AN ECOLOGICAL STUDY OF THE PATTERN OF PLANT SPECIES DIVERSITY AROUND LAKE MANYARA, NORTHERN TANZANIA.

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Dedications

I am dedicating this thesis to my uncle reverent father Titus Ntalwila, my father Augustino Ntalwila and my mother Everada. M. Ntalwila.

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Abstract

The plant species diversity and plant communities around Lake Manyara have been described. Soil samples collected from each plot were analysed for soil pH, electric conductivity, cation exchange capacity, organic matter, sodium, calcium, phosphorus, magnesium, total Nitrogen, Soil texture (sand, silt, clay) and Trampling effect. Results obtained show that 84 species representing 40 families were recorded. Classification results using SYNTAX revealed seven plant communities. These include *Sporobobolus spicatus-Cyperus laevigatus* community type, Cynodon *dactylon-Sporobolus spicatus* community type, *Hyphaene petersiana-Digitaria velutina* community type, *Sporobolus consimilis* community type, *Acacia tortilis* community type, *Hypoestes forsskalei-Clausena anisata* community type, and *Trichilia emetica-Tabernaemontana pachysiphon* community type. The distributions of plant community types in relation to the environmental variables have been analyzed. Organic matter, clay content, silt content, soil pH cation exchange capacity, available phosphorus, electrical conductivity and trampling effect are the most important environmental factor that determines community distribution in lake Manyara area. Species diversity and evenness are high in plant community type V (*Acacia tortilis* community type) and community type VI (*Hypoestes forsskalei-Clausena anisata* community type) while plant community type I (*Sporobolus spicatus-Cyperus laevigatus*) show less species diversity. Vegetation cover and species diversity increased with distance from the lake. Recommendations towards the conservation of species in lake Manyara area are given.

1 INTRODUCTION

1.1 General introduction

The level of biological diversity differs from one area to another, and abiotic and biotic factors have been the major factors contributing to the biodiversity at all levels. According to Huston (1994), the diversity would not be interesting if the levels of diversity were the same everywhere.

Each region has particular patterns of spatial heterogeneity and bio geographical history, and temporal heterogeneity imposed by climate and its interaction with biological processes. The effects of environmental conditions and disturbance regimes on the patterns that occur on different patches within a landscape may create a constant change of species composition and diversity.

The structure and composition of vegetation is often a consequence of Environmental gradients. Gradient can be defined as a change in the value of a particular parameter, such as temperature, soil pH, soil moisture or species composition over space (Whittaker, 1975; Huston, 1994). Generally gradient is characterised as a change along linear distance. Gradients of gradual change in species diversity or species composition are common. On most landscapes the pattern of zonation is defined by the visually dominant species (Whittaker, 1975; Huston, 1994; Crawley, 1997).

Variations in species diversity are influenced by different physical and biological factors. For almost any gradient of diversity, some properties of the environment will be positively correlated with diversity and some negatively correlated (Magurran, 1988; Huston, 1994).

Factors that correlate with diversity may be underlying factors for identifying and understanding mechanisms that produce patterns. In order to be able to understand the patterns of species diversity, factors correlated with species diversity should be determined. Correlation can be positive or negative, can be direct interaction that may be simple to understand or complex interaction, which is difficult to understand (Crawley, 1997).

Globally, patterns of plant species diversity have been influenced by latitudinal gradient, altitudinal gradient and soil gradient (Huston, 1994; Gold-Smiths *et al.* 1986). Many physical conditions change along both altitudinal and latitudinal gradients. For groups of terrestrial organisms, diversity seemed to be lower in the poles and higher towards the tropics, reaching its peak in the tropical rain forest. However it is not true that all groups of organisms increase their diversity towards the lower latitudes (Huston, 1994). Generally species diversity tends to decrease with an increase in the elevation (Whittaker, 1975).

1.1.1 Species diversity

Biological diversity is influenced by different mechanisms, to the extent that particular species may exist where others perish in response to the same environmental conditions (Crawley, 1997). Environmental conditions make it difficult to completely understand biodiversity until the regulations of each mechanism are understood (Goombridge, 1992).

Biological diversity includes all levels of natural variation (Huston, 1994). It encompasses the natural variation from the molecular level, genetic level to the species level, where most interactions of the biological divesity takes place (Whittaker, 1975; Magurran, 1988). On the other hand bilogical diversity encompasses all variations in genes, species and ecosystems (Heywood, 1995). Diversity of species have remained the central theme in ecology for several decades (Magurran, 1988; Goombridge, 1992). Measures of the diversity are usually seen to be the key indicators of the well being of ecological systems (Heywood, 1995).

Undestanding the diversity of living things had become a difficult task in most cases, as a result many ecologists have devised a huge range of indices and models for measuring diversity (Magurran, 1988). According to Magurran (1988), diversity is hard to define because it consists of more than one component. The two components of ecological important are the variety and relative abundance of the species in a given area.

In studying species diversity the ecological diversity are often restricted to species richness (Magurran, 1988; Huston, 1994; Økland, 1990; Goombridge, 1992). Thus no community in any study could have species of equal abundance (Mugarran, 1988).

Conservationists normaly view species diversity as species richness (Whittaker, 1975; IUCN, 1994; Magurran, 1988; Palmer and Dixon, 1990; Huston, 1994; Norse, 1994). They always base on the rationale that species have the right to exist, they have the actual or potential economic benefits to man.

Several attempts have been made at generalizing the patterns of species diversity at different scales (Økland,1990; Palmer and Dixon, 1990; Norse, 1994). However there is a common view that species richness increases from more extreme harsh envinroment to low extremes (Magurran,1988; Økland,1990; Lawton *et al.* 1994).

According to Crawley (1997), for every combination of soil, altiude, slope, aspect and other climatic factors, there will be one species that grows better than others. In uniform and temporally constant world this single species would come to dominate the community and thus species richness in that particular place will be low(Økland,1990).

It has been argued that species diversity varies from one place to another due to spatial and temporal heterogeneity of environmental parameters (Magurran, 1988; Moughalu and Awonkunle, 1994; Crawley, 1997).

It has been reported that, in lake Mnayara area biodiversity conservation has mainly been confined to protected areas (Mwalyosi, 1995). Population pressure may result to biodiversity loss. Degradation of natural resources has an adverse effect on the conservation of biodiversity and so endangers species.

1.1.2 Vegetation description

Vegetation of lake Manyara area is much more related to the environmental variability of the East African Rift valley and volcanic activities that took place in the past (Loth, 1999). Most of these areas have soils with high amount of sodium carbonate that have been resulted from chemical weathering (Loth, 1999). It has been argued that a zonation of sodium tolerant species can be observed at the lakeshore of which *Sporobolus spicatus*, *Cyperus laevigatus* and *Cynodon dactylon* are common (Walter, 1971). Usually a forest around the lakeshore is dominated by *Acacia xanthophloea*, however they may become submerged during flood periods. In most cases palms appear to grow on soils that are at least periodically flooded (Walter, 1971). This is particularly in the areas where rainfall is not distributed quite uniformly.

Vegetation of lake Manyara area can be described as heterogeneous vegetation varying from swamp to short grassland, bush land, and woodland. Generally, savannah vegetation is predominant (Grandin, 1991; Solbring, *et al.* 1996). According to Loth (1999) plants in savannah ecosystems have to be well adapted to highly variable environmental conditions, which have been brought, by unpredictable rainfall and other unpredictable environmental changes. Generally African savannah are dominated by *Acacia tortilis* and some other *Acacia* species (Prins and Van der Jeugd, 1993).

Due to the high variability of hydrological and pedologic conditions in the valley bottom in lake Manyara area the vegetation is also diverse (Crawley, 1997). Plant distributions differ according to the salinity of the mostly clayey soils (Bauer *et al*, 1993). The rift valley bottom of the lake Manyara area has been filled with weathered materials from Mbulu highlands (Douglas-Hamilton, 1972, Loth, 1999).

The status of vegetation in lake Manyara has been partly influenced by the lake level (Douglas-Hamilton, 1972). This results from the lake level fluctuation with rainfall intensity and subsequent runoff in the catchment area (Vesey-FitzGerald, 1973; Mwalyosi, 1990)

The alkaline grasslands occur on the alkaline and saline, mostly clayey soils on the resent lake deposits (Douglas-Hamilton, 1972). Thus their distribution and colonization depends on the frequency of flooding by lake.

In the North at the foot of the escarpment, major rivers form large alluvial fans that are free from lake disturbances dominate the area. Close to the springheads where soils are kept nearly salt free by perennial overland flow with fresh water from spring, the ground water forest occurs (Greenway and Vesey-Fitzgerald, 1969). In locally better-drained areas bush lands of the *croton macrostachyus* replace the ground water forest. The valley bottom around the village of Mto wa Mbu North east of the lake is used mainly for irrigated banana plantation. The original vegetation has been cleared, and the clearing is still in progress.

Generally riverine vegetation occurs on salt free soils along rivers and streams. In neutral to slightly acid, well drained soils, and where moisture do depend mainly on rain fall, *Acacia tortilