variety of variables, each with quite different dimensions can be combined with one another into a composite index number.

For a series of values to be called index numbers they must be scaled relative to the value obtained at one particular time. This is known as the *reference base of the series and conventionally it is assigned a value of 100*.

Larger populations often show more variation in population size and more common species show more variability in both spatial and temporal abundance. In such cases a population size is better described on a logarithmic scale than a linear one.

In this study the essence is that a series of index number that can reflect changes in abundance at all the thirteen (13) sites in a fair way must be developed. No one site should influence the series more than the other sites.

The calculation of temporal (annual) index numbers from wildlife monitoring data in this study was based on the approach of Crawford (1991).

To calculate index numbers from site abundance after logarithmic transformation, it is a common practice to add a constant, usually 1 to the abundance before transformation, otherwise zero observations cannot be transformed.

Transformed site abundance = $\log (x+1)$

The main consequence of the transformation is to reduce the variations in the index numbers around the value of 100. This way very high index numbers are considerably reduced.

A major limitation associated with index numbers calculations based on untransformed and transformed data is their dependence on the choice of reference year. To solve this problem geometric means were used.

Index number based on *geometric mean* [$\text{Antilog} (\log X_1 + \log X_2 + \dots \dots \log X_n)/n$] have a particular satisfying property of not depending on choice of reference year. Therefore index numbers based on geometric means are more reliable.

2.6 Remote sensing and GIS application on Habitat and Biodiversity

Perhaps the most common application of remote sensing data has been the production of land cover and vegetation maps. The classification of habitat types is usually based on vegetation. Remote sensing (RS) and Geographical Information Systems (GIS) are recent tools for analysing, monitoring and managing earth resources.

2.6.1 Remote sensing and wetland mapping

Remote sensing is an important source of spatial data in land resources surveys. Remote sensing is defined as the science and art of acquiring information about material objects from measurements made at a distance (measurements made without coming into physical contact with the materials of interest (Budd 1991). The human eye is actually one of the most sophisticated remote sensor known, however the term is generally restricted to mean data collected by man made instruments usually carried on aircraft or satellites.

The physical basis of remote sensing lies in the ability to measure variation in field strength (spatial, spectral and temporal). Sensors in use for remote sensing can be active or passive. Active systems such as radar use man-made sources of energy while passive systems like Photography make use of existing energy (Sun). The portions of the electromagnetic spectrum use for remote sensing (Budd 1991) are;

- Ultraviolet, visible to reflected infra-red (0.3 - 3.0 μm)
- thermal infra-red (3.0 - 15 μm) and
- microwave (0.1cm - 30cm).

In the application of RS to wetland surveys there are three options for data collection. These are Aerial photograph, Aircraft multispectral and satellite derived remote sensor data.

Interpretation of colour and infra-red aerial photography can be used to accurately map inland wetlands (Welch et.al.1988). The acquisition of photographs on demand when cloud cover conditions are ideal is a further advantage of this technique. The accuracy of wetland surveys using aerial photograph are limited when certain films and filter combinations are used, relief displacement and significant vignetting causing photo interpretation inconsistencies. The cost per unit area is higher when larger regions are to be surveyed.

The technique of analyzing high resolution aircraft multi-spectral scanner data can provide accurate information for wetland survey of small areas. Jensen et. al (1986) however stated that the data are expensive to obtain and must undergo pre-processing techniques of radiometric and geometric corrections.

Satellite imagery acquired by Landsat TM (30 x 30 m), SPOT (20 x 20 m) and panchromatic (10 x 10 m) sensor systems can be used for wetland surveys (Jensen et. al 1991). This technique is limited by its spatial resolution compared to the techniques of aerial photography and aircraft multi- spectral scanner data. However the radiometric and geometric attributes of the data sets are suitable for wetland mapping if a more coarse mapping minimum unit is acceptable.

Johnson (1993) compared the use of aerial photography and satellite multi spectral scanning for resource inventories. Aerial photography the first method of remote sensing and even today in the face of modern age of satellite and electronic scanner, still remains the most widely used form of remote sensing. There are three principally attractive characteristics of aerial photography (Lillesand and Keifer, 1987) listed in Box 2.7:

<ul style="list-style-type: none"> • Simplicity: aerial photographs are easy to interpret by eye without the need for complex electronic or skilled operators
<ul style="list-style-type: none"> • Good spatial resolution: depending on the flight height, spatial resolution can be in the ranges of centimetres. Spectral resolution can be optimised by choosing film sensitive to different wavelengths.
<ul style="list-style-type: none"> • Three dimensional perspective: a stereoscopic view of the earth's surface can be created and measured both horizontally and vertically, to quantify specific features of interest.

Box 2.7 Characteristics of Aerial Photography

As an alternative to aerial photography, the satellite borne multispectral scanner, of which the Landsat Thematic Mapper TM is the most widely used. This has four characteristics listed Box 2.8.

<ul style="list-style-type: none"> • High radiometric resolution: data are received simultaneously in narrow wave bands
<ul style="list-style-type: none"> • Large radiometric range: data are collected across the range of the spectrum from ultraviolet through thermal infrared.
<ul style="list-style-type: none"> • High temporal resolution: most commercial platforms operate on global coverage time of days (e.g. Landsat 18 days)
<ul style="list-style-type: none"> • Digital Format: data are received electronically and downloaded in digital format facilitating easy manipulation and analysis using computers.

Box 2.8 Characteristics of satellite-borne multispectral scanner.

2.6.2 RS and GIS integration for wildlife conservation

Aronoff (1991) described geographical information system as a computer based system that can store and manipulate spatial information. In the field of wildlife studies GIS technology is useful because it enables us to organize, synthesize and analyze the data we collect about a species and helps us to understand spatial and non spatial relationships. Integrating RS and GIS and Global Positioning Systems (GPS) offers a powerful means of improving our understanding of dynamic ecosystems.

Efforts to understand the effects of landscape heterogeneity and dynamic processes such as habitat changes on animal populations are constrained by difficulties in mapping habitats at a meaningful resolution. In particular the characterization of vegetation structure is laborious, time consuming and expensive. RS applications of aerial photograph, Landsat TM, SPOT, and RADAR are being used to classify and map vegetation types.

The use of RS and GIS is on the increase in the field of conservation. This is assisting in the planning and conservation of natural resources. Current RS and GIS applications in conservation biology and wildlife management include various aspect of habitat description, delineation and monitoring.

A number of literature on the discrimination of wildlife habitat by classifying remotely sensed data and on the characterization of wildlife habitat using GIS from 1980 -1993 have been catalogued (Skidmore et.al 1996).

GIS technology appeared to be a valuable tool for the study of Sitka black tailed deer habitat selection in an extensively logged area in Southern Alaska by Chang et. Al.(1994). This made it possible to combine the complex task of wildlife habitat and timber management.

The Bald eagle *Haliaeetus leucocephalus* habitat on the Chesapeake Bay in Maryland was analyzed using RS and GIS (Chandler et. al 1994) .

Schell and Lockwood (1995) reported how RS and GIS were integrated for the spatial analysis to optimize grasshopper management in the United States. Integration of RS imagery of Landsat, SPOT and METEOSAT and GIS by the FAO to monitor vegetation and rainfall variables of the desert locust hatching sites in Africa was further elaborated.

GIS has great potential for the conservation related issues, making it possible for researchers to systematically examine interacting factors that place a population or species at risk of extinction. Skidmore et.al (1996) classified the kangaroo habitat distribution in Australia using three GIS models. Remotely sensed data and GIS is being

used in the restoration of Red-cockaded woodpecker *Picoides borealis* habitat at Fort Benning (Ertep, 1996). The Gray wolf which nearly became extinct in North America prior to the 1973 Endangered Species Act is reported to be recovering as a result of the current use of GIS by scientists in the Great Lakes region to map its habitat for conservation planning (Conway, 1996). The U.S. National Biological Survey (NBS) is using remotely sensed data and GIS to fill "GAPS" in biological diversity conservation. This will draw correlation among land cover, species distribution, habitat locations and existing conservation lands (Corbley 1996).

More recently, Aspinall and Humble (1997) reported how using RS technology, land cover map of Scotland provided detailed habitat knowledge which together with GIS application was used to study the Short eared owls in the Orkney Islands for planning and conservation purposes. Satellite tracking, GPS and GIS as reported by Schofield (1997) are being used to map the slender-billed curlew's migration path, changes in habitat or climate in a bid to learn where it is disappearing on the map. The mapping of Harpy eagle's territory with GPS, using GIS to create buffer zones around nests and informing the public about the eagle's plight is assisting in the protection of the raptors habitat and stabilization of its declining population in Venezuela (Kung and Alvarez-Cordero, 1997).

Previous studies have shown the applicability of integration of RS and GIS to provide systematic way to organize and interpret ecosystem health and assessment data. The integration of RS and GIS has been used for mapping wildlife habitat to assist the recovery of endemic and threatened species.

One remote sensing technique is not better than another for ecological monitoring tasks (Budd 1991). Therefore, it must be left to the user to decide which method is best. The results of this study is mainly on analysis and mapping of habitats of fish eagle and Hippopotamus using both aerial photography and Landsat TM.

CHAPTER THREE: STUDY AREA

3.1 General site description

Lake Naivasha, a shallow freshwater lake 100 km Northwest of Nairobi, in Nakuru District, Rift Valley Province of Kenya, is located between latitude $0^{\circ} 45'$ South and longitude $36^{\circ} 21'$ East (Figure 3.1). A false colour composite (Landsat TM, bands 541) of the study area is shown in Figure 3.2. The boundary of the study area is limited to the lake zone which is also the Ramsar site (Figure 3.3).

The main lake system has fringing swamps and submerged vegetation. Drainage water from the two major rivers, the Malewa and Gilgil, enter the lake from the North forming a floodplain and a delta. The mean depth of the main lake is about 4m with the deepest part of the submerged crater (crescent island) being 16m. Lake levels can vary several meters from year to year and within years, making the lake ecosystem highly dynamic.

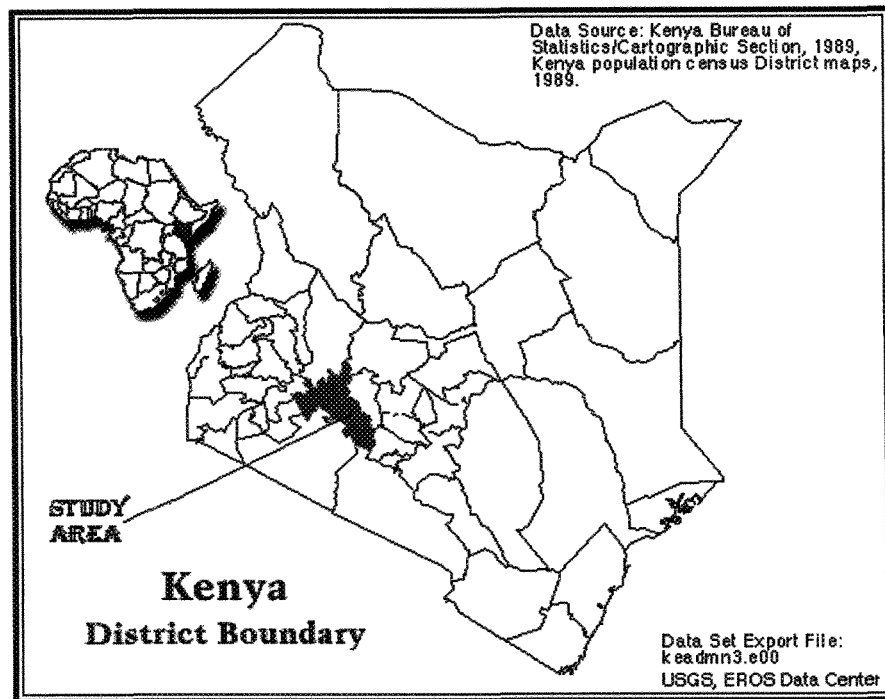


Figure 3.1 Map of Kenya Showing the Nakuru District and the Study Area

Apart from providing diverse habitats supporting a wide variety of animals especially birds, Lake Naivasha, being a significant freshwater resource to the republic of Kenya, contributes to its socio-economic development by providing employment for the people, supporting large scale irrigated agriculture, particularly horticulture and geothermal power generation. The rivers and ground water sources in its watershed provide water to

Nakuru and Naivasha The market for important commercial fisheries based on introduced species also includes Nairobi. These markets have grown significantly since 1975 (Lowery and Mendez, 1977). Furthermore, the natural beauty of the area including nearby Hell's Gate National park and Mt. Longonot (2777 m), and its mild climate attract many tourists.

3.2 Climate

The mean annual rainfall in the study area of 627 mm is generally low, and is concentrated into two seasons, from March - May and from October - November. The mean annual rainfall varies between 443 mm to 939 mm. The total amount of rainfall on the lake is only a third of the evaporation rate (Clarke et. al 1990).

The mean monthly maximum temperatures range from 24.6°C to 28.3°C with the highest temperatures in January and February, while the mean minimum temperatures range from 6.8°C to 8.0°C with July and August being the coldest months. The mean monthly temperature ranges from 15.9°C to 17.8°C. Relative humidity is less than 75 % at Naivasha.

Winds are generally calm in the morning but in the afternoon winds of 11 - 15 Km/h are common. In August - October winds are strongest and can reach speeds of 21 Km/h.

3.3 Geology and soils

John Goldson Associates (1993) provided a list of literature on the geology of Lake Naivasha and its catchment. Lake Naivasha is found on the highest part of the Rift valley in Kenya. The rift floor is covered with sediments, Pleistocene in age, (Quaternary era 1.5 to 2.0 million years) associated with the Pleistocene movements are faults, scarps and fissures. Geologically it is a young area and there is still evidence of volcanic activity. The rocks of volcanic origin are a mixture of acid and basic lava like Tephrites, Rhyolites and sodic Rhyolites.

About 80% of Lake Naivasha consist of lacustrine sediments of mid/late Pleistocene - Holocene (<0.45 my BP). Waterloo ridge pantellerites of welded and unwelded pyroclastics and Eburru pumice of pantellerite and trachyte pumice and ash fall deposits form a band in the North-western boundary and lava flows and pyroclastic cones of Eburru trachyte occupy the Masai Gorge. Three complexes of pantellerite lava flows, Akira pumice and Olkaria comendites are found at Hippo point (Kenyan Government, Geological map 1988).

The soils around the lake on the lacustrine plains have developed on sediments from volcanic ashes. The texture of the soils ranges from fine to sandy silts and clay loam of varying colours but often pale. Generally the soils which are easy to work with are of have different fertility.

3.4 Drainage

The catchment area is approximately 3200 km² and is drained by the rivers Malewa, Gilgil and Karati. The area lies in a high trough of the rift valley with the Eburu (2700 m) range forming the north western boundary and the active volcano Mt. Longonot (2700

m) forming the southern limit of the drainage basin. The eastern and western boundaries of the drainage basin is marked by the Nyandarua range (4000 m) and the Mau escarpment (3100 m) respectively.

3.5 Vegetation

Gaudet (1977) described the diverse and complicated lakeside flora of lake Naivasha and recorded 108 species of 43 families. The vegetation zonation is presented in Figure 3.4.

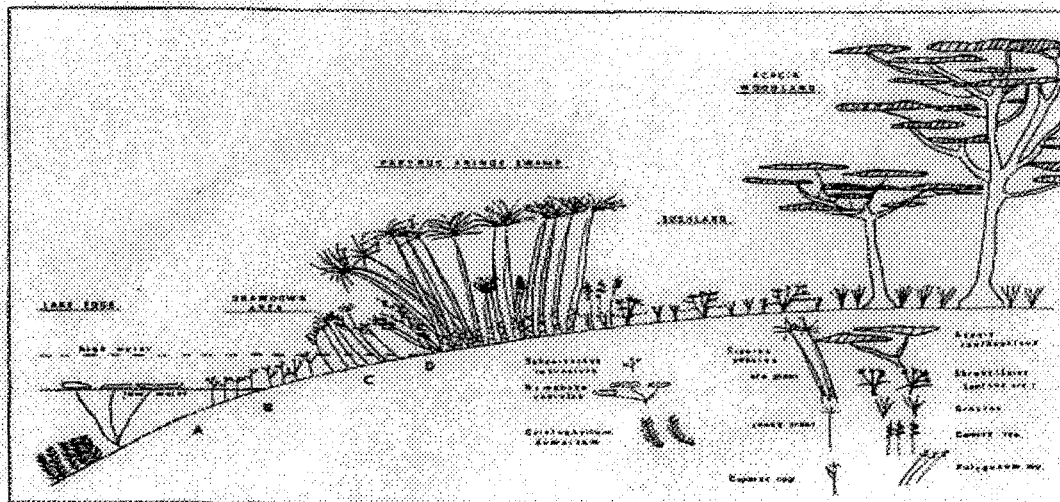


Figure 3.4 Vegetation zonation of Lake Naivasha (Gaudet 1977)

3.6 Land use

The area was occupied formerly by the Masai pastorals who used the land for grazing and the lake for watering of their cattle. The pattern of land use has changed from pastoral to sedentary farming and ranching over the years. The present land use are intensive irrigation based agriculture with high inputs of agro-chemicals, geothermal power generation, fishery, conservation, and tourism.

3.7 Land tenure/ownership

The waters of the lake and the riparian lands are the property of the State. The surrounding land is mainly privately owned with access to the riparian land and lake granted to the owners.

3.8 Activities and threats

In the Management Plan the main threats to a sustainable use of the lake's freshwater resources are described and actions to be undertaken (pp.7-15, LNROA 1996).

The following human activities are threatening the Lake Naivasha System (John Goldson Associates 1993, LNORA 1996):

- The threat of out of basin transfer of water from the rivers feeding the lake and water abstraction from the lake.
- Water pollution and nutrient enrichment from increasing urban and agriculture activities in the whole catchment area might, in combination with a reduction of the water level, lead to eutrophication of the lake.
- Introduction of exotic plant and animal species affecting native species.
- Increased soil erosion from the catchment causing siltation and nutrient enrichment in the lake.
- Commercial fisheries.
- Increasing number of (uncontrolled) tourists.

On the land below the 1906 lake level the following activities are threatening the sustainability of the lake.

- Intensive irrigated agriculture involving the use of fertilizers and pesticides.
- Drainage of land for cultivation.
- Destruction of Papyrus
- Conversion of the buffer zone (50 m) behind the Papyrus fringe
- Construction of buildings, sewage works, cattle dips and any other permanent structures.

3.9 Conservation status

No protection status (National Park/Reserve) exist for the lake. The use of the lake's resources are governed by a wide range of sectoral statutes.

3.10 MANAGEMENT

The Lake Naivasha Riparian Owners Association (LNORA) is the principal management authority for Lake Naivasha. This association is leading a community based conservation approach for the sustainable management of the lake and the initiators of the Management Plan (John Goldson Associates 1993, LNORA 1996).

For the purpose of the management plan, the area has been divided into two zones, the Lake Zone and the Catchment area and rivers.

The Lake Zone of about 300 km² is an open water wetland and riparian area with characteristic plants and animals, and is delimited by the Lake Road and the road from Nairobi to Nakuru. The shoreline embraces about 70 km.

Present management:

Lake Naivasha is Kenya's second Ramsar site (Wetland of international importance). It cannot further sustain development on the scale seen over the past 10 to 15 years without a coordinated plan for the future. The lake being a wetland is fragile and as such there is the need to develop management options of wise use of the resources of Naivasha to ensure its conservation.

The stakeholders interested in the utilization of resources and management of the lake are:

Lake Naivasha Riparian Owners Association (LNROA)

Kenya Power company

Kenya wildlife Service

The municipal Council

Local administration

Local communities

Universities and other Research Institutes and

IUCN(World Conservation Union).

The LNROA is currently leading a multiple use community based management of Lake Naivasha. This involves activities that can be conducted within, and around the lake, the riparian land below the 1906 lake level and to some extent the catchment. In this approach a management plan for the period 1995-2000 is being implemented by LNROA in conjunction with the other stake holders (LNROA 1996). These measures will assist to maintain, conserve and restore the habitat of endangered species and the natural scenery beauty of the lake. This way the lake will continue to support the high level of diverse species of plants and animals particularly bird species, as for example the kingfisher (Figure 3.5).

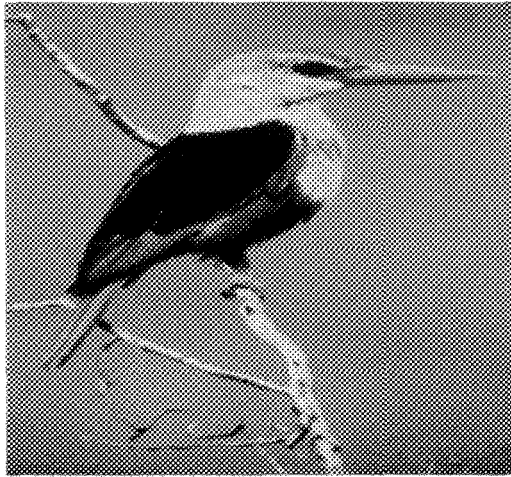


Figure 3.5 The kingfisher a common bird at Lake Naivasha.

CHAPTER FOUR: METHODS AND MATERIALS

4.1 Introduction

Chapter four of this thesis explains the three phases: pre-field work, fieldwork and post fieldwork. The materials used for the study are also listed.

The general approach of the habitat and biodiversity mapping is illustrated in Figure 4.1.

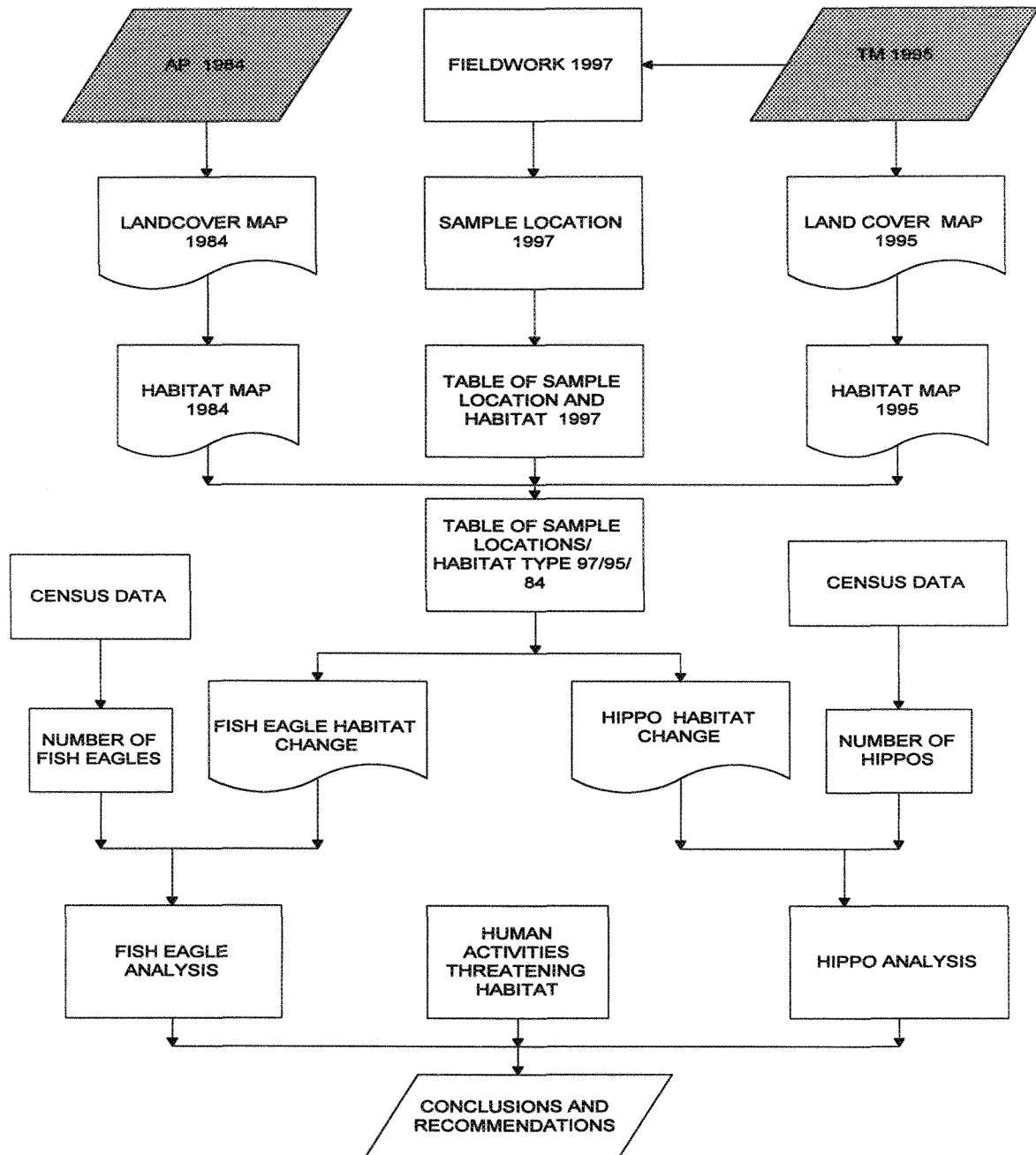


Figure 4. 1 General structure of Habitat and Biodiversity Mapping.

4.1.1 Pre-fieldwork phase

The pre-fieldwork consist of eight main activities.

- **Literature Review**

The available literature on research conducted on Lake Naivasha, habitat and biodiversity mapping and RS and GIS application on wildlife were reviewed.

- **Draft proposal**

A draft proposal was written.

- **Image processing**

A Landsat Thematic Mapper TM image of January 1995 was used for the design of a sample scheme and the preparation of a land cover map. A false colour composite (FCC 541) was made using the following band combinations.

1. Band 1 = blue band
2. Band 4 = green band
3. Band 5 = red band

The above band combination was made to be able to distinguish different cover types from the image e.g. water, vegetation cover, agricultural fields and built up areas.

- **Georeferencing TM image 1995**

The FCC 541 image was georeferenced using a 1975 topographical map scale of (1:50 000).

- **Visual image interpretation**

Preliminary visual image interpretation of the image was done to classify land cover types. The main strata were defined based on geology, landform and expected vegetation cover (color and texture, shape)

- **Preparation of relevee sheet**

A relevee sheet for field sampling was designed to obtain information on land cover and general land use. A sample of the relevee sheet is shown in Appendix 1.

- **Visit to Wetland International**

A visit was made to Wetland International in Wageningen (Lake Naivasha Information sheet + MedWet data base were obtained).

- **Design of sample scheme**

A stratified representative sample scheme was designed based on the preliminary landcover units and existing geological and landform maps.

4.1.2 Fieldwork

During the fieldwork both primary and secondary data were collected.

- **Reconnaissance survey.**

A two day reconnaissance trip through the fieldwork area was carried out.

This was done for the

1. overview of the study area in respect to land cover, landuse, landform, lake level and general orientation of the study area.
2. Identification of vegetation zonation of the lake zone.
3. testing of the relevee and stratified representative sampling according to vegetation zones using linear transects (from the lake up to the road)

- **Field Sampling**

-Number of samples

108 samples out of the 160 samples initially selected could be investigated.

-Method of sampling

The stratified representative sampling method was selected based on visual difference in vegetation pattern in the field (zonation) in relation to landform and distance to the lake (soil water depth). This method is very cost efficient compared to random sampling and often yield very useful results, especially when only small numbers of samples can be obtained under time constraints as was the case of this study.

Furthermore, part of the area was not accessible so that these parts needed to be interpreted from image characteristics, which have been related to samples with similar image characteristics in accessible parts of the study area.

A disadvantage is that the statistical precision of the mapping cannot be evaluated.

-Distribution of samples

The coordinates of each sample point were taken with the help of a GPS Figure 4.2 shows the spatial distribution of the sample points on the TM image.

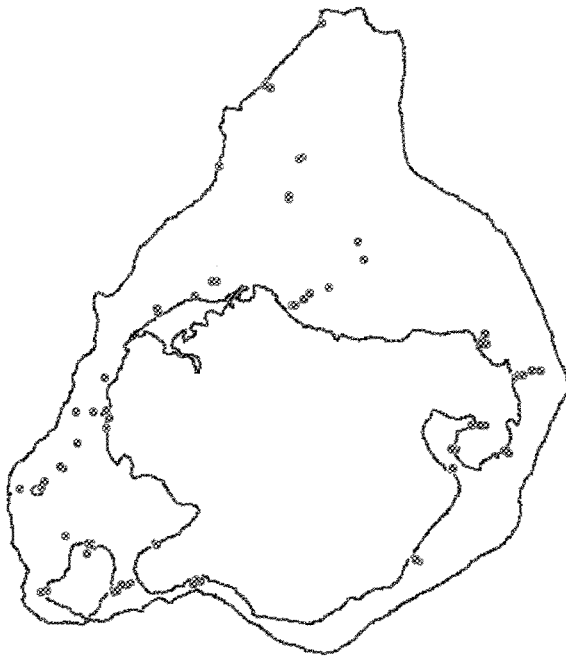


Figure 4.2 Spatial distribution of sample points

-Size of samples

The plot sizes were according to structural cover. The plot sizes were:

5m x 5m	grassland
10m x 10m	homogenous shrub cover
20m x 20m	heterogeneous shrub cover
25m x 25m	Open Woodland
50m x 50m	Dense woodland

-What to be sampled

In addition to the coordinates the following information about sample locations were recorded:

- * structural cover classes (average height and percentage of cover per structural layer)
- * Dominant species composition according to Braun-Blanquet scale (average height, growth-form and cover percentage per species; for papyrus: diameter at breast height of 10 species of one stand/clump)
- * main landform
- * soil characteristics (ground water level, texture and color)
- * water salinity (conductivity)
- * main land use (incl. signs of grazing/droppings by livestock and or wildlife)
- * signs of (human) impacts (burning, drainage, clearing, erosion)

For the details see sample of relevee sheet in Appendix 1.

- **Census of indicator species**

A two day boat survey was carried out in June 1997 along the shore of Lake Naivasha. The lake shore was divided into nine sections with identified landmarks. The first day covered sections West of Elsamere - Hopcraft while the second day covered sections from East of Hopcraft - Elsamere (see Figure 4.5).

The locations of *H. amphibius* and fish eagle were recorded with the help of GPS. The total number of animals in each location were counted together with two assistants by means of pairs of binoculars. Habitat types in which fish eagles were located were also recorded.

- **Secondary data collection, visit offices/institutes/persons**

Secondary data collection included visit to offices/institutes/ persons were made during the period of 15th May 1997 to 12th June 1997. The type of data collected and their sources are indicated in Table 4.1

Table 4.1 Secondary Data Sources

ORGANISATION	UNIT	DATA TYPE
Fisheries Department	District Office Naivasha	Monthly Fish and Crayfish production from 1989 - 1996
The National Museums of Kenya	Kenyan Wetland Working Group	Annual waterfowl counts 1993 -1997
Leicester University/ Earthwatch/ Elsamere	African fish eagle project	Monthly fish eagle monitoring figures April 1995 - February 1997 and hippo counts figures of april 1995 - February 1997
Kenya Wildlife Service	National Headquarters	General information on animal species of Naivasha area
	Kenya Wildlife Service Training Institute	Literature from Library
Ministry of Planning and National Development	Department of Resource Surveys and Remote Sensing	Aerial photographs, Land use maps and topomaps.

4.1.3 Post fieldwork

This phase involved the interpretation of aerial photographs, Landsat TM image and digitizing using ILWIS 2.1 software to generate habitat maps. The steps used for the habitat mapping are shown in Figure 4.3.

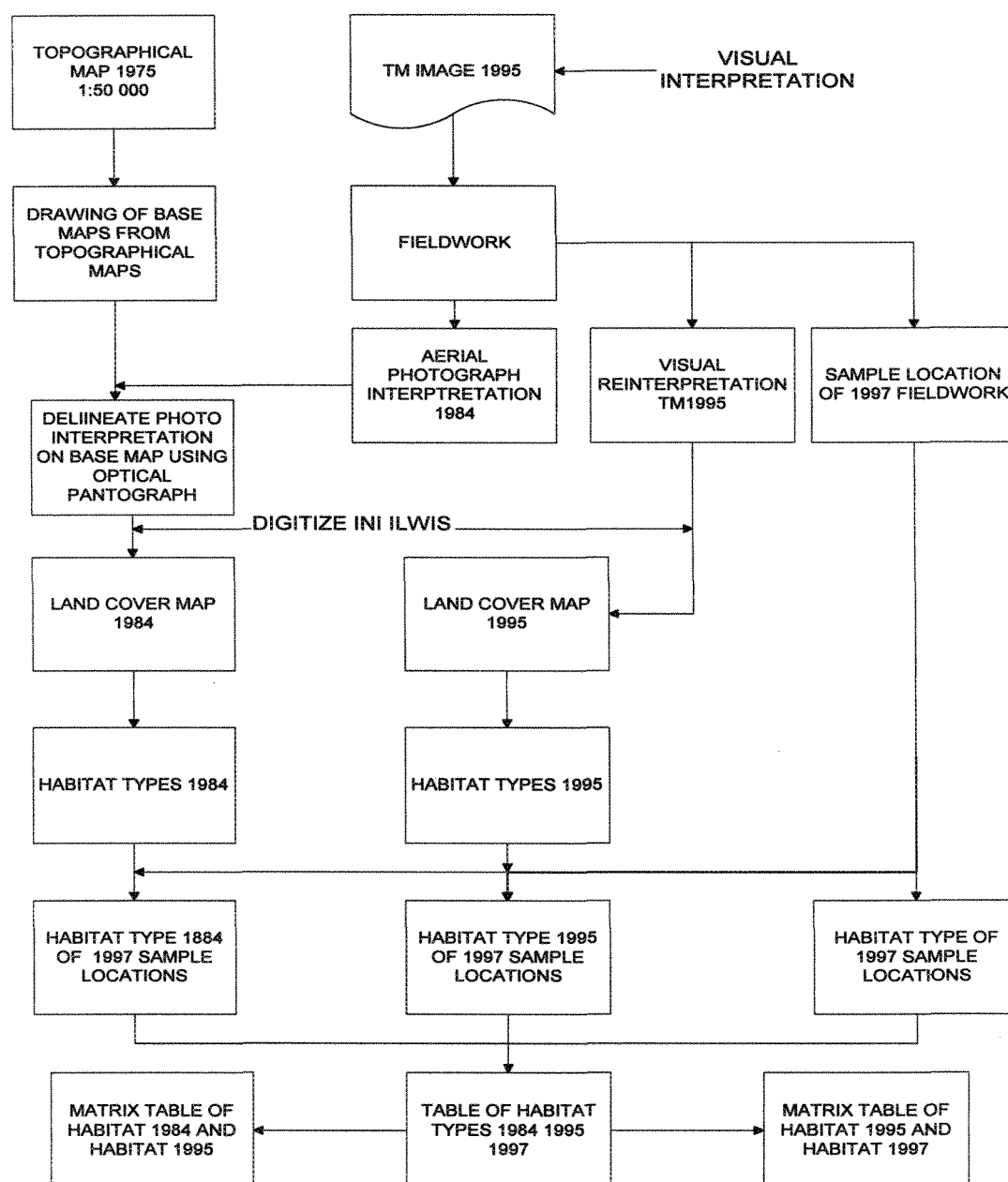


Figure 4.3 A flowchart showing steps for Habitat mapping

- **Aerial Photographs and Satellite image interpretation**

Aerial photographs of 1984 scale 1:12 500 and hard copy of Landsat TM image of 1995 were visually interpreted after fieldwork to delineate land cover units. Photo image characteristics (Field pattern, shape, tone, texture and vertical structure) were described to distinguish different land cover types. A photo interpretation key was designed and land cover maps and legend were made (see Appendix 2).

- **Generation of 1984 and 1995 Land cover maps**

The interpreted Land cover maps of 1984 and 1995 were of varying scales, therefore a common scale of 1:50 000 was selected for the output. A 1:50 000 base map traced from a 1:50 000 topographic map of 1975 was used. The cover types were transferred from the interpreted aerial photographs to the base map by means of the pantograph. In addition, the inherent errors of the photo graphs due to tilt and relief displacement were corrected.

- **Digitizing**

The generated Land cover maps of 1984 and 1997 scale 1:50 000 were digitized and rasterized using ILWIS software.

- **Fish eagle nesting habitat**

The fish eagle's nesting and roosting habitat for 1984 and 1995 were obtained from habitat type maps of 1984 and 1995 by using map calculation formulae.

The area covered by woodland for 1984 and 1995 were calculated using the Histogram operation option from ILWIS. The resulting change in area was calculated from the difference in area.

- **Sections for monitoring**

The sections for monitoring by the Kenyan Wetland Working group (KWWG) and Leicester University/Earthwatch/Elsamere (LEE) were digitized (Figures 4.4 and 4.5) and areas calculated (Tables 4.2 and 4.3).

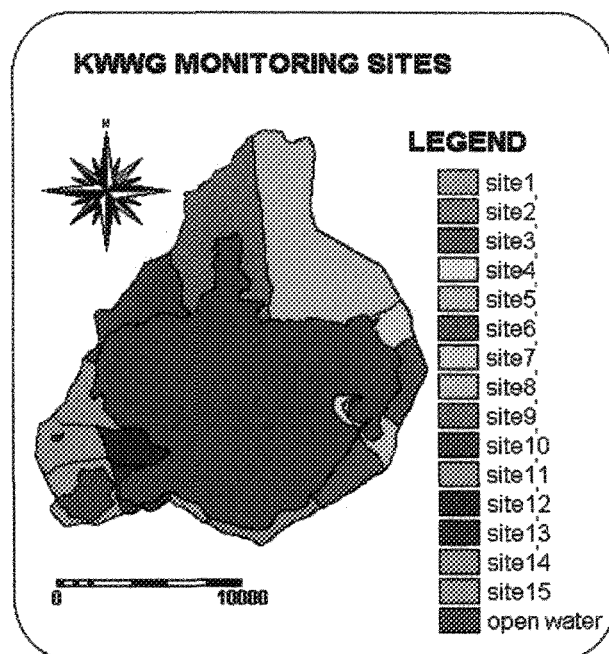


Figure 4.4 Sections for waterbirds monitoring by Kenyan Wetlands Working Group (KWWG).

Table 4.2 A table showing the areas of sections for monitoring by KWWG

SECTION	LOCATION	AREA (HA)
1	Elsamere - Fisherman's camp	114.2
2	Fisherman camp - Safariland jetty	412.5
3	Safariland jetty - Crescent Island tip(west)	665.0
4	Crescent Island tip (west) - Crescent Island tip (east)	117.3
5	Crescent Island tip (east) - Lake Naivasha hotel	334.9
6	Lake Naivasha hotel - Game institute building	563.9
7	Game institute building - New fisheries jetty	400.4
8	New fisheries jetty - Gilgil river input	4515.3
9	Gilgil river input - Hopcraft (green mill)	2893.7
10	Hopcraft(green mill) - Rema island	1187.5
11	Rema island - Mennel lagoon	664.5
12	Mennel lagoon - Hippo point	581.6
13	Hippo point - Elsamere	246.3
14 SO	Lake Sonachi	812.4
15 OL	Lake Oloiden	634.8

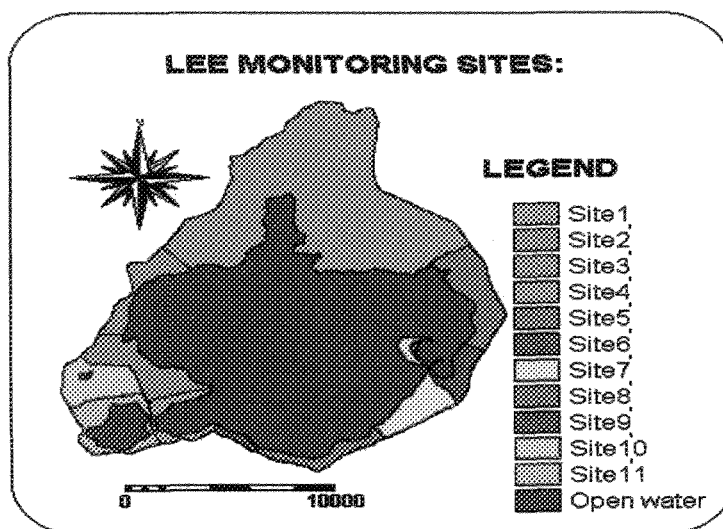


Figure 4.5 Sections for monitoring by Leicester University/Earthwatch/Elsamere (LEE).

Table 4.3 A table showing the areas of sections for monitoring by LEE

SECTION	LOCATION	AREA (HA)
1	Elsamere - Hippo point	343.8
2	Hippo point - Rema Island	981.3
3	Rema Island - Hopcraft	591.5
4	Hopcraft - Karati	803.0
5	Karati - Lake Naivasha hotel	1005.3
6	Crescent Island - Lagoon	436.3
7	Outside Crescent Island - Safariland	782.3
8	Safariland - Fisherman's camp	412.5
9	Fisherman's camp - Elsamere	114.2
10	Lake Sonachi	812.4
11	Lake Oloiden	634.8

- **Fish eagle and it's prey distribution maps 1993 - 1997**

The data on waterfowls monitoring by Kenyan Wetlands Working Group (KWWG) from 1993 - 1997 were used for the calculation of index (see Chapter2, section 2.5 on Index number calculation). Data on African fish eagle, Cormorants and Red Knobbed coot were extracted from the raw census files of KWWG.

- The sections for monitoring waterfowls annually by KWWG were digitized as segments, polygonized and Rasterized .
- Attribute tables of African fish eagle, cormorant and coot abundance were created in ILWIS table menu. This was linked to the rasterized site by a common domain.
- An attribute rasterized map was created from the operations menu of ILWIS.
- The attribute rasterized map was classified by using the slicing operation. Slicing classifies the values of the attribute raster map. The ranges of values of the input are grouped together into one output class. A domain group which lists the upper boundaries of the groups and the group names was created before hand. Slicing operation requires an input value map and group domain.

- **Fish eagle location June 1997**

The fish eagle locations recorded with Global Positioning System during the fieldwork in June 1997 can be found in Appendix 4 . The Leicester University/Earthwatch/ Elsamere sections for monitoring the African Fish Eagle were used during the June 1997 fieldwork, census. These sections were digitized, polygonized and rasterized .

- **Fish analysis**

Records of monthly fish and crayfish production from the District Fisheries Office in Naivasha from 1989 - 1996 were compiled into annual production and displayed graphically for trend analysis.

- **Calculation of Index Numbers**

The calculation of temporal (annual) index numbers from wildlife monitoring data in this study was based on the approach of Crawford (1991).

The detailed steps for the calculation of index numbers are shown below:

- Site abundance are first transformed logarithmically. A constant 1 is added to the abundance before the transformation in order to transform sites with zero observations.
- Geometric means for each year is calculated .

- Calculated geometric means are used for the calculation of yearly index numbers. The first year in this case 1993 is selected as the reference base.

$$\text{INDEX NUMBER} = \frac{\text{GEOMETRIC MEANS OF A YEAR}}{\text{GEOMETRIC MEANS OF REFERENCE BASE}} \times 100$$

$$\text{Index number} = \frac{[\text{Antilog } (\log X_1 + \log X_2 + \dots + \log X_{13})/13] \text{ of a year}}{[\text{Antilog } (\log X_1 + \log X_2 + \dots + \log X_{13})/13] \text{ of reference base(1993)}} \times 100$$

where X_1, X_2, \dots, X_{13} are site abundance for the thirteen sites for monitoring on Lake Naivasha by the Kenyan Wetlands Working Group (KWWG)

- **Hippo Grazing Habitat analysis**

The Hippo nocturnal grazing habitat was derived from the cover of Grassland Papyrus and Agricultural area of the 1995 Habitat type maps. The map calculation operation option was used. The areas covered by Grassland, papyrus and Agricultural area in 1995 were calculated using Histogram operation option of ILWIS (Appendix 7).

- **Hippo distribution map**

The hippo locations recorded with GPS during the June 1997 fieldwork were used to create the hippo distribution map. The Leicester University/Earthwatch/ Elsamere sections for monitoring were used during the June 1997 fieldwork, census. These sections were digitized, polygonized and rasterized. The point map was overlaid.

- **Hippo density calculation**

The hippo population density was calculated by using population figures of April 1995 - April 1997 from LEE monitoring data.

$$\bullet \text{ Nocturnal Grazing density} = \frac{N}{A_1}$$

Where N is the total population of hippo and A_1 is the area covered by Agricultural area, Grassland and papyrus in 1995.

There is an assumption that there is no significant change in habitat areas between 1995 and 1997.

- **Hippo distance map**

A distance map using the distance from water was created and used to estimate the distance covered by Hippos in Naivasha.

- Source map open water was created from the habitat map 1995 using map calculation formula (Appendix 7)
- A domain open water was created and representation edited. A distance operation from ILWIS menu was used on the created Source map, Open Water.
- The distance map was classified into value ranges with upper class boundaries of 1000, 1500, 3000, 6000, 10000.

4.2 Materials

The following materials were used for the study:

Remote Sensing materials.

These included

- **Aerial photographs 1984 scale 1:12,500**
- **Landsat thematic mapper TM imagery of January 1995**
- **Landsat thematic mapper TM imagery of March 1989**

Maps

The maps used during the study are indicated in Table 4.4

Table 4.4 Maps used in the study

MAP TYPE	MAP SHEET NO.	SCALE	DATE	SOURCE
Topo map	SA -37 - 1	1:250,000	1981	Surveys of Kenya
Topo map	133/2(Naivasha), 133/4(Longonot)	1:50,000	1975	Surveys of Kenya
Geological map	-	1:100,000	1988	Government of Kenya, Ministry of Energy, Geothermal section

Other materials

- Computer Softwares for data processing and analysis.
 - ILWIS 2.1 (Windows application)
 - Microsoft Excel (Windows application)
 - Microsoft Word (Windows application)
 - Visio (windows application)
- Relevee sheet for vegetation cover
- GPS (Germini)
- Pair of Binoculars
- Mirror stereoscope
- Pantograph
- Conductivity meter
- Soil auger, Munsell color chart and soil texture description
- Haga meter (to measure tree height)

CHAPTER FIVE: HABITAT DISTRIBUTION AND HUMAN ACTIVITIES

5.1 Introduction

The spatial distribution of habitat (land cover) types in the Ramsar site of Lake Naivasha was mapped and analysed. The habitat distribution of 1984, 1995 and fieldwork 1997 were compared. Furthermore the human activities affecting habitat and biological diversity were identified.

5.2 Vegetation mapping

The structural vegetation cover classes were derived by plotting the % of cover of the different vegetation strata for each sample. The result is a structural vegetation cover classification diagram as indicated in Figure 5.1. The sample numbers plotted in the classification diagram can be found in Appendix 3.

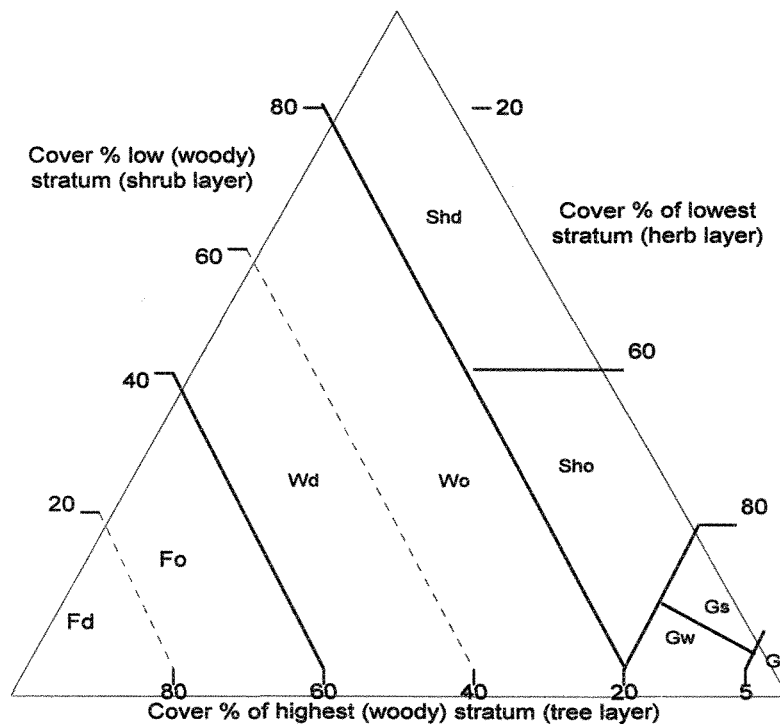


Figure 5.1 Structural vegetation cover classification diagram

Fd = Dense forest, Fo = Open forest, Wd = Dense woodland, Wo = Open woodland, Shd = Dense shrubland, Sho = Open shrubland, Gw = Woody grassland, Gs = Shrubby grassland and G = Grassland.

To facilitate the discrimination between the classes on both the aerial photograph and hard copy of Landsat TM image some classes were amalgamated (Table 5.1).

Table 5.1 Structural vegetation cover classification scheme

ESTIMATED COVER (%)	INFERRED VEGETATION TYPE
Tree layer > 60	Forest
20 - 60	Woodland
Tree layer <20, but shrub layer ≥20	Shrubland
Tree layer < 20, shrub layer <20 but grass cover ≥80	Grassland

The study further provided an updated list of species based on field work, Gaudet (1977) and Literature (Agnew and Agnew 1994, Beentje 1994, Blundell 1994 and Ibrahim and Kabuye 1987.) in Appendix 5. A preliminary TWISPAN analysis of the sampling data produced a table of vegetation type and species groups (Appendix 6). A further investigation is needed when recent and higher resolution imagery becomes available.

5.3 Habitat types

In this study the concept of habitat as an environment within which many species may live was used. The following cover types (habitat types) were identified in the study: Open water, Macrophytes, Papyrus, Grassland, Shrubland Woodland and Agricultural area. Of these habitats, particularly the Woodland, Papyrus, Grassland, Open Water and Macrophytes are used by many animal species living around the lake.

Woodland is mainly dominated by *Acacia xanthophloea* and is the nesting and roosting habitat for the African fish eagle (*Haliaetus vocifer*), Grey-backed Fiscal Shrike (*Lanius excubitorius*) and many other bird species. The under-story of this monotypic stand of *Acacia* woodland is occupied by commonly perennial shrubs *Achyranthes aspera*, *Hypoestes verticillaris* and *Solanum incanum*. The Giraffe (*Giraffa camelopardalis*) was observed in the field feeding on the leaves of *Acacia*. (Figure 5.2).



Figure 5.2 A Giraffe (*Giraffa camelopardalis*) Feeding on *Acacia*.

Papyrus as a habitat is used by many birds as cover, roosting and perching. The buffalo (*Syncerus caffer*) and hippopotamus (*Hippopotamus amphibius*) also use it as cover. Henderson and Harper (1992) in their study Bird Distribution on Lake Naivasha identified the long-tailed cormorant (*Phalacrocorax africanus* L.), the Great cormorant (*Phalacrocorax carbo* L.), night heron (*Nycticorax nycticorax* L.), malachite kingfisher (*Alcedo cristata* L.) and little bittern (*Ixobrychus minutus*) as some of the species using papyrus for roosting and perching. The Goliath heron (*Ardea goliath*) was observed in the papyrus (Figure 5.3.). The Papyrus prevent excessive eutrophication of the lake through filtering out of nutrients. Therefore the destruction of this habitat not only affects the avifauna but also the quality of the lake.



Figure 5.3 A Goliath Heron Perching in a Papyrus stand.

Grassland host many ground feeding bird species like finches, starlings, crowned plovers, secretary birds and francolins. It is also the hunting grounds of some raptors. This habitat is also the home of many mammalian species, like buffalo, zebra (Figure 5.4.), Thomson gazelle, impala etc. The Hippopotamus amphibius graze in this habitat during the night.

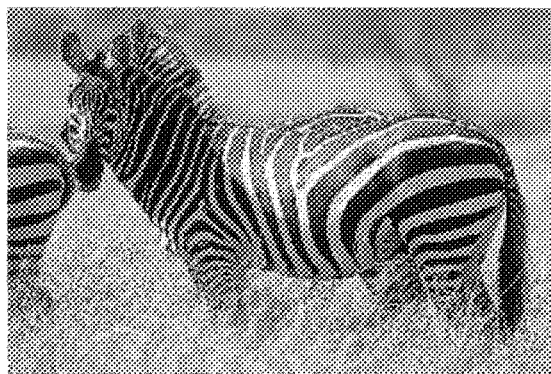


Figure 5.4 A Zebra in a Grassland.

Shrubland is also the habitat of many bird species like White-fronted bee eaters, cattle egrets, swifts and sparrows.

Agricultural areas benefit species like weavers, pigeons, cattle egrets and sparrows.

Macrophytes play an important role by providing food, shelter for animals especially young fish. It also host many bird species like the Avocet (Figure 5.5).



Figure 5.5 An Avocet feeding in a Macrophyte bed

The *Eichhornia crassipes* rooted in shallow water provides dwelling place for 28 invertebrates species of the Hemiptera and Coleoptera (Haper 1992). The *Eichhornia crassipes* beds fringing the papyrus are perching site for the African Jacana (Figure 5.6).



Figure 5.6 The African Jacana perching on an *Eichhonia crassipes* bed.

The cormorants (*Phalacrocorax* spp.), grebes, gulls, terns are frequent bird species on the *open water* (Henderson and Harper 1992). The open water is also the habitat of fish species and *Hippopotamus amphibius*.

5.4 Spatial distribution of Habitat types 1984

The spatial distribution of the different habitat types in 1984 is presented in Figure 5.7

Figure 5.7 Spatial Distribution of Habitat Types 1984

The total area of each habitat type and percentage for 1984 are listed in Table 5.2.

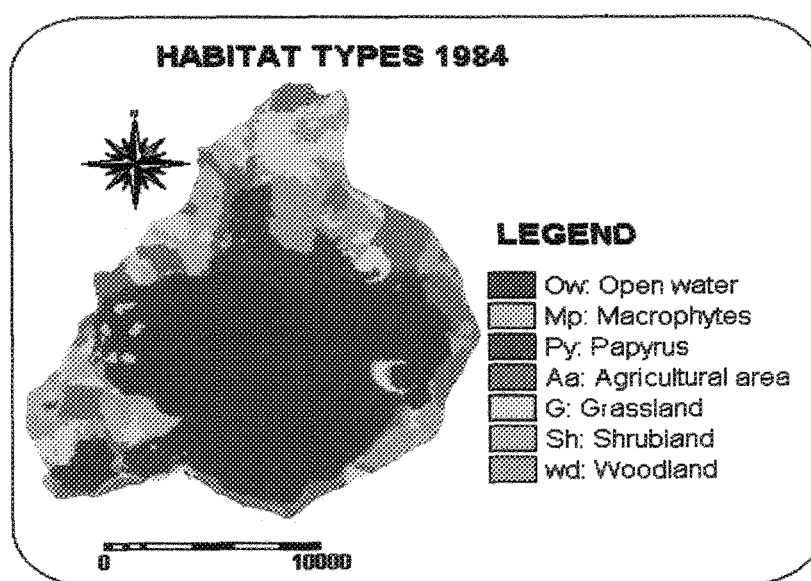


Table 5.2 Habitat Types and Percentage of Total area for 1984

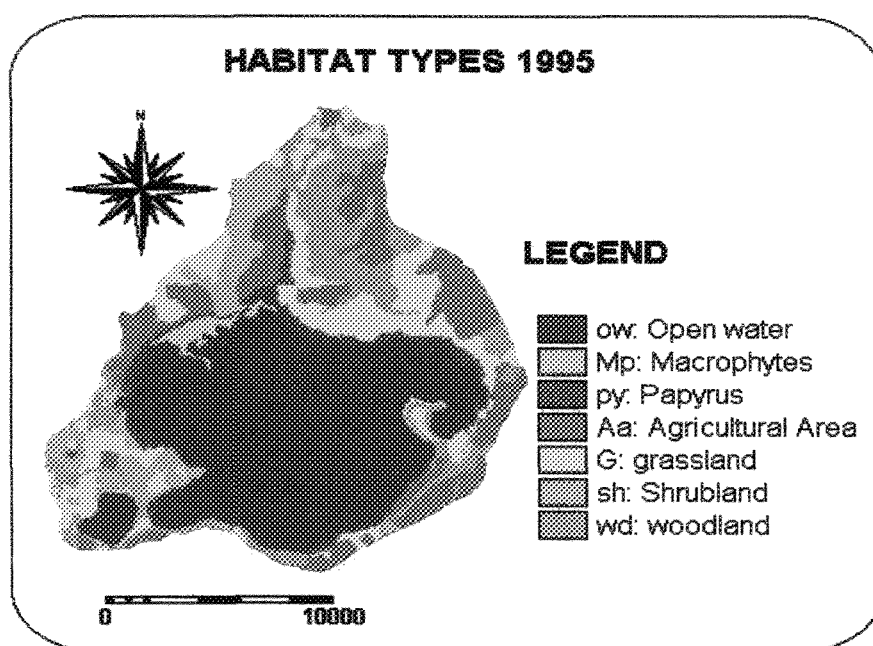
HABITAT TYPE	AREA (HA)	% OF TOTAL AREA
Open water	14695.16	48.77
Macrophytes	210.00	0.70
Papyrus	2395.80	7.95
Agricultural Area	3797.52	12.60
Grassland	3090.64	10.26
Shrubland	1944.32	6.45
Woodland	3998.96	13.27

5.5 Spatial distribution of Habitat types 1995

Figure 5.8 shows the spatial distribution and Table 5.3 lists the total area and percentage of total area for each habitat type for 1995.

Figure 5.8 Spatial Distribution of Habitat Types 1995.

Table 5.3 Habitat Types and Percentage of Total area for 1995



HABITAT TYPE	AREA (HA)	% OF TOTAL AREA
Open water	12722.92	42.22
Macrophytes	361.80	1.20
Papyrus	1400.28	4.65
Agricultural Area	4560.80	15.14
Grassland	4859.28	16.13
Shrubland	2065.44	6.85
Woodland	4162.08	13.81

5.6 Habitat changes 1984 - 1997

The changes resulting from the habitat maps of 1984 and 1995 are summarised into Table 5.4 below.

Table 5.4 Habitat Type changes in Lake Naivasha 1984 -1995

HABITAT TYPE	AREA (HA) 1984	AREA (HA) 1995	AREA DIFF. (HA) 1984 - 1995	% CHANGE
Open water	14695.16	12722.92	- 1972.24	-13.42
Macrophytes	210.00	361.80	+ 151.80	+71.00
Papyrus	2395.80	1400.28	- 995.52	-41.58
Agricultural area	3797.52	4560.80	+ 763.28	+20.09
Grassland	3090.64	4859.28	+1768.64	+57.22
Shrubland	1944.32	2065.44	+ 121.12	+ 6.23
Woodland	3998.96	4162.08	+ 163.12	+ 4.07

The percent change column was calculated relative to the area of coverage in 1984. Positive (+) values indicate an increase in area for that habitat type during the period and negative (-) values indicate a reduction in area. Open water and papyrus show a decrease of nearly 2000 and 1000 ha or 13.4% and 41.6%, respectively. The other habitat types all show an increase in area. In contrast to earlier reports mentioning a decrease in (Acacia) woodlands, the habitat type woodland shows an increase of 163 ha or 4.1%.

5.7 Human activities and Biodiversity

Species and communities tend to persist in the same place with time provided the conditions remain undisturbed. This is because species and the communities they belong are adapted to the pertaining local environmental conditions. Though there are natural changes in the ecosystem and climate, this change is gradual and slow, that species are able to adjust gradually in relation to the changes (Gates 1993).

This slow pattern of change in biological communities has been disrupted by human activities which altered, degraded and destroyed these communities. The six threats to biodiversity resulting from human activity are habitat destruction, habitat fragmentation, habitat degradation (including pollution), the introduction to exotic species, the increased spread of disease and the over-exploitation of many species for human use (Primack 1993). Three of these threats are habitat related.

Human activities, issues and the type of threat to biological diversity were identified after reviewing the management plan and field observations. The type of threat to

biodiversity for each issue of human activity were subjectively assigned a score of 20 (Table 5.5). This gives equal weight to each threat. The three habitat related threats were used. A matrix of human activity against threats to biodiversity and their scores are shown in Table 5.6.

Table 5.5 Human activity, issues and type of threat to Biodiversity

HUMAN ACTIVITY	ISSUE	TYPE OF THREAT	SCORE
Agriculture	Reclamation of land from Papyrus swamps for large scale and subsistence arable crops.	Habitat destruction	20
	Division of agricultural areas into pieces by fields, roads and fences.	Habitat fragmentation	20
	Sediment deposits from eroded hillsides.	Habitat degradation (including pollution)	20
	Agricultural run off- pesticides, herbicides, fungicides , fertilisers and organic from livestock etc.	Habitat degradation (including pollution)	20
	Irrigation of crops with lake water	Habitat destruction	20
Deforestation in catchment areas	Clearing of forest areas	Habitat destruction	20
	Fragmented farms	Habitat fragmentation	20
	Resulting hillside erosion	Habitat degradation (pollution).	20
Commercial Fishing	Water quality (oil spills from boats)	Habitat degradation (Pollution).	20
Industrialisation	Access to water for geothermal plant	Habitat destruction	20
Urbanisation	Damming of Malewa river reducing water flow to the lake	Habitat destruction	20
	Urban run-off from Naivasha township	Habitat degradation (pollution).	20

Table 5.6 A matrix of threats to Biodiversity against human activities

THREATS TO BIODIVERSITY HUMAN ACTIVITY	HABITAT DESTRU- CTION	HABITAT FRAGME- NTATION	HABITAT DEGRAD- ATION	SCORE
AGRICULTURE	XX	X	XX	100
DEFORESTATION	X	X	X	60
COMMERCIAL FISHING			X	20
INDUSTRIALIZATION	X			20
URBANIZATION	X		X	40

From Table 5.6 Agriculture is the major human activity threatening biodiversity, followed by deforestation, urbanisation and commercial fishing and industrialisation.

5.8 Discussion

This study has provided information on the changes in habitat types between 1984 and 1995 of Lake Naivasha's Ramsar site (Table 5.4). From the results of the study the main changes of habitat in Lake Naivasha are the loss of open water areas of 1972.2 ha (13.42%) and papyrus of 995.52 ha (41.58%). This is due to the frequent decline in lake level. The receding water level give rise to drawdown zone of stranded Papyrus clumps, grasses (*Cynodon dactylon*, *Cynodon plectostachyus*, and *Pennisetum* spp.) and herbs like *Polygonum* spp.. Lost areas are naturally taken over by grasslands and Acacia woodland. From the results in Table 5.4 there was an increase of 1768.64 ha (57.22%) in grassland and 163 ha (4.07%) in woodland from 1984 to 1995. The results of the study confirm the phenomenon of grassland and woodland taken over lost areas of open water as the water level recede.

The negative effect of converting the lost areas into farms is a major threat to the lake. From 1984 - 1995 there was an increase of 763.28 ha (20.09%) in Agricultural area. The flat and fertile land of these Papyrus and grassland zone are reclaimed for both commercial and subsistence agriculture as the lake level declines (Haper 1990). The consequence of this action is increased levels in nutrients through leaching and run-off directly from the farms and through loss of swamps buffering effect (Gaudet 1980).

Eichhornia crassipes was observed at the fringes of the papyrus zone. There was an increase of 151.80 ha (71.0%). Henderson and Harper (1992) concluded in their study that macrophytes have major influence on Lake Naivasha's bird community since past and present information indicated that waterfowl abundance is closely linked with macrophyte development.

The major threat of habitat to biological diversity is habitat destruction (habitat loss), from expanding human populations and human activities (Ehrlich 1988). When habitat is destroyed there is often a patchwork of habitat fragments which can be described as islands in an inhospitable agricultural sea. Fragmentation goes with severe reduction in habitat area but can occur even when an area is reduced to only a minor degree if the original habitat is partitioned by roads, fences, canals or other barriers as observed in Lake Naivasha. Furthermore if a habitat is not affected by over destruction or fragmentation it can be affected by external factors resulting from human activities that do not change the structure and dominant plants in the habitat that the damage is not immediately apparent (Primack 1993). This is the case of fire, pesticide, other agro-chemicals and sediments from eroded cultivated areas that contribute to environmental degradation.

Significant losses of biodiversity can take place when the habitat is not affected by habitat destruction, fragmentation and degradation as result of the introduction of exotic species and over exploitation particular species by people. Lake Naivasha is marked with species introductions ranging from plants, fishes, reptiles to mammals (Harper et. al 1990). One of such introductions worth mentioned is the Louisiana crayfish (*Procambarus clarkii*) which has cyclic interaction with macrophytes on the lake.

Whiles humans have imposed many undesirable and often unexpected changes on habitats, they often have the capacity to modify the rate of such changes or to reverse them. In the case of chemicals the discontinuing of a practice which has proved undesirable or replacing it with another which has been less detrimental in its effect can reverse the situation.

It is not always possible to distinguish and separate the part played by humans and that played by natural climatic changes. Nonetheless in Lake Naivasha human actions like damming of the Malewa river, water abstraction for irrigation purposes, industrial withdrawals for geothermal energy generation and agricultural activities are contributing to the falling lake levels.

The changes in water levels led to increase salinity of the lake. Furthermore, the effect of the changes in level has been a decline in fish numbers due to the disappearance of shallows waters. These are biologically the most productive zone of the lake, providing food base for the fish and also serving as spawning grounds for some species.

- Limitations

There was no Hyper-spectral data of the study area, and the available TM image is too small scale to map specific vegetation zonation from the lake up to the road. The level of details from the aerial photographs and Landsat TM image were different therefore some

of the land cover units were amalgamated. These were used for the mapping of broad habitat types used in the study.

In this study the 1984 habitat coverage was digitized from aerial photograph scale 1:12500, and the 1995 habitat coverage also digitised from Landsat TM image. Errors in the alignment of the coverage are therefore inherent due to different sources of materials of varying scales (aerial photograph and Landsat TM image). Chandler et. al (1994) in their study using Geographical Information System to analyze Bald eagle habitat detected that coverage from different source materials do not have the mutual consistency needed for the determination of area of habitats.

The tools used for mapping habitat in the study were remote sensing by aerial photographs (Panchromatic), and Satellite imagery (Landsat TM). The aerial photograph (scale 1:12500) appeared to be more accurate and easy in the delineation of the habitat types. The aerial photographs can be used in the determination of the accuracy of a classified Satellite image (Lantieri 1988).

The aerial photograph of 1984 was an aid in the interpretation of the satellite imagery of 1995. The interpretation of the photographs and the hard copy of the TM image is subjective in the determination of habitat boundary whereas if computers were used for the classification of habitats it would have been determined objectively through the use of digital classification.

It is arguable, however whether the removal of analyst subjectivity by using computer based classification is truly advantageous. The human eye can readily assimilate important textural properties in the photographs that require sophisticated image processing techniques to objectively generate.

The manual (visual) interpretation experiences shortfalls if several analyst work on the same data since there will undoubtedly be some variation in interpretation between individuals. The objective approach will be quicker, less expensive and more accurate, particularly if the study area were to be extensive. Clearly if the site is small it may prove less expensive to use aerial photography rather than to purchase a satellite imagery.

The Landsat TM image is useful for large areas, when area photographs are not available as was the case of this study and/ or when less precise delineation is needed.

To determine whether the 1995 TM image can be used as a reliable source for the 1997 sample data I had to find out if there are not too many changes in land cover. Therefore the Samples locations of the 1997 fieldwork were plotted on the 1995 habitat maps. The following assumption was made.

The assumption is that:

Not more than 10% changes in habitat types have occurred from 1995 - 1997.

The habitat type of these samples locations from the 1995 habitat maps and the 1997 fieldwork were summarised into a Table. Matrix tables of habitat types and number of sample locations for 1995 against 1997 constructed are shown in Tables 5.7.

Table 5.7 Matrix of habitat types and number of sample locations for 1995 against 1997

HABITAT 1995 \ HABITAT 1997	OW	WD	AA	SH	G	PY	MP
Ow	2 (13.3)	-	-	-	-	3 (9.1)	-
Wd	-	10 (50)	-	2 (28.6)	-	-	-
Aa	-	-	3 (60)	-	-	-	-
Sh	-	6 (30)	-	2 (28.6)	1 (3.1)	1 (3.0)	-
G	11 (73.3)	4 (20)	2 (40)	3 (42.8)	29 (90.6)	9 (27.3)	-
Py	2 (13.3)	-	-	-	2 (6.3)	20 (60.6)	-
Mp	-	-	-	-	-	-	-

Figures in brackets are percent of samples.

* Ow = Open water, Wd = Woodland, Aa = Agricultural area, Sh = Shrubland, G = Grassland, Py = Papyrus and Mp = Macrophytes.

Changes that occurred between 1995 and 1997 were the reduction in areas which were under water to grassland (11 samples, 73.3 %) and papyrus (2 samples, 13.3 %). There were also changes of papyrus to grassland (9 samples, 27.3 %), woodland to shrubland (6 samples, 30 %) and woodland to grassland (4 samples, 20 %). Those changes of samples follow the general trend of changes in Table 5.4.

Therefore, the assumption that not more than 10% changes in habitat types have occurred from 1995 - 1997 does not hold.

Though aware of the differences between 1995 TM and the 1997 field data, the analysis had to be based on the 1995 TM image, as there are no recent aerial photographs or imagery.

Habitat coverage from the same source of remote sensing material could be used effectively to improve the consistency needed for the determination of the total area of the different habitats. For delineation and survey of wetland habitats infrared aerial photographs are recommended (Taylor et. al 1995).

CHAPTER SIX: AFRICAN FISH EAGLE AS AN INDICATOR

6.1 Introduction

The African fish eagle (*Haliaeetus vocifer*), more than any other species, represents a barometer of the quality of Lake Naivasha. Where the bird continues to fare well, we can be confident that the water systems are clean, where they do not, there is cause for concern.

The African fish eagle (*Haliaeetus vocifer*) and its prey of fish, cormorants (*Phalacrocorax* spp) and the red knobbed coot (*Fulica cristata*) were selected based on their relation in the food chain of Naivasha ecosystem. The trends in the abundance of African fish eagle and its prey (Cormorant and Red knobbed coot) were determined by calculating Index numbers from the annual waterfowl monitoring records obtained from the Kenyan Wetlands Working Group's (KWWG) (see details of the calculation at Chapter four, section 4.1.3). In section 6.4 bird species diversity within Lake Naivasha is described and the annual composite index is calculated, mainly to see whether the same pattern in total species numbers can be observed as that of the two prey species, coot and cormorant.

6.2 Fish eagle's Habitat

Harper (1989) concluded that the preferred habitat of the Fish eagle is that with Acacia trees along the shore or situated back from the shore where the shoreline is fringed by papyrus. The results of habitat use by the Fish eagle during the month of June 1997 fieldwork indicated that the relative probabilities of seeing a fish eagle on Acacia and Ficus woodland, Papyrus and Floating vegetation were 0.73, 0.11 and 0.16 respectively (Appendix 4). The Acacia woodland is used for roosting, nesting and perching. The spatial distribution of the woodland habitat per sections for monitoring by KWWG for 1984 and 1995 are as displayed in Figures 6.1 and 6.2.

The comparison between the habitat revealed that between 1984 and 1995 there was an increase of 163.12 ha (4.07%) woodland (Table 5.4). The shoreline woodland preferred by the fish eagle remained undisturbed. Sites 1, 2, 4, 7, 8, 9, 10, 11, and 13 have increase while sites 3, 5, 6 and 12 have decrease in area of woodland between 1984 and 1995 (Table 6.1).

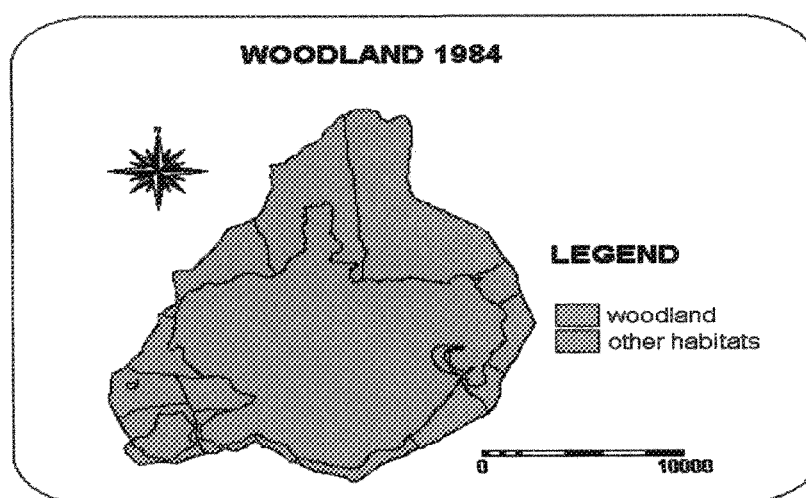


Figure 6.1 Fish Eagles habitat distribution 1984 per section

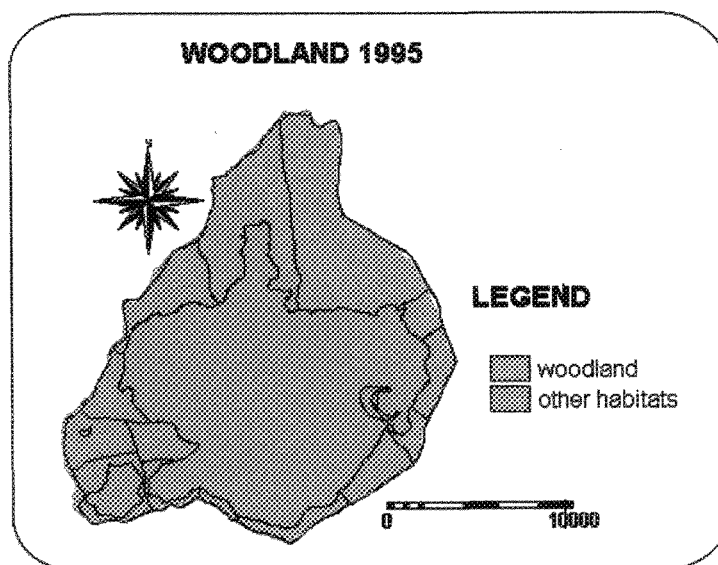


Figure 6.2 Fish Eagles habitat distribution 1995 per section

Table 6.1 A table showing area of woodland and change in area from 1984 -1995

SITE	1984(HA)	1995 (HA)	DIFFERENCE (HA)
1	21.8	41.6	+19.8
2	84.0	109.4	+25.5
3	425.2	163.3	-251.9
4	25.4	40.2	+14.8
5	205.7	156.4	-49.3
6	131.0	82.4	-48.6
7	85.8	136.4	+50.6
8	1647.0	1679.2	+32.2
9	574.0	776.8	+202.8
10	0.4	4.0	+3.6
11	160.0	225.8	+65.8
12	112.8	1.3	-111.5
13	39.1	81.4	+42.3
14	248.4	198.5	-49.9
15	205.9	150.9	-55.0

Positive (+) values indicate increase and negative (-) values indicate reduction in area of woodland between 1984 -1994. The sections 1,2,4,7,8,9,10,and 13 show an increase in woodland, with a main increase in section 9 of 202.8 ha. The biggest decrease in woodland was in the sections 3 and 12, 251.9 and 111.5 ha respectively.

6.2.1. Fish eagle Distribution

The number of Fish eagles per section is presented in Table 6.2.

Table 6.2 NUMBER OF AFRICAN FISH EAGLE AT 15 SECTIONS OF LAKE NAIVASHA, FROM 1993 -1997

SITE/YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14 SO	15 OL	Total
1993	7	5	3	6	9	3	2	5	5	26	7	9	7	1	7	102
1994	15	16	4	4	9	4	0	0	11	11	9	5	0	1	7	96
1995	4	9	6	4	12	3	0	4	0	10	17	0	6	0	11	96
1996	6	4	0	4	0	4	2	5	8	8	3	13	8	0	10	75
1997	4	6	3	15	1	1	3	0	4	7	8	4	18	1	7	82

At first glance, there seems to be no clear relation between the changes in woodland and the number of fish eagles per section. Only in section 12, where nearly all the woodland is gone in 1995, also the number of fish eagles reduced to zero for that year. However, the next year 13 fish eagles were counted for that section.

Looking at the total number of fish eagles for all the sections, there is a decrease of 6 fish eagles from 1993 to 1994. From 1995 to 1996 the number of fish eagles even dropped with 21! In 1997 82 fish eagles were observed, an increase of 7 birds.

The abundance of fish eagle (Table 6.2), coot (Table 6.8) and cormorant (Table 6.10) were classified into value ranges per section (Table 6.3). The distribution of the fish eagle from 1993 - 1997, based on these value ranges, is displayed spatially in Figure 6.3.

TABLE 6.3 VALUE RANGES USED FOR SLICING OPERATION

FISH EAGLE	CORMORANT	COOT
0 - 5	0 - 50	0 - 50
6 - 10	51 - 150	51 - 150
11 - 15	151 - 250	151 - 250
16 - 20	251 - 450	251 - 450
21 - 25	451 - 650	451 - 650
26 - 30	651 - 1500	651 - 1550
		1551 - 2050
		2051 - 3400

The density of fish eagle per area of woodland is calculated for each section, for 1995 (see Table 6.4). The highest densities of fish eagle are found in sections with relative low areas of woodland, while the sections 7, 9 and 14 have large areas of woodland but no fish eagles were observed in those sections in 1995.

Table 6.4 Density of fish eagle per section of woodland for 1995

SECTION	FISH EAGLE NO	WOODLAND (HA)	DENSITY (KM2)
1	4	41.64	9.6
2	9	109.44	8.2
3	6	163.68	3.6
4	4	40.24	9.9
5	12	156.40	7.6
6	3	82.36	3.6
7	0	136.44	0
8	4	1679.28	0.2
9	0	776.80	0
10	10	4.08	245
11	17	255.88	6.5
12	0	1.32	0
13	6	81.40	7.4
14	0	198.52	0
15	11	150.88	7.3

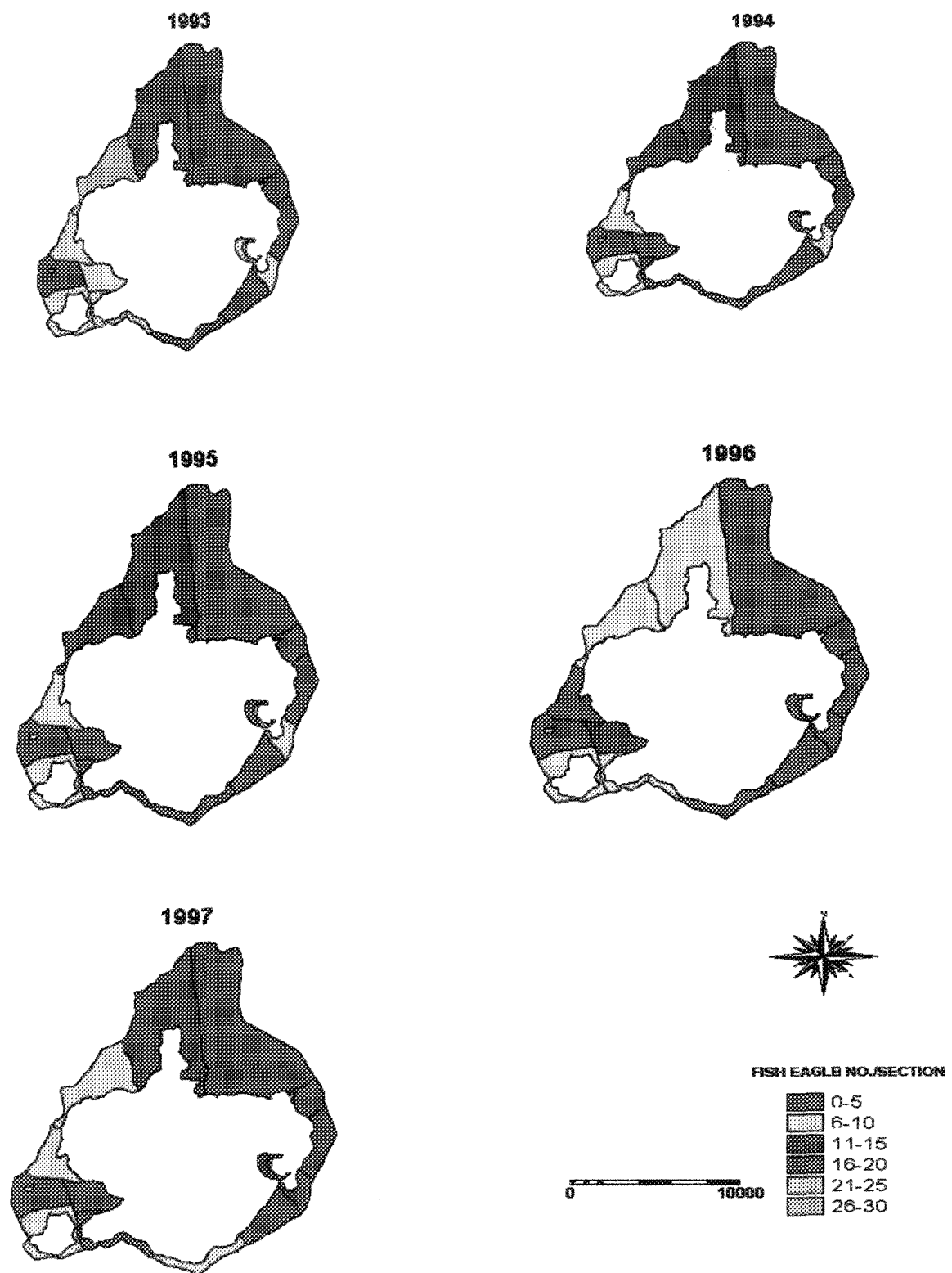


Figure 6.3 Spatial Distribution of Fish eagle abundance 1993 -1997

To determine the changes in abundance at the thirteen sites in a fair way, a series of Annual Composite Index Numbers that reflects changes from 1993 -1997 were calculated (see details in chapter 4, section 4.1.3). The index numbers were calculated from data in Table 6.2 after logarithmic transformation (Table 6.5).

Table 6.5 A TABLE SHOWING YEARLY INDEX NUMBERS FOR AFRICAN FISH EAGLE ABUNDANCE CALCULATED FROM DATA IN TABLE 6.2 AFTER LOGARITHMIC TRANSFORMATION.

SITE/YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	GM	INDEX NO.
1993	0.9	0.78	0.6	0.85	1	0.6	0.48	0.78	0.78	1.43	0.9	1	0.9	8.23	100
1994	1.2	1.23	0.7	0.7	1	0.7	0	0	1.08	1.08	1	0.78	0	5.35	64.99
1995	0.7	1	0.85	0.7	1.11	0.6	0	0.7	0	1.04	1.26	0	0.85	4.75	57.73
1996	0.85	0.7	0	0.7	0	0.7	0.48	0.78	0.95	0.95	0.6	1.15	0.95	4.76	57.82
1997	0.7	0.85	0.6	1.2	0.3	0.3	0.6	0	0.7	0.9	0.95	0.7	1.28	5.00	60.76

The result from the calculated index numbers indicate a dramatic decline in numbers from 1993 -1994 and a trend of a stable fish eagle population in Lake Naivasha since 1994 (Figure 6.4).

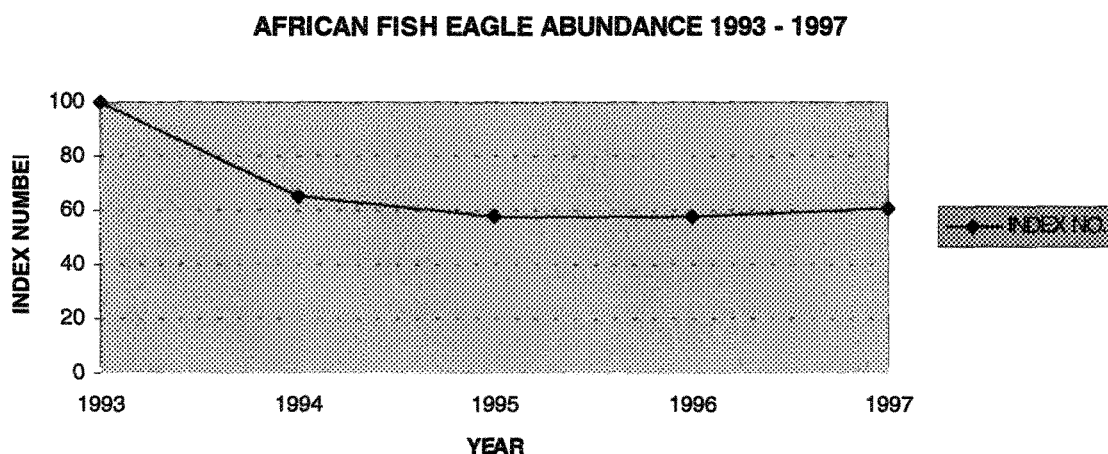


Figure 6.4 Trend in Fish eagle Abundance in Lake Naivasha 1993 - 1997

6.3 Preys of African fish eagle

The fish eagle preys mainly on fish, which they catch by swooping down to the water from a vantage point or perch. In lake Naivasha fish eagles also feed on crayfish, and other small birds like coots, cormorants and teals. They also seize fish from other fish-eating birds like Osprey, Herons and Pelicans.

The trends in fish and crayfish production for the period 1989 - 1996, the cormorants and the coot abundance for the period 1993 -1997 were determined and compared to provide indication of causes of variation in fish eagle abundance.

6.3.1 Fish

Records available at the Fisheries Department at Naivasha indicate the present fish species in lake Naivasha as shown in Table 6.6. Lake Naivasha currently has five species of fish. The first three fish species are commercially exploited.

Figure 6.5 indicates the annual production values in metric tons of the three commercially exploited species from 1989 - 1996. The *Oreochomis leucostictus*, remained the dominant species in commercial catch up to 1995. The observation is that there is a fall in the production of *Micropterus salmoides* and *Oreochomis leucostictus* species since 1991 and particularly after 1992, *Tilapia zillii* production, though low, has since 1995 increased.

Table 6.6 A TABLE SHOWING THE PRESENT FISH SPECIES OF LAKE NAIVASHA.

SPECIES	COMMON NAME
<i>Micropterus salmoides</i>	Large mouth bass
<i>Oreochomis leucostictus</i>	Tilapia
<i>Tilapia zillii</i>	Tilapia
<i>Barbus amphigramma</i>	Barbus
<i>Lebistes reticulata</i>	Guppy

Lake Naivasha had only one endemic fish species *Aplocheilichthys antinorii* which was last recorded in 1962 (Elder et. al. as cited in University of Leicester 1992). The lake is marked with introduction of fish by man. A summary of the sequence in the introduction of fish species is shown in Table 6.7.

TABLE 6.7 SUMMARY OF CHANGES TO THE FISH POPULATION OF LAKE NAIVASHA

SPECIES	DATE AND SUCCESS OF INTRODUCTION
<i>Aplocheilichthys antinorii</i> (vinc.)	Endemic. Probably extinct, last reported in 1962.
<i>Oreochromis spirulus niger</i> (Gunter)	Introduced in 1925. Disappeared by 1971
<i>Micropterus salmoides</i> (Lacepede)	Introduced in 1929, several times during 1940's and in 1951. Present today.
<i>Tilapia zilli</i> (Gervais)	Introduced in 1956. Present today.
<i>Oreochromis leucostictus</i> (Trewavas)	Introduced unintentionally in 1956 with <i>Tilapia zilli</i> . Present today.
<i>Oreochromis leucostictus</i> x <i>Oreochromis spirulus niger</i> hybrid	Abundant in the early 1960's but due to back crossing with <i>Oreochromis leucostictus</i> disappeared by 1972
<i>Oreochromis niloticus</i> L.	Introduced in 1967. Disappeared by 1971
<i>Gambusia</i> sp. and <i>Poecilia</i> sp.	Introduced but dates unknown. Absent since 1977.
<i>Lebistes reticulata</i> Peters	Introduced, date unknown. Recorded since 1982. Present today.
<i>Oncorhynchus mykiss</i> (Walbaum)	Introduced into river Malewa, dates unknown. Caught in the lake on rare occasions.
<i>Barbus amphigramma</i> Blgr.	Natural invader from inflowing rivers. Recorded since 1982. Present today.

SOURCE: Muchiri and Hickley (1991)

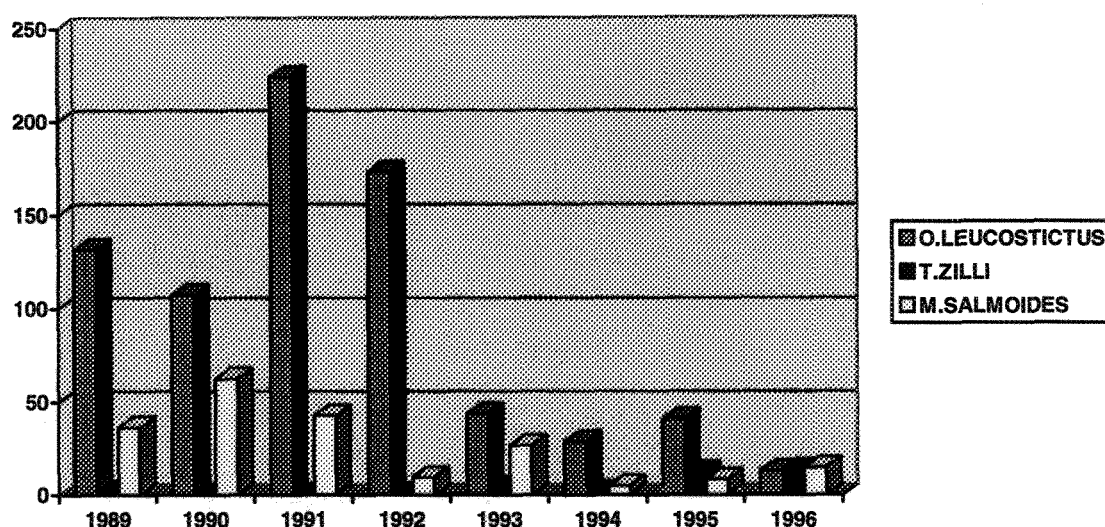


Figure 6.5 Commercially exploited fish species catch variation 1989 - 1996

The total fish production reached its highest peak in 1991 and started declining to date, with a slight increase in 1995 (Figure 6.6).

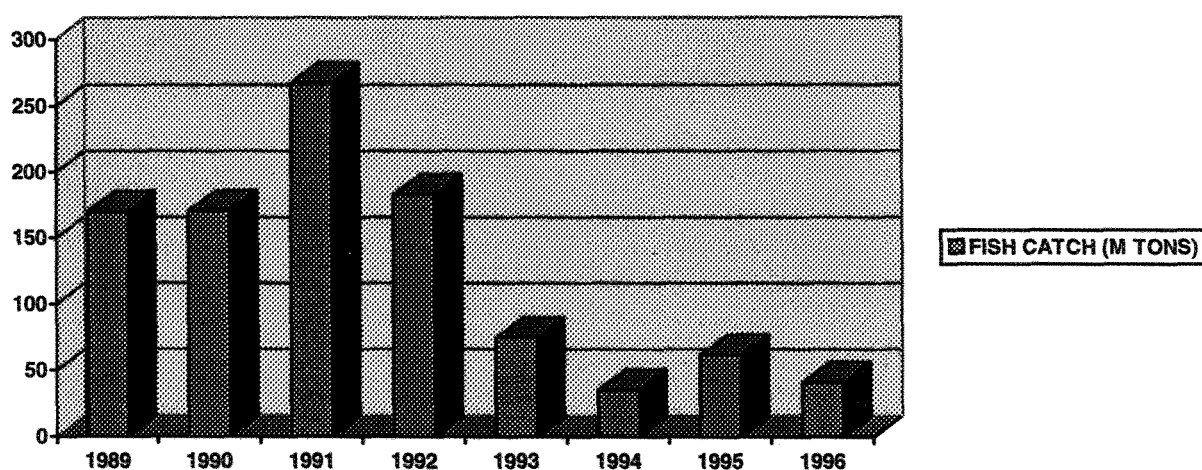


Figure 6.6 Fish catch variation 1989 - 1996 of Lake Naivasha

6.3.2. Crayfish

The only crustacean in Lake Naivasha, the Louisiana crayfish *Procambarus clarkii*, was introduced in the 1970's to diversify the commercial fishery of the lake. The crayfish is also commercially exploited. The crayfish production is declining since 1989, showing the same slight increase in 1995 as the fish production (Figure 6.7).

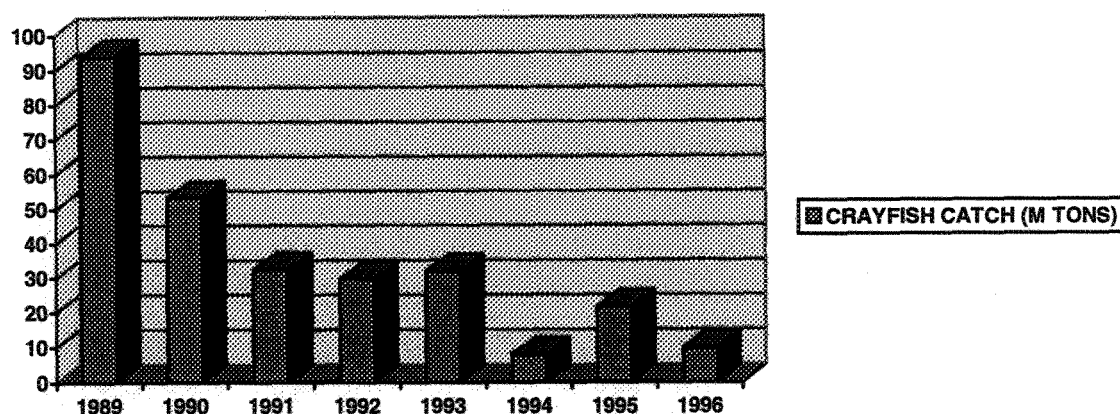


Figure 6.7 Crayfish catch variation 1989 - 1996 of Lake Naivasha.

6.3.3 Red-knobbed coot distribution

Table 6.8 shows the abundance of red knobbed coot per section. All the 13 sections of Lake Naivasha show a decrease in number of coots, particularly after 1995. In 1997 only 524 coots were observed on the main lake.

The spatial distribution of coot abundance per section, from 1993 - 1997, is shown in Figure 6.8.

Table 6.8 NUMBER OF RED KNOBBED COOT AT 15 SECTIONS OF LAKE NAIVASHA STUDY AREA, FROM 1993 - 1997.

SITE/ YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14 SO	15 OL	TOTAL
1993	120	527	345	1973	480	122	3	498	386	92	37	206	13	0	497	5,299
1994	268	352	0	0	671	244	2	89	289	220	180	230	0	0	1677	4,192
1995	2	46	0	1403	3366	42	0	245	3	0	0	0	3	0	114	5,224
1996	102	149	3	411	161	786	178	215	28	0	0	0	1	0	361	2,395
1997	0	1	30	488	2	1	0	0	0	0	0	0	2	0	600	1,124

The site abundance of red knobbed coot in Table 6.8 were logarithmically transformed and annual composite site index numbers from 1993 - 1997 were calculated (Table 6.9).

Table 6.9 A TABLE SHOWING YEARLY INDEX NUMBERS FOR RED KNOBBED COOT ABUNDANCE CALCULATED FROM DATA IN TABLE 6.8 AFTER LOGARITHMIC TRANSFORMATION.

SITE/YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	GM	INDEX NO.
1993	2.08	2.72	2.54	3.3	2.68	2.09	0.6	2.7	2.59	1.97	1.58	2.32	1.15	183.51	100
1994	2.43	2.55	0	0	2.83	2.39	0.48	1.95	2.46	2.34	2.26	2.36	0	49.71	27.08
1995	0.48	1.66	0	3.15	3.53	1.63	0	2.39	0.6	0	0	0	0.6	12.05	6.56
1996	2.01	2.18	0.6	2.61	2.21	2.9	2.25	2.33	1.46	0	0	0	0.3	28.24	15.39
1997	0	0.3	1.49	2.69	0.48	0.3	0	0	0	0	0	0	0.48	2.68	1.45

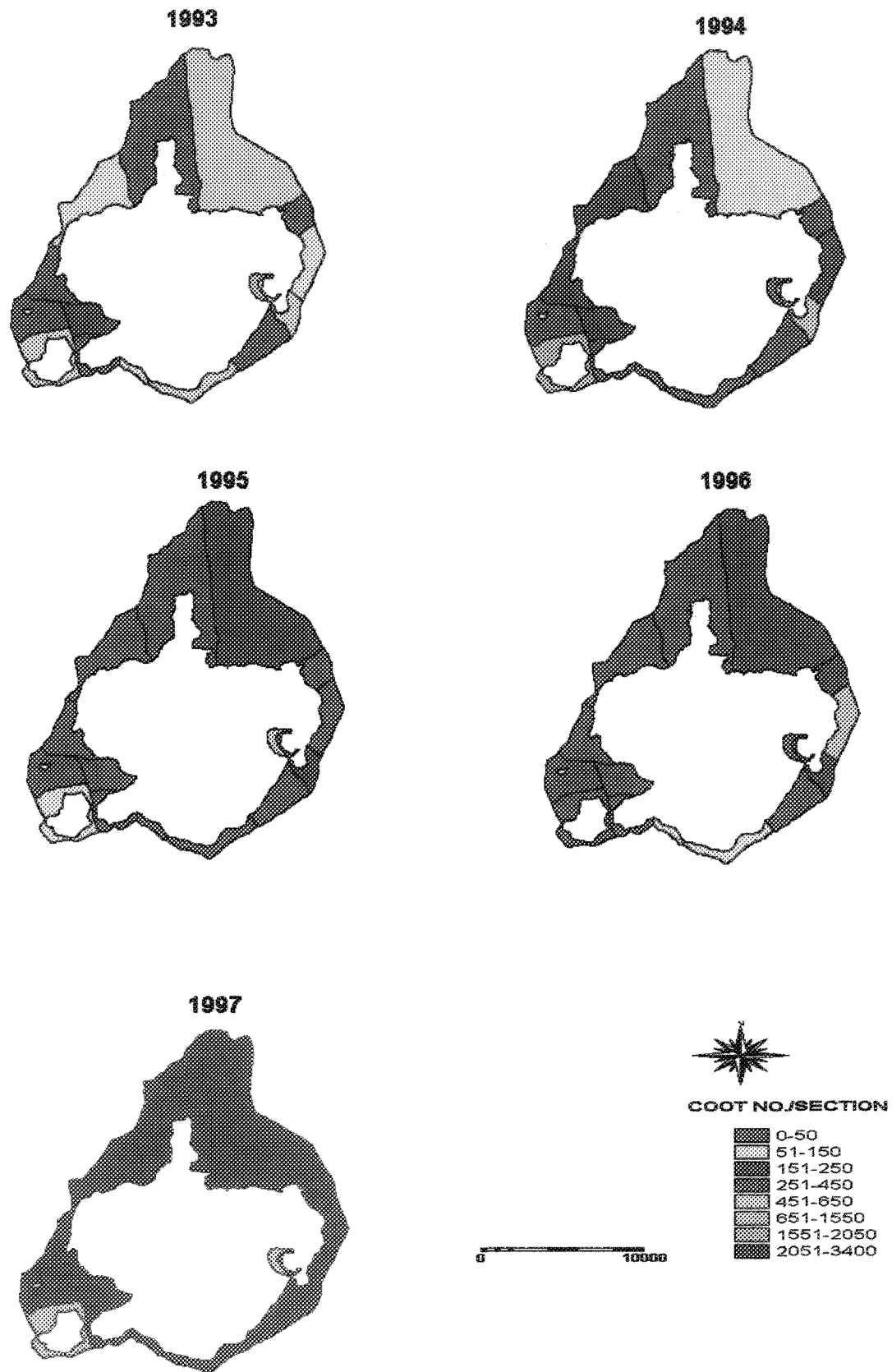


Figure 6.8. The spatial distribution of coot abundance from 1993-1997.

COOT ABUNDANCE 1993 - 1997

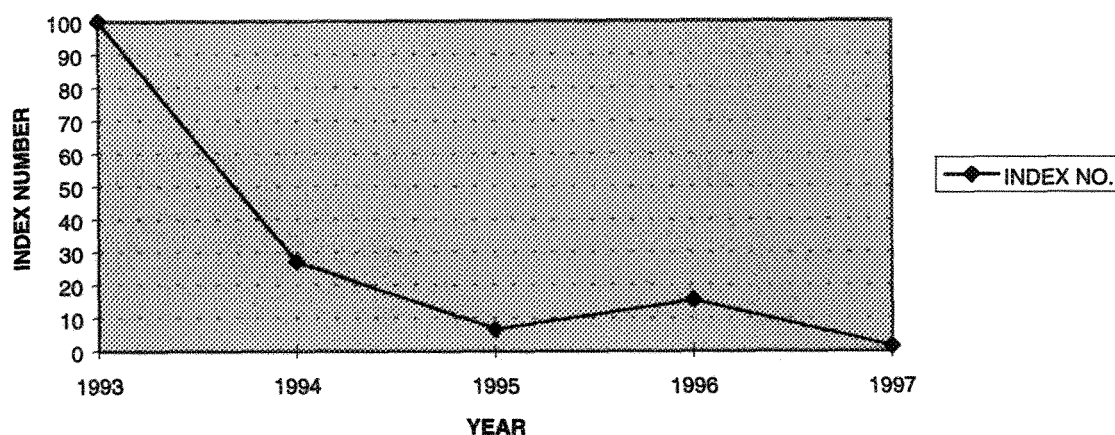


Figure 6.9 Trend in Red Knobbed Coot Abundance in Lake Naivasha 1993 - 1997

The coot abundance is declining since 1993, as shown in Figure 6.9 above.

6.3.4 CORMORANT DISTRIBUTION

The abundance of the two species of cormorant is tabulated in Table 6.10. The distribution is spatially displayed in Figure 6.10

Table 6.10 CORMORANT ABUNDANCE AT 15 SECTIONS OF LAKE NAIVASHA, STUDY AREA, FROM 1993 -1997.

SITE/ YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14 SO	15 OL	Total
1993	3	86	64	443	184	185	96	235	153	32	11	2	8	0	22	1,524
1994	90	108	100	105	93	68	6	8	628	60	150	91	18	0	159	1,684
1995	9	98	48	31	243	24	229	40	13	6	15	0	49	0	453	1,258
1996	17	52	21	273	2	26	69	5	118	2	421	264	56	0	1476	2,802
1997	79.2	221	33	37	0	27	35	0	33	12	56	5	12	0	933	1,483

The total number of cormorants is more or less stable over the years, with a slight increase in 1994, a decrease in 1995 (1258), and a large increase in numbers (2,802) in 1996, mainly in Lake Oloidien. Most of the section show a decrease in numbers, except the sections 1,2, 11 and section 15, Lake Oloidien.

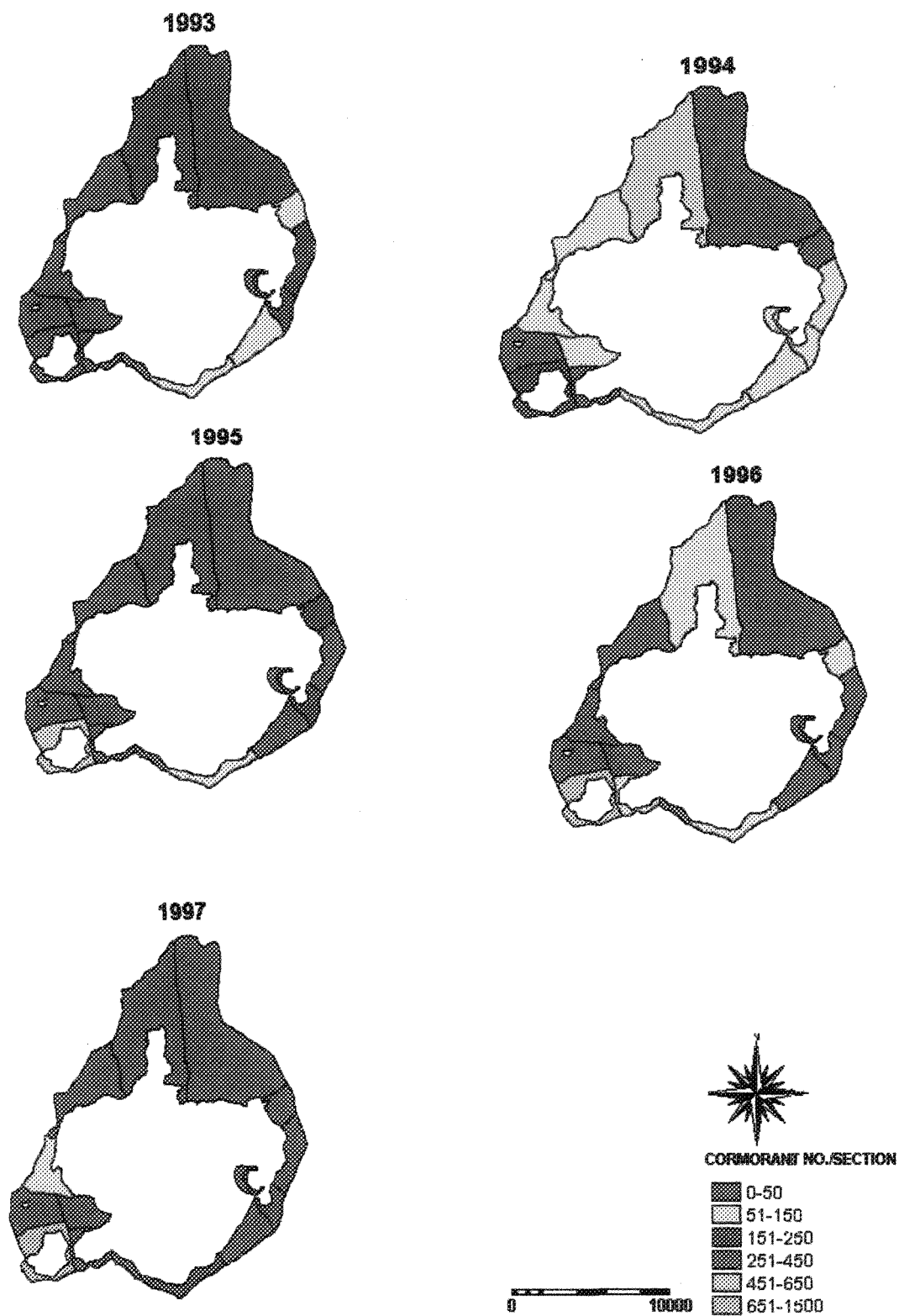


Figure 6.10 Spatial distribution of Cormorant abundance 1993 -1997

Index numbers as calculated in Table 6.10 have been logarithmically transformed (see Table 6.11). After a rise in 1994, it started declining to date (Figure 6.11)

Table 6.11 YEARLY INDEX NUMBERS FOR CORMORANT ABUNDANCE CALCULATED FROM DATA IN TABLE 6.10 AFTER LOGARITHMIC TRANSFORMATION.

SITE/YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	GM	INDEX NO.
1993	0.6	1.94	1.81	2.65	2.27	2.27	1.99	2.37	2.19	1.52	1.08	0.48	0.95	50.25	100
1994	1.96	2.04	2	2.03	1.97	1.84	0.85	0.95	2.8	1.79	2.18	1.96	1.28	65.87	131.08
1995	1	2	1.69	1.51	2.39	1.4	2.36	1.61	1.15	0.85	1.2	0	1.7	28.16	56.03
1996	1.26	1.72	1.34	2.44	0.48	1.43	1.85	0.78	2.08	0.6	2.63	2.42	1.76	38.76	77.12
1997	0.48	2.35	1.53	1.58	0	1.45	1.56	0	1.53	1.11	1.76	0.78	1.11	19.12	38.04

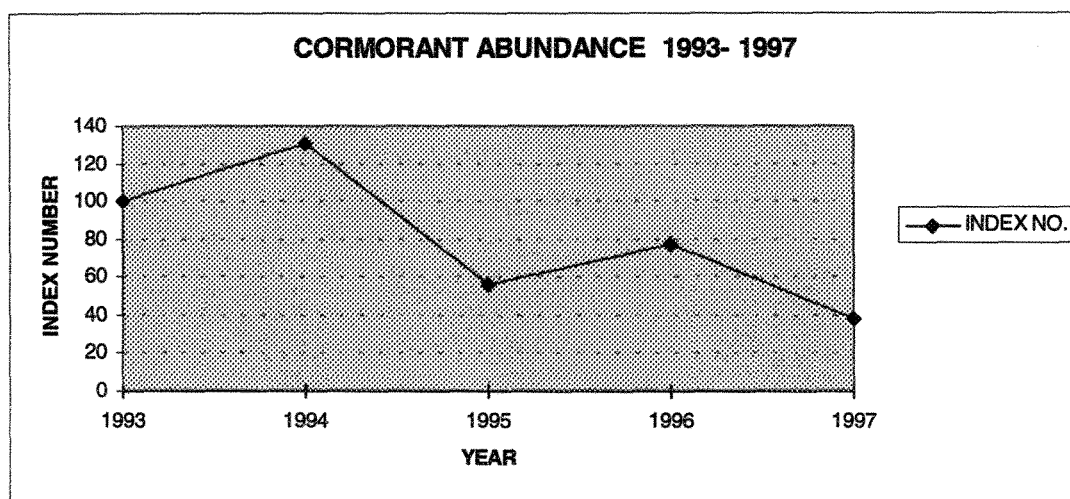


Figure 6.11 Trend in Cormorant Abundance in Lake Naivasha 1993 - 1997

6.4 Bird species diversity

Lake Naivasha is famous as an Ornithological site. To date the lake and its immediate environment are the home of three hundred and fifty (350) bird species of which ninety (90) are aquatic or semi aquatic (Henderson and Harper 1992). Annual monitoring of water birds in Naivasha have been carried regularly in January since 1991. The census of waterbirds provide data for the sustainable management of wetlands. The number of waterbirds and species richness serve as useful indicators of wetland productivity and biological diversity (Nasirwa and Bennun 1995). This study reviews the waterbirds census data from 1993 - 1997 of the sections for counting waterbirds in Lake Naivasha.

The number of bird species for the KWWG monitoring sections are as shown below.

Table 6.12 A TABLE OF BIRD SPECIES ABUNDANCE AT 13 SECTIONS OF LAKE NAIVASHA, 1993 -1997

SITE/ YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14 SO	15 OL	Total
1993	23	46	37	52	45	33	26	29	25	33	22	21	25	0	36	453
1994	44	41	56	56	47	44	27	30	53	44	44	14	10	14	61	585
1995	23	39	31	41	54	13	5	27	39	28	29	0	24	22	43	418
1996	27	34	30	42	31	55	34	42	27	26	27	8	31	0	32	446
1997	26	39	38	53	25	36	42	0	30	28	25	12	26	14	56	450

The number of species within Lake Naivasha is more or less the same (around 450) from 1993-1997, with an increase in species in 1994 (585) and a decrease in 1995 (418).

The number of species per section was logarithmically transformed and annual composite Index numbers calculated (Table 6.13) to show the trend in species abundance (Figure 6.12.).

Table 6.13 YEARLY INDEX NUMBERS FOR BIRD SPECIES ABUNDANCE CALCULATED FROM DATA IN TABLE 6.12 AFTER LOGARITHMIC TRANSFORMATION.

SITE/YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	GM	INDEX NO.
1993	1.38	1.67	1.58	1.72	1.66	1.53	1.43	1.48	1.41	1.53	1.36	1.34	1.41	31.76	100
1994	1.65	1.62	1.76	1.76	1.68	1.65	1.45	1.49	1.73	1.65	1.65	1.18	1.04	36.55	115.0766
1995	1.38	1.6	1.51	1.62	1.74	1.15	0.78	1.45	1.6	1.46	1.48	0	1.4	20.9	65.80451
1996	1.45	1.54	1.49	1.63	1.51	1.75	1.54	1.63	1.45	1.43	1.45	0.95	1.51	30.59	96.31051
1997	1.43	1.6	1.59	1.73	1.41	1.57	1.63	0	1.49	1.46	1.41	1.11	1.41	23.77	74.82887

BIRD SPECIES ABUNDANCE FROM 1993 -1997

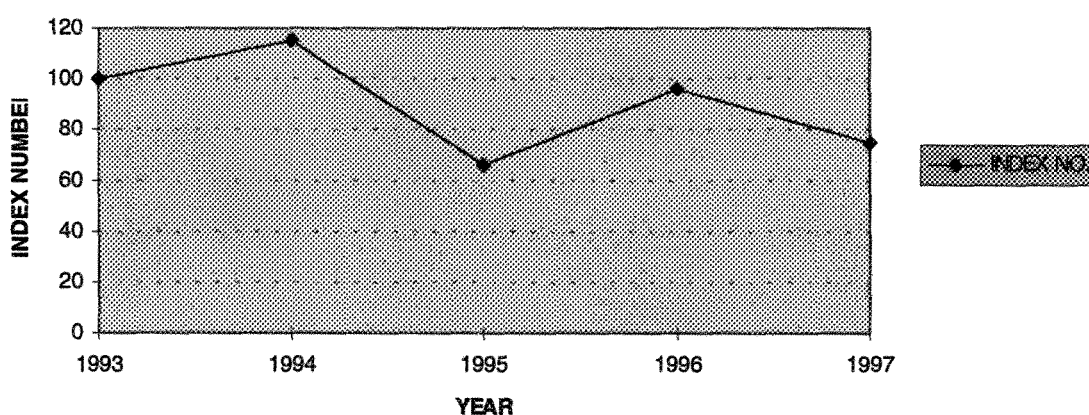


Figure 6.12 Annual Trend in Bird species Abundance in Lake Naivasha 1993 - 1997

The annual trend of bird species follows the general declining trend from 1993 - 1997 of the cormorant.

As the number of species in Naivasha is quite large, a species by species approach will be time consuming and in the Naivasha context there are neither trained nor the financial resources to do this properly. This suggests the need to place emphasis on indicator species to monitor the state of health of the entire Naivasha ecosystem.

6.5 Discussion and final conclusions

Figure 6.4 indicated that, after a decline in 1994, the fish eagle population is stable since 1993. In general, a population is stable when the growth rate is zero. This occurs when the average birth rate equals the average death rate. While a population with an average growth rate of zero is expected to be stable over time and a growth rate above zero should lead to an expanding population, random variation in population growth rates among years can lead to population decline (Primack 1993).

Looking at the spatial distribution of the fish eagle per section (Figure 6.3), the north-western sections show relative low values (0-10) since 1993. An exception might be Crescent island (section 4), where there is a slight increase in numbers. Most of the changes since 1993, seem to take place in the North-western part of the study area, particularly section 10, showing a drop in value from 26-30 to 6-10. In 1997 all the sections show relative low values (red and yellow colors), with exception of the Western part of Crescent island.

The spatial distribution of the coot, an important prey of the fish eagle, seems to follow this trend. In 1997 all the sections show a very low value (red color), with exception of the Western part of Crescent island and Lake Oloidien.

The cormorant distribution (Figure 6.10) also show a decline in number since 1993, with relative low values for all the sections in 1997, with exception of Lake Oloidien and section 2, in the South.

Regarding the (nesting and roosting) habitat of the fish eagle, the woodlands, the results of this study show an increase of 163 ha (4.07%) in woodland between 1984 - 1995.

The results of the study indicated that some sections with large tracts of woodland have low density or no fish eagle at all, while some sections with a relatively small area of woodland have very high densities (Table 6.4). This shows that the distribution of fish eagle is not controlled by the area of nesting sites only (woodland). Woodland therefore, does not seem to play a role to explain the present distribution of fish eagles, as there is no loss, but actually an increase in woodland habitat.

Other factors like changes in food supply, human disturbance and/or pollution might affect their distribution.

The results of this study also show a dramatic reduction of lake level between 1984 and 1995. The open water habitat was reduced by 1972.24 ha (13.42%) .

A comparison with the trends in estimates of fish catches, coot and cormorant numbers might provide some indication of the causes of variation.

The fish catches are declining since 1989 (Figure 6.6). A study by Muchiri and Hickley (1991) indicated that fish catches were related to trends in water level changes. A rise in lake level was followed by increased catches whilst a fall in lake level was followed by a corresponding decline in fish catches. Fluctuations in lake level influence fish numbers through effects on food, breeding grounds and predator-prey relationships. The same study showed that food is not a limiting factor to fish in Lake Naivasha.

A more probable effect of fluctuations in Lake level is that on the breeding behaviour. Predation by piscivorous fish and birds and pressure on fishing (overfishing) are also factors contributing to the declining fish catches.

Fish catches are also linked to availability of submerged macrophytes (Harper et. al. 1990). The macrophytes provide breeding and nursery grounds, food and cover for the fish. Muchiri and Hickley (1991) showed that even when lake level was low, but there was an increase in submerged and swamp macrophytes, fish catches increased. The results of this study indicate an increase of 151.80 ha (71%) of macrophytes between 1984 and 1995, yet fish catches declined in that period. In 1997

The declining crayfish catches since 1989 might also be related to the availability of macrophytes.

The low level of macrophytes observed in the field in 1997 might explain the drastic decline in coot numbers in 1997 in Lake Naivasha. Muchiri and Hickley (1991) mentioned a relation between the availability of macrophytes and number of coots.

The downward trend of cormorant distribution since 1993 might be explained by the declining fish and crayfish catches.

The declining fish catch, crayfish and coot numbers hardly explain the stable trend in fish eagle distribution in Lake Naivasha. Also, there is no reduction in nesting and roosting habitat since 1984. Therefore, it seems other factors might influence the distribution of the fish eagle. Primack (1993) identified that if a habitat is not affected by over destruction and fragmentation it can be affected by habitat degradation (including pollution) resulting from human activities. Organochlorine pesticides persistent residues remain sufficiently high to reduce recruitment and survival of numerous population of freshwater birds (Clark and Krynitsky 1983)

Increasing use of agro-chemicals have a negative impact on wetland quality (Sheehan et. al 1987). Many studies have been done on the effect of residues of organo-chlorine insecticides on birds and their eggs. In Lake Naivasha the increase in use of agro-chemicals in recent years should be investigated to determine their effect on the quality of lake water. The reproductive success and the thickness of egg shells of the fish eagle must be measured to determine the effect of residues of pesticides.

The information on habitat quantity, water quality and the reproductive success can be put together to offer possible explanation to the distribution of the fish eagle population in Lake Naivasha.

In conclusion, the declining lake water level, pollution from agricultural activities and over-fishing might be the main factors influencing the fish eagle population, resulting in declining fish and crayfish catches, as well as a reduction in number of coots and cormorants.

CHAPTER SEVEN: HIPPOPOTAMUS HABITAT ANALYSIS

7.1 Introduction

In this chapter of the study the habitat, distribution, the foraging distance and nocturnal grazing density of the hippopotamus population at Lake Naivasha is analysed and mapped. In Lake Naivasha increase of agriculture activities around the lake has led to restriction in access to nocturnal grazing areas of the *Hippopotamus amphibius*. As the Lake level drops there is the loss of areas of habitat previously used by the hippopotamus. This is due in part to land reclamation, drainage and clearance of papyrus for arable crop cultivation. Most farms are fenced to prevent hippopotamus from grazing.

7.2 Hippopotamus habitat

The habitat of the hippopotamus is generally limited to small to large waters with flat banks, sand banks, etc. bordering rich grass plains. Dense high reed beds and forested banks are avoided. At day time they prefer to stay in the water. Water temperature must be between 18°C - 35°C. The territories on the banks are divided among individuals, the best held by the strongest male. Areas of good pasture are used in common. The daily rhythm of activities is to rest in or by water during day time and go ashore to graze in the evening. The hippo consumes soft grass and other plants 40 - 60 kg at each meal. The submerged macrophytes are eaten occasionally (Haltenorth and Diller 1980).

The grazing areas of the hippopotamus, made up of the agricultural areas, papyrus and grassland, were extracted from the 1995 Habitat map (Figure 7.1).

7.3 Hippopotamus distribution

Figure 7.2 shows the spatial distribution, while Table 7.1 gives the detailed results of *Hippopotamus amphibius* census carried out during the June 1997 fieldwork using the same sections as the Leicester University /Earthwatch/ Elsamere (LEE) monitoring project.

The highest numbers of hippos are found in the Eastern part of the Lake in the sections 5 (66), 7 (62) and 8 (49); and in the Western part of the Lake, in the sections 2 (64) and 3 (40), and in Lake Oloidien (42).

7.4 Hippopotamus foraging distance.

The locations where hippopotamus activities were recorded during the fieldwork in June 1997 were plotted on a distance map created to determine the foraging distances at Lake Naivasha (Figure 7.3).

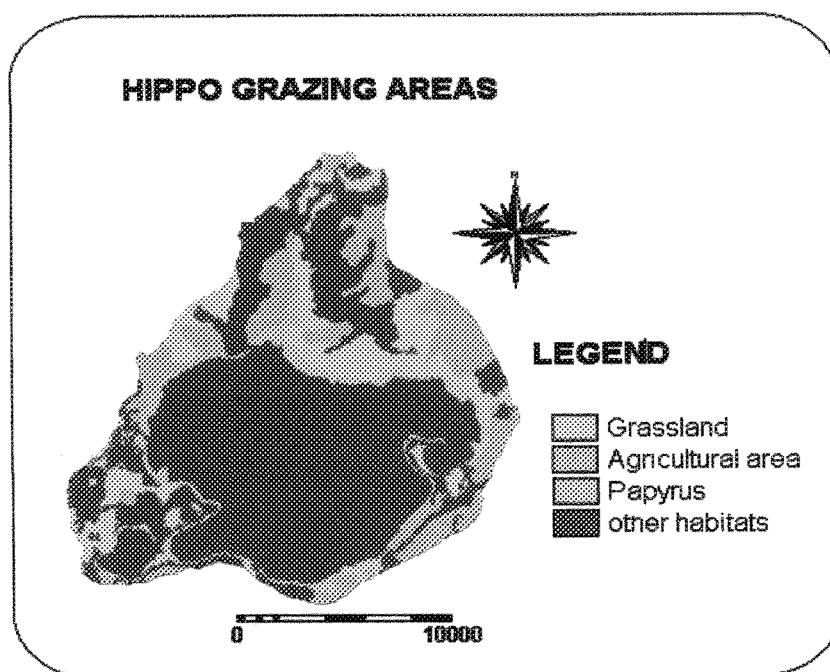


Figure 7.1 Hippopotamus grazing areas.

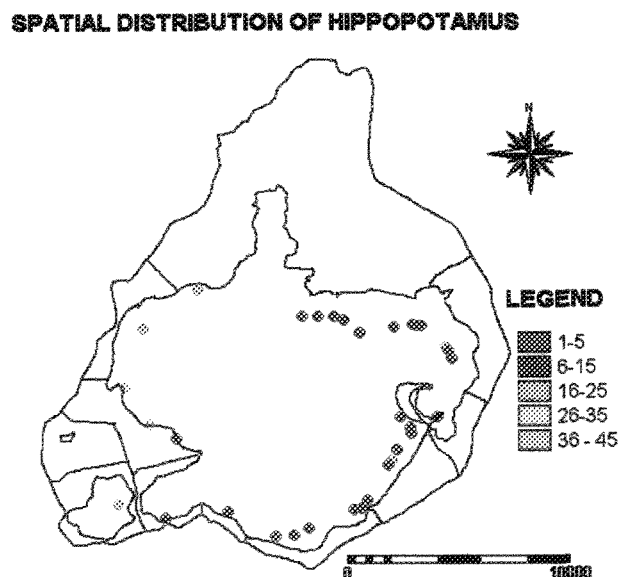


Figure 7.2 Spatial distribution of *Hippopotamus amphibius* in June 1997

TABLE 7.1 CENSUS FIGURES OF HIPPOPOTAMUS POPULATION AT LAKE NAIVASHA IN JUNE 1997

COORDINATE		NUMBER	SITE IDENTIFICATION
199687	9909918	5	ELSAMERE - HIPPO POINT
200180	9913637	1	HIPPO POINT- REMA ISLAND
198973	9914312	28	HIPPO POINT- REMA ISLAND
197857	9916064	35	HIPPO POINT- REMA ISLAND
198722	9918799	22	REMA ISLAND - HOPCRAFT
201135	9920614	18	REMA ISLAND - HOPCRAFT
205830	9919303	1	HOPCRAFT - KARATI
206538	9920500	8	HOPCRAFT - KARATI
207162	9919783	10	HOPCRAFT - KARATI
207690	9920600	6	HOPCRAFT - KARATI
208356	9918547	5	KARATI -LAKE HOTEL
209935	9918820	10	KARATI -LAKE HOTEL
210745	9918930	13	KARATI -LAKE HOTEL
210920	9918870	12	KARATI -LAKE HOTEL
211119	9918870	6	KARATI -LAKE HOTEL
212217	9917900	20	KARATI -LAKE HOTEL
211800	9914600	5	LAKE HOTEL - CRESCENT ISLAND TIP
212500	9917350	2	CRESCENT ISLAND TIP - SAFARILAND
212340	9917740	11	CRESCENT ISLAND TIP - SAFARILAND
210181	9914641	9	CRESCENT ISLAND TIP - SAFARILAND
210685	9913877	7	CRESCENT ISLAND TIP - SAFARILAND
210610	9914155	10	CRESCENT ISLAND TIP - SAFARILAND
210023	9913084	1	CRESCENT ISLAND TIP - SAFARILAND
209778	9912624	16	CRESCENT ISLAND TIP - SAFARILAND
209613	9912393	6	CRESCENT ISLAND TIP - SAFARILAND
208700	9910737	10	SAFARILAND - FISHERMAN CAMP
208415	9910366	12	SAFARILAND - FISHERMAN CAMP
208085	9910280	8	SAFARILAND - FISHERMAN CAMP
206108	9909411	8	SAFARILAND - FISHERMAN CAMP
205422	9909096	10	SAFARILAND - FISHERMAN CAMP
204630	9909065	1	SAFARILAND - FISHERMAN CAMP
202464	9910209	6	FISHERMAN CAMP - ELSAMERE
SUMMARY			
1 ELSAMERE - HIPPO POINT			5
2 HIPPO POINT- REMA ISLAND			64
3 REMA ISLAND - HOPCRAFT			40
4 HOPCRAFT-KARATI-			25
5 KARATI -LAKE HOTEL			66
6 LAKE HOTEL - CRESCENT ISLAND TIP			5
7 CRESCENT ISLAND TIP - SAFARILAND			62
8 SAFARILAND - FISHERMAN CAMP			49
9 FISHERMAN CAMP - ELSAMERE			6
TOTAL			322

* LAKE OLOIDEN 42

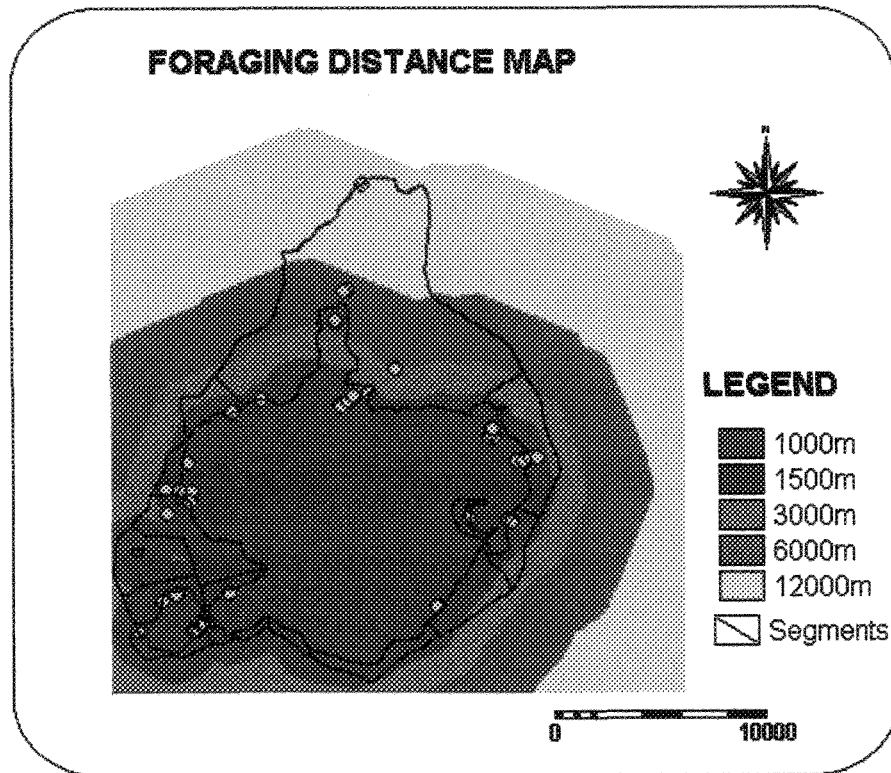


Figure 7.3 *Hippopotamus amphibius* Foraging distance.

The results show that in the study area the average distance from the lake to the road for most of the sections for monitoring is up to 1.5 km but in the northern sections goes up to 10 km. The Hippopotamus forages actually up to 6 km in the North swamp area as shown in Figure 7.3.

7.5 Density of Hippopotamus

Previous published work by Diedrichs in 1976 indicated a hippopotamus population of 227, and 228 by Smart (Smart, 1990). Local estimates from farmers ranges between 500-1000. Estimates from Leicester University /Earthwatch/ Elsamere (LEE) monitoring project gives a mean number of 382. Fieldwork in June 1997 provided estimate of 322

for Lake Naivasha and 42 for Lake Oloiden (see Table 7.1). About 30 animals were found out of water around Lake Oloiden in the afternoon of June 5th. LEE does not include Lake Oloiden in their monitoring project.

In this study the estimates of the number of hippo's per section of LEE were used to calculate the nocturnal grazing density of the hippo's. It covers the period April 1995 - April 1997.

The map of hippopotamus grazing areas of Papyrus, Grassland and Agricultural areas, extracted from the 1995 Habitat map was crossed with the Hippopotamus foraging distance map. The resulting map was crossed with the LEE sections and the grazing areas up to 6km per section were calculated to determine the grazing density per section (Table 7.2). The number of hippo's used in the calculations for sections 1- 9 were based on average number of hippos per section of LEE while that of Lake Oloiden was based on the 1997 fieldwork (only one record).

Table 7.2 A Table Showing Grazing Area and Density per section.

SECTION	H/NO	AGRIC (HA)	PAPYRUS(HA)	GRASSLAND(HA)	DENSIT Y (KM ²)
1	22	22.04	52.88	60.12	9.8
2	23		135.68	272.32	5.6
3	8	315.36	7.60	94.62	3.1
4	50	1133.16	49.00	1560.44	2.2
5	54	56572	4.50	159.00	12.1
6	8	205.40		36.84	5.7
7	60	460.00	0.20	239.32	12.7
8	35	167.80	12.56	5.44	34.3
9	10		15.68	31.20	21.33
10	*	*	*	*	*
11	42	90.52		270.76	13.29

*Lake Sonachi No hippopotamus H/NO = Hippopotamus number counted per section

The results indicate that with exception of sections 3 and 4, all the remaining sections have nocturnal grazing density of more than 4.0 km².

The results of Smart (1990) and personal observation in the field suggested that considerable movement occur between groups. Therefore, density at sections will be fluctuating. Further calculations of the nocturnal grazing density using the total estimated number of hippopotamus 424 (382 in main lake and 42 in Lake Oloiden) and available grazing area was calculated. Also, the grazing density was calculated assuming half of the agricultural areas are not available for grazing due to fences or other barriers (Table 7.3).

Table 7.3 Calculation of Hippopotamus Nocturnal grazing density.

Agricultural area	45.6km ²
Grassland	48.6km ²
Papyrus	14 km ²
Estimated Hippopotamus population: 424	
Maximum Grazing density (km ²) =	$\frac{424}{45.6 + 48.6 + 14}$
	$= 3.9$
The agricultural areas are protected with electric fences. Assuming only half of the agricultural areas are available for grazing, the grazing density is calculated as follows:	
Maximum Grazing density (km ²) =	$\frac{424}{(45.6 \times 0.5) + 48.6 + 14}$
	$= 5.0$

The grazing density is 3.9 hippos per km² and 5 hippos per km² if only half of the agricultural areas are available for grazing.

7.6 Discussion and final conclusions

The estimates of the *Hippopotamus amphibius* population carried out in June 1997 during the study using the boat appeared to be less accurate. Ideally the count along the shore should have been carried out in one day as movement from one group to another occur between days. In the case of this study two days were used because it was a condition from the boat owner to prevent accidents as it was too windy in the afternoons during the period of the census. A number of the animals remain in the fringing papyrus and therefore could be missed during the boat survey. The engine noise was a problem as the animals tend to dive on hearing the noise.

In the Luanga river in Zambia, Tembo (1987) found ground counts to be a more accurate method. The ground count could not be used as most of the shoreline of the sections used for the census were not accessible. The fear of buffaloes, especially in the Northern section, was also a limiting factor.

The mean *H. amphibius* population estimates of 384 animals by the LEE monitoring project is more reliable since the population was monitored over a longer period (April 1995 - April 1997). The other estimates were all based on short period of few days or months. Therefore the estimate of LEE was used in the analysis of this study.

Field and Law (1970) in Uganda found the mean foraging distance of *H. amphibius* to be 5km. In Lake Naivasha hippopotamus foraging distance extends to 6km in the North swamp area. The observation of hippopotamus eaten Papyrus and aquatic macrophytes confirms similar observations by Smart (1990). Haltenorth and Diller (1980) indicated that areas of good pasture are used in common, therefore density for the available grazing area taken all sections into account was useful.

The density per section in Table 8.3 are very high with the exception of sections 3 and 4 which are in the North swamp. Field and Law (1970) gave density below 4.0 km² as "slight"(low) and above that as "heavy"(high) This suggest that there are more potential grazing areas in the North swamp but expansion of agriculture may limit their accessibility for hippos..

The maximum nocturnal grazing density of 3.9 km² using the available grazing areas of Agricultural areas, Papyrus and Grassland and 5.0 km² considering restriction to agricultural areas due to electric fencing are "heavy" according to the definition of Field and Laws (1970). A heavy nocturnal grazing density of 4.0 km² precipitated calls for investigation of damage to grassland (Tembo 1987) and in Uganda approximately half of this density initiated a culling program. The nocturnal grazing density of 3.9 km² (without fencing restriction and 5.0 km² (with fencing restrictions) of this study is higher than that calculated by Smart for the year 1987 (Smart 1990), 0.3 and 1.1 hippo per km² respectively . The increase in hippopotamus population and increase in less accessible agricultural areas from 1984 -1995 as shown by this study (Table 5.4), might be an explanation.

The present trend of lake level reduction, reclamation and drainage of land for cultivation, if allowed to continue, is likely to raise the nocturnal grazing density further. This may lead to over utilization of the available grazing areas and hence intensified conflicts between farmers and the hippopotamus.

A further study of hippopotamus damage to grasslands must be undertaken. The option of culling to reduce the number of hippopotamus must be considered.

CHAPTER EIGHT: CONCLUSIONS AND RECOMMENDATIONS.

This chapter reviews the hypothesis and objectives of the study, outlines specific conclusions on the African fish eagle and the Hippopotamus and provides recommendations for further study. The results of this study demonstrate the use of Remote sensing and GIS in mapping of habitat and biodiversity

8.1 Conclusions

The first hypothesis of the study is that:

Changes in the habitat of the African Fish Eagle are related to changes in species numbers

The hypothesis does not hold for the African fish eagle because there was an increase in its nesting and roosting habitat (woodland) from 1984 - 1995, while the population, after a decrease in 1993, was stable. The sections 9 and 7 have an increase in woodland area, but no fish eagle was found there in 1995. Furthermore, sections with large tracts of woodland have a relative low density of fish eagles or no fish eagle at all, while some sections with a relatively small area of woodland show very high densities (Table 6.4). This suggests that the distribution of fish eagle is not controlled by the area of nesting sites only (woodland).

The second hypothesis is that:

Expansion of agricultural areas will increase the density of the Hippopotamus population

In the case of the Hippopotamus the hypothesis holds as the reduction in its grazing areas is affecting its grazing density. Agricultural areas increased by 763.28 ha between 1984 and 1995, while the nocturnal grazing density was raised from 0.3 hippo per km² (1987, based on the survey of Smart (1990)) to 3.9 km². Taking into account fencing restrictions, the nocturnal grazing density raised from 1.1 to 5.0 hippo per km².

The primary objective of mapping the present vegetation cover could not be reached with full satisfaction due to the fact recent high resolution imagery and aerial photographs were not available in time. Therefore, the mapping had to be based on the most recent imagery available, a TM of 1995. It must be noted that the lake ecosystem is dynamic and changes are occurring at a fast rate.

The second objective was to identify indicator species. The fish eagle, being at the top of the food chain in the Lake Naivasha ecosystem, is a good indicator species for monitoring. Using annual composite index numbers for the period 1993-1997, the fish eagle population dropped from 1993 to 1994 and is up to 1997 stable.

Though woodland does not seem to play a role to explain the present distribution of fish eagles, as there is no loss, but actually an increase in woodland habitat, other factors like loss of open water area, changes in food supply, human disturbance and/or pollution might affect their distribution.

The results of this study show a dramatic reduction of lake water levels between 1984 and 1995. The open water habitat was reduced by 1972.24 ha (13.42%) .

Declining lake water levels affect fish catches and macrophytes.

Fish, crayfish and coot, the main prey of the fish eagle are declining in numbers.

The other causes are over-fishing and probable pollution from agricultural activities in the lake zone and the catchment which need further investigation.

The fish eagle can be used as an indicator to monitor the quantity (available habitat) and quality of the Lake Naivasha ecosystem.

The Hippopotamus is a good indicator to monitor the expansion of agricultural areas, ie in relation to its density. The declining lake levels and its accompanying land reclamation for agricultural purposes have raised the nocturnal grazing density of Hippopotamus in the area. Further investigation is needed for possible culling to reduce the "heavy" nocturnal grazing density or to stop a further increase of land reclamation.

The third objective is mainly described as part of the previous objective. The distribution and changes in habitat of the fish eagle and the hippopotamus were mapped and analyzed. There was an increase of 163.12 ha of woodland between 1984 and 1995, the fish eagle's roosting and nesting habitat. The hippopotamus lost 1972.92 ha of its open water habitat and papyrus (995.5 ha), which was mainly converted into agricultural area (763.3 ha) and grassland (1768.6 ha).

The final objective was to investigate the impact of human activities on community diversity.

Increase in agriculture, deforestation in the catchment area and urbanization are the main human activities affecting the habitats, and therefore species diversity, of the Lake Naivasha ecosystem. The open water and the papyrus are habitats that are affected most by human activities. The short period for the study did not allow to study the effects of deforestation and urbanization in the catchment on species diversity.

The continuous drop in lake water level is a key issue affecting the biodiversity of the lake ecosystem. The drop in lake water level reduces the fish population and macrophytes production which are the base of the food chain.

The clearance of the lake edge vegetation, especially papyrus, for both commercial and subsistence agriculture, together with declining lake water levels, is a major threat to the wetland habitats and bio-diversity of the lake system. The increased agricultural activities and use of agro-chemicals might accelerate the degradation of the habitats.

It could be argued the drop in lake water levels is a natural cyclical phenomenon which has been occurring in Lake Naivasha regularly. However agricultural activities were little in the past period of such decrease in lake water levels. The present rate of use of lake water for irrigation and the damming of Malewa river has led to the present concern over the drop in lake water levels.

To assist in the conservation of biological diversity and sustainable utilization of the resources of Lake Naivasha the following recommendations explained in section 8.2 are made.

8.2 Recommendations

The main objective of the management plan for Lake Naivasha is to manage existing human activities in the Lake ecosystem through voluntarily adopted sustainable wise use principles to ensure its conservation (LNROA 1996). To achieve this objective the sections that follow outline recommendations which will promote the sustainable utilization of the freshwater resources of Lake Naivasha.

8.2.1 Ecosystem Approach to Management

Sustainable living in the Lake Naivasha area requires that stakeholders move from an exclusive, sectoral approach to valuing and using natural resources in the area to an integrated approach. I therefore recommend the ecosystem approach to management as the path that stakeholders can use to attain the vision of sustainable living. The ecosystem approach to management allows people to manage for the economic, social, cultural, and ecological forces and factors at the same time (Figure.8.1). This way the interest of farmers, local people and ecologist are taken into account in an integrative and holistic framework to seek answers to management issues.

The Lake Naivasha Riparian Owners Association (LNROA) has taken a step forward in this direction, however their activities should be widened to include the catchment.

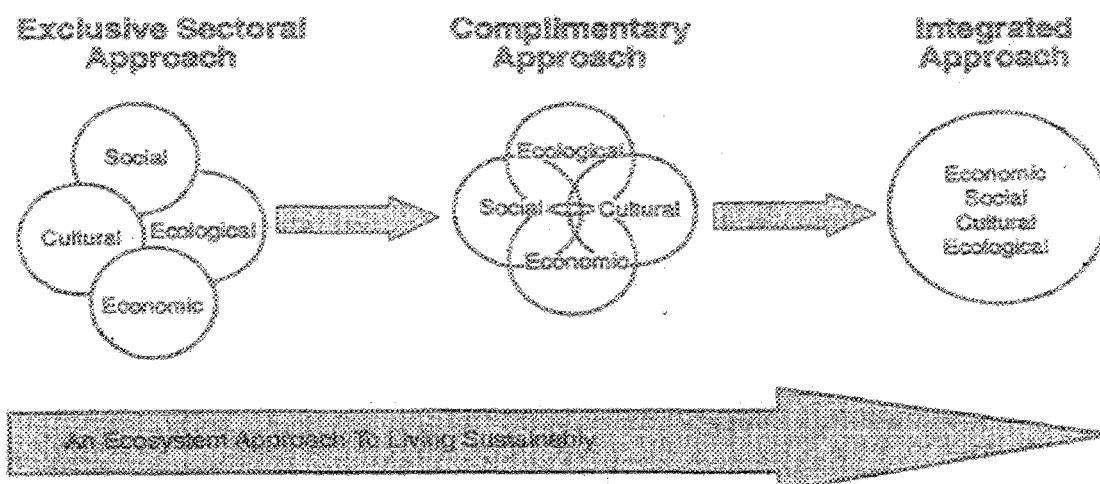


Figure 8.1 Ecosystem Approach to Living Sustainability (Adapted from Gray et. al. 1995).

8.2.2 Monitoring and research.

Research and monitoring provide the scientific data necessary for management decisions. This is an effective way to detect changes, to establish the significance of the changes (i.e. acceptable short-term changes or unacceptable long-term changes), to determine the appropriate management response (s) and to assess the effectiveness of any measures carried out.

Lake Naivasha and its surroundings have been researched in the past and continue to receive research attention. The establishment of a research station with a resident ecologist and close cooperation with universities and scientist both inside and outside Kenya is important for the successful running of a research and monitoring programme. The coordination and dissemination of research outputs to the stakeholders will assist in updating the management programmes.

A monitoring scheme in Table 8.1 is recommended.

Table 8.1 A recommended monitoring scheme for Lake Naivasha.

ACTIVITY	PERIOD INTERVAL
Fish yield	1 month
Lake pH	1 month
Lake levels	1 month
Lake phyto and zooplankton	1 month
Lake dissolved oxygen	1 month
Lake transparency	1 month
Water chemistry (Nitrogen and Phosphorus)	1 month
Habitat type mapping from Air-photographs/satellite imagery	5 years
Sampling in specific Habitat types	2.5 years
Fish eagle, coot and cormorant abundance	1 month
Wetland birds	January and June every year
Hippopotamus count	1 month
Invertebrates survey	1 year

8.2.3 Buffer of vegetation

A buffer of vegetation along the perimeter of the lake is also recommended. The buffer requirements should be based on public acceptability and /assumed aquatic resource functional value. In Naivasha the criteria for determining adequate buffer size to protect the lake and its aquatic resources must be based on the functional value of the lake, level of disturbance, adjacent land use and functions of the buffer required.

8.2.4 Public awareness and Education

Public support and sufficient participation are essential for the success of sustainable use of the resources of Lake Naivasha. Farmers, local people and other stakeholders should be informed about the threats to the lake. They need to agree that there is a problem, that it is important to solve it and the right approach has been chosen to address the problem. Public awareness and education programs must be intensified within the lake and catchment zones.

8.2.5 Enforcement of fisheries regulation.

The fisheries department needs to be re-organised and equipped. More trained personnel and provision of transport is needed to enforce fisheries regulations and checking of illegal fishing. A closed season for fishing based on a study to determine the breeding period of the fish in the lake will assist in the sustainable utilization of the fisheries resource.

8.2.6 Suggestions for further research.

1. The effects of Agricultural practice and land use changes on the wetland habitats. Within this topic, the implications of nitrate and pesticides run-off from land to lake must be studied.
2. The effect of toxic substances on the nesting success of the Africa fish eagle must be studied. The parameters to be studied must include the percent of hatch and egg shell strength.
3. Identify on farm Best Management Practices (BMPs) to control pollution from agricultural activities. These BMPs should include water management systems, fertilizer and pesticides management, waste management systems and soil conservation practices.
4. A detailed study of the grazing pressure on grasslands and agricultural areas by the Hippopotamus should be initiated.
5. The fixed -width buffer of 50m around Papyrus recommended will be easier to enforce, but variable-width buffers are more likely to provide adequate protection. I therefore recommend a detailed study to determine variable width buffer depending on the conservation value and acceptability of the farmers.

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LANDCOVER - RELEVÉ SHEET FOR NAIVASHA FIELDWORK, MAY/JUNE, 1997.**GENERAL INFORMATION**

Relevé no: Photo no: Date:

 Sample size: (m²) Observer(s):
PHOTO CHARACTERISTICS

Map unit:				
Image object characteristics	Field/No field			
Field pattern	Yes/No			
Strata		Cover %		Tone Texture
Lowest stratum			W/L/M/D	C/F/S
Low stratum			W/L/M/D	C/F/S
High stratum			W/L/M/D	C/F/S

Key: W - White L - Light M - Medium D - Dark C - Coarse F - Fine S - Smooth

SATELLITE IMAGE

FCC color:

Unsupervised

Color:

SITE DESCRIPTION

Location(UTM) Map - N: E:

GPS- N: E:

Altitude (M.A.S.L.):

GENERAL LANDUSE:

Relief type	Slope type
very flat	Straight, Concave, Convex, irregular
Almost flat (<2%)	
Undulating (3 - 7%)	Slope length(m):
Rolling (8 - 13%)	
Hilly (14 - 20%)	Geological unit (from map):
Steeply dissected (21 - 55%)	
Mountainous (>55%)	

Remarks (Traces of :

 burning
 grazing
 droppings
 watering points
 foot prints
 trampling
 ploughing
 any other
SOIL AND WATER DATA

EROSION		SOIL DRAINAGE		FLOODING		
Type	Magnitude:		excessive	Agent	Frequency	Duration
None	very low		well	none		days
sheet	low		moderately well	rain per	weeks
rill	moderate		imperfect	run-on years	months
gully	strong		poor	river	month	
eolic	severe		very poor	lake	week	

Soil horizon:	Depth (cm)	Texture	colour	PH	Mottling	Remarks

COMMENTS:

VEGETATION:

Layer	>6m	4 - 6m	1 - 3m	>1m	Remarks
Av. height					
Sample size					
Cover %					

[illegible]

1-Cover: (+) =present; 1=1-10%; 2= 11-25%; 3= 26-50%; 4= 51-75%; 5= 76-100%

2-Height: 1= <1m; 2=1m - 3m; 3= 4m - 6m; 4= >6m

APPENDIX 2 PHOTO/IMAGE CHARACTERISTICS

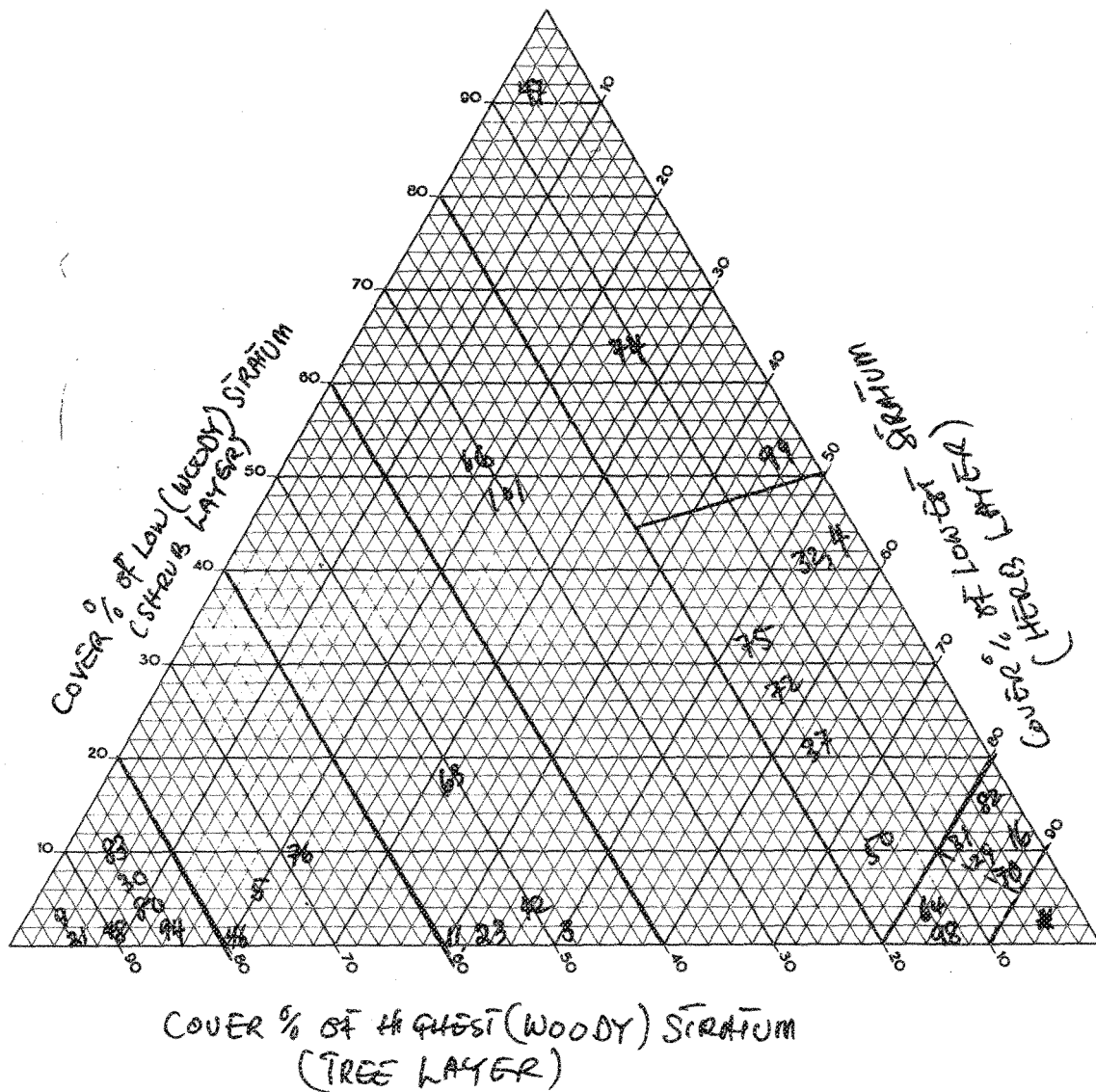
IMAGE OBJECT CLASS	FCC COLOUR	FIELD PATTERN	TEXTURE	EPECTED COVER
1	Bl	No	smooth	Open water
2	dP	No	smooth	Open water
3	M	Y	smooth	Agricultural Field
4	B	Y	smooth	Agricultural Field
5	dG	Y	smooth	Agricultural Field
6	lG	Y	smooth	Agricultural Field
7	R	Y	smooth	Agricultural Field
8	Br	Y	smooth	Agricultural Field
9	dG	N	smooth	Grassland
10	Br	N	Coarse	Woodland
11	R	N	smooth	Papyrus
12	Br	N	smooth	Shrubland
13	lB	Y	smooth	Agricultural field
14	lB	N	smooth	Grassland
15	lG	N	smooth	grassland
16	B	N	Coarse	Built up
17	gB	N	Coarse	Woodland

Bl = Black, dP = dark Purple, M = Magenta, B = Blue, dG = dark Green,
lG = light Green, R = Red, Br = brownish Red, lB = light Blue, and
gB = Greenish brown

IMAGE OBJECT	FIELD PATTERN	TONE	TEXTURE	STEREO HEIGHT	COVER CLASS
1	No	lg -dg	coarse	Yes	Woodland
2	No	g - dg	fine	Yes	Shrubland
3	No	lg	smooth	No	Grassland
4	No	dg	fine	Yes	Papyrus
5	No	dg-b	smooth	No	Open water
6	Yes	l -dg	smooth	No	Agricultural area
7	No	w	smooth	yes	Built up

B = Black, g = grey, w = white, lg = light grey, dg = dark grey, l = light

APPENDIX 3 SAMPLE NUMBERS PLOTTED ON CLASSIFICATION DIAGRAM



* 1, 6, 7, 8, 10, 12, 13, 14, 15, 17, 20, 24, 26, 27, 28, 34, 35, 36, 39, 40, 41, 43, 44, 47, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 67, 68, 69, 73, 77, 78, 79, 84, 85, 86, 87, 88, 89, 90, 91, 92, 95, 96, 97, 100, 102, 103, 104, 18, 19, 25, 38.

APPENDIX 4 FISH EAGLE CENSUS JUNE 1997

COORDINATES		NUMBER	HABITAT	SITE IDENTIFICATION
200986	9910380	2	ACACIA	ELSAMERE - HIPPO POINT
199780	9909918	2	ACACIA	ELSAMERE - HIPPO POINT
199687	9909918	4	ACACIA	ELSAMERE - HIPPO POINT
199438	9911700	2	ACACIA	ELSAMERE - HIPPO POINT
200428	9912060	2	ACACIA	ELSAMERE - HIPPO POINT
200645	9912469	2	FICUS	HIPPO POINT - REMA ISLAND
200985	9912593	1	FICUS	HIPPO POINT - REMA ISLAND
201170	9912931	1	FICUS	HIPPO POINT - REMA ISLAND
201077	9913177	2	ACACIA	HIPPO POINT - REMA ISLAND
200180	9913637	2	ACACIA	HIPPO POINT - REMA ISLAND
199777	9914098	1	FICUS	HIPPO POINT - REMA ISLAND
198230	9914896	2	ACACIA	HIPPO POINT - REMA ISLAND
197857	9916330	1	EICHHORNIA	HIPPO POINT - REMA ISLAND
197857	9916064	2	RHUS N.	HIPPO POINT - REMA ISLAND
197981	9916924	2	ACACIA	REMA ISLAND - HOPCRAFT
198382	9918308	2	PAPYRUS	REMA ISLAND - HOPCRAFT
198722	9918799	4	EICHHORNIA	REMA ISLAND - HOPCRAFT
199557	9919783	2	PAPYRUS	REMA ISLAND - HOPCRAFT
200114	9920276	1	ACACIA	REMA ISLAND - HOPCRAFT
200485	9920429	2	ACACIA	REMA ISLAND - HOPCRAFT
201723	9920553	1	ACACIA	REMA ISLAND - HOPCRAFT
202671	9920777	1	FICUS	HOPCRAFT - KARATI
208699	9918500	1	PAPYRUS	HOPCRAFT - KARATI
209305	9918440	1	EICHHORNIA	HOPCRAFT - KARATI
210745	9918930	1	ACACIA	KARATI - LAKE HOTEL
209305	9918440	1	EICHHORNIA	KARATI - LAKE HOTEL
212505	9913600	2	ACACIA	LAKE HOTEL - CRESCENT ISLAND TIP
212450	9913550	2	ACACIA	LAKE HOTEL - CRESCENT ISLAND TIP
211100	9914700	2	ACACIA	LAKE HOTEL - CRESCENT ISLAND TIP
210800	9915850	1	ACACIA	LAKE HOTEL - CRESCENT ISLAND TIP
211841	9916614	2	ACACIA	CRESCENT ISLAND TIP - SAFARILAND
209341	9915800	1	ACACIA	CRESCENT ISLAND TIP - SAFARILAND
210142	9916937	1	EICHHORNIA	CRESCENT ISLAND TIP - SAFARILAND
209654	9916541	2	EICHHORNIA	CRESCENT ISLAND TIP - SAFARILAND
208700	9910737	1	ACACIA	SAFARILAND - FISHERMAN CAMP
208085	9910280	2	ACACIA	SAFARILAND - FISHERMAN CAMP
206108	9909411	2	ACACIA	SAFARILAND - FISHERMAN CAMP
203530	9909089	4	ACACIA	SAFARILAND - FISHERMAN CAMP
201375	9910516	2	ACACIA	FISHERMAN CAMP - ELSAMERE
201034	9910450	2	ACACIA	FISHERMAN CAMP - ELSAMERE

SUMMARY					
ELSAMERE - HIPPO POINT			12		
HIPPO POINT- REMA ISLAND			14		
REMA ISLAND - HOPCRAFT			14		
HOPCRAFT - KARATI			3		
KARATI -LAKE HOTEL			2		
LAKE HOTEL - CRESCENT ISLAND TIP			7		
CRESCENT ISLAND TIP - SAFARILAND			6		
SAFARILAND - FISHERMAN CAMP			9		
FISHERMAN CAMP - ELSAMERE			2		
			69		

RELATIVE PROBABILITIES : WOODLAND = 0.73, PAPYRUS = 0.11 AND
FLOATING VEGETATION = 0.16

APPENDIX 5 PLANT SPECIES LIST FOR LAKE NAIVASHA

DICOTYLEDONS

ACANTHACEAE

Hypoestes aristata (Vahl) Roem. & Schultes
Hypoestes forskalei (Vahl) R.Br.
Monechma debile (Forsk.) Ness

AIZOACEAE

Glinus lotoides L.X *oppositifolius* (L.) A.D.C

AMARANTHACEAE

Achyranthus aspera L.
Amaranthus angustifolium
Amaranthus graecixans L.

ANACARDIACEAE

Rhus natalensis
Rhus vulgaris Meikle

APIACEAE

Hydrocotyle ranunculoides L.F

ASCLEPIADACEAE

Gomphocarpus fruticosus (L.) Ait.f
Gnmphocarpus physocarpus E.Mey
Gomphocarpus semilunatus A.Rich.
Pentarrhinum insipidum E. Mey.
Sarcostemma viminale (L.) R. Br.

ASTERACEAE

Aspilia mossambicensis (Oliv.) Wild
Aster muricatus Less
Circium vulgare (Savi) Ten.
Conyza bonariensis (L.) Cronq
Conyza floribunda H.B.K.
Conyza hypoleuca A. Rich
Conyza steudii A. Rich
Conyza stricta Willd.
Crassocephalum picridifolium (D.C.) S.Moore
Felicia muricata (Thunb.) Nees
Galinsoga parviflora Cav.
Gnaphalium luteoalbum L.
Gnaphalium undulatum L.
Helichrysum globosum Sch. Bip.
Melanthera scandens (Schumach.&Thonn.)
Pluchea ovalis (Pers.) D.C.
Psiadia punctulata (D.C) Vatke
Senecio discifolius Oliv.

senecio moorei R.E. Fries.
Senecio nandensis S. Moore
Senecio petitianus A. Rich
Senchus oleraceus L.
Sidons pilosa L.
Sphaeranthus confertifolius Robyns
Sphaeranthus gomphrenoides O.Hoffm.
Sphaeranthus napierae Ross -Craig
Sphaeranthus suaveolens (Forsk.) D.C
Tagetes minuta L.
Tarchonanthus camphoratus L.
Vernonia auriculifera (Welw.) Hiern.
Vernonia glabra L.

BORAGINACEAE

Cordia monoica Roxb.
Heliotropium steudneri Vatke

BRASSICACEAE

Erucastum arabicum Fisch.&Mey
Gynandropsis gynandra (L.) Briq.

CACTACEAE

Opuntia vulgaris L.

CAPPARACEAE

Maerua endlichii Gilg & Bened.
Maerua Triphylla A.Rich.

CARYOPHYLLACEAE

Polycarpon prostratum (Forsk.) Aschens&Schweinf.

CELASTRACEAE

Maytenus arbulifolia (A.Rich.)

CERATOPHYLLACEAE

Ceratophyllum demersum L.

CHENOPODIACEAE

Chenopodium album L.
Chenopodium ambrosioides L.
Chenopodium carinatus
Chenopodium murale
Chenopodium opulifolium Koch &Ziz
Phytolacca dodecandra L'Herit

CONVOLVULACEAE

Cuscuta campestris Yuncker
Ipomoea cairica (L.) Sweet

CUCURBITACEAE

Momordica foetida Schumach.

Zechneria scabra (L.f.) Sond.

EUPHORBIACEAE

Euphorbia kibwezensis

Euphorbia prostrata Alt.

Ricinus communis L.

FABACEAE**CAESALPINIOIDEAE**

Senna didymobotrya

MIMOSACEAE

Acacia abyssinica

Acacia drepanolobium

Acacia xanthophloea Benth.

PAPILIONACEAE

Centrosema pubescens Benth.

Crotalaria scassellatii Chiov.

Indigofera Schimperii

Indigofera erecta

Lotus corniculatus L.

Rhynchosia elagans A.Rich.

Sesbania sesban (L.) Merr.

Trifolium Semipilosum Fres.

Vigna luteola (Jacq.) Benth.

GERANIACEAE

Monsonia senegalensis Guill.&Perr.

LAMIACEAE

Leonotis nepetifolia (L.) Ait.f.

Ocimum gratissimum L.

Plectranthus caninus Roth

Plectranthus lanuginosus (Benth.) Agnew

Pycnostachys coerulea Hook.

Pycnostachys deflexifolia Bak.

Satureja biflora (D.Don) Benth.

Tinnea aethiopiaca Hook.f.

LENTIBULARIACEAE

Utricularia gibba L.

Utricularia inflexa Forsk.

Utricularia reflexa Oliv.

MALVACEAE

Abutilon mauritanum (Jacq.) Medic.
Abutilon rehmannii (Jacq.) Medic.
Hibiscus diversifolius Jacq.
Hibiscus flavifolius Uibr.
Hibiscus fuscus Garcke
Malva parviflora L.
Pavonia elegans Garcke
Sida tenuicarpa Vollesen

NYMPHAEACEAE

Nymphaea caerulea Savigny

OLEACEAE

Olea Africana (Mill)

ONAGRACEAE

Ludwigia stolonifera (Guill. et. Perr.) Raven

OXALIDACEAE

Oxalis obliquifolia A. Rich

PASSIFLORACEAE

Commicarpus pedunculatus (A. Rich.) Cuf.

POLYGONACEAE

Oxygonum sinuatum (Meisn) Dammer
Polygonum pulchrum Blume
Polygonum salicifolium Willd.
Polygonum senegalense Meisn. f.
Polygonum strigosum R.Br.
Rumex usambarensis (Dammer) Dammer

PORTULACACEAE

Portulaca oleracea L.

RANUNCULACEAE

Clematis brachiata Thunb.
Ranunculus multifidus Forsk.

RUBIACEAE

Pentas lanceolata (Forsk) Deflers
Rubia cordifolia L.

RUTACEAE

Teclea nobilis Del.

SCROPHULARIACEAE

Cynium tubulosum (L.f.) Engl.
Rhamphicarpa montana N.E.Br.

SOLANACEAE

Solanum Incanum L.
Solanum nigrum L.
Physalis peruviana L.

TILIACEAE

Grewia similis K.Schum.

URTICACEAE

Urtica massaica Mildbr.

VAHLIACEAE

Kanlachoe densiflora Rolfe

VERBENACEAE

Lantana camara L.
Lantana trifolia L.
Verbena officinalis L.

ZYGOPHYLLACEAE

Tribulus Cistoides L.

MONOCOTYLEDONS**ARACEAE**

Pistia stratiotes L.

CYPERACEAE

Cyperus alopecuroides Rottb.
Cyperus digitaris L.
Cyperus dives L.
Cyperus exaltus L.
Cyperus immensus C.B.CL.
Cyperus laevigatus L.
Cyperus papyrus L.
Cyperus rigidifolia Sted.
Cyperus stuhlmannii C.B.CL.
Kyallinga alba L.
Kyallinga cylindrica L.
Pycnus mundtii Nees
Scirpus inclinatus (Del.) Aschers. & Schweneinf.

DRACAENACEAE

Sansevieria suffruticosa N. E. Br.

LEMACEAE

Lemna perpusilla Torrey
Lemna triscula L.
Spirodela polyrhiza (L.) Schleid

Wolffia arrhiza (L.) Wimmer
Wolffiopsis welwitschii (Hegelm.) den Hartog & v.d. Plas

NALADACEAE

Najas pectinata (Peri.) Magnus

ORCHIDACEAE

Eulophia paivaena (Reichb. f.) Summerh. ssp. *borealis*
Summerh.

POACEAE

Aristida kenyensis Henr.
Bracharia jubata (Fig. & De Not.) Stapf
Cenchrus ciliaris L.
Chloris gayana Kunth
Cynodon dactylon (L.) Pers.
Cynodon plectostachyus (K. Schum) Pilg.
Dactyloctenium aegyptium (L.) Willd.
Digitaria Milaniana (Rendle) Stapf
Digitaria scalarum (Schweinf.) Chiov.
Eragrostis tenuifolia (A. Rich.) Steud.
Eragrostis pilosa (L.) P. Beauv.
Oropetium capense Stapf
Panicum maximum Jacq.
Pennisetum clandestinum Chiov.
Pennisetum stramineum Peter
Psilolemma jaegeri (Pilg.) S.M. Phillips
Setaria verticillata (L.) P. Beauv.
Tragus berteronianus Schult.

PONTEDERIACEAE

Eichornia crassipes (C. Martius) Solms-Laub.

POTAMOGETONACEAE

Potamogeton octandrus Poir.
Potamogeton pectinatus L.
Potamogeton schweinfurthii A. Bennett
Potamogeton thunbergii Cham. & Schlecht

TYPHACEAE

Typha domingensis Pers.
Typha latifolia L.

FERNS

ADIANTACEAE

Pteris dentata Forsk.

AZOLIACEAE

Azolla africana Desv.

MARSILEACEAE

Marsilea gibba A.Br.

SALVINIACEAE

Salvinia molesta Mitch.

THELYPTERIDACEAE

Thelypteris confluens (Thunb.) Morton

MOSSES**AMBLYSTEGIACEAE**

Drepanocladus sparsus C. Mull.

LIVERWORTS**RICCIACEAE**

Ricciocarpus natans L.

ALGAE**CHARACEAE**

Chara braunii Gmel.

Nitella oligospira Br.

Nitella knightiae Gr. et St.

APPENDIX 6 VEGETATION TYPE AND SOCIO-ECOLOGICAL GROUPS

Vegetation Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000
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APPENDIX 7 MAP CALCULATION FORMULAE

Map calculation formulae for generating input maps.

1. Fish eagle Nesting habitat

These were calculated from the 1984 and 1995 habitat maps

- Woodland 1984=IFF(habitat map1984="wd",1,0)
- Woodland 1995=IFF(habitat map1995="wd",1,0)

2. Hippo distance map

The source map calculated from the 1995 habitat map .

Open water = IFF(Habitat1995="ow", "ow",?)

3. Hippo grazing area

This was calculated from the 1995 habitat map

Hippo grazing area =IFF habitat1995="G",1,iff(habitat1995="Py",2,IFF(habitat1995="Aa",3,0)))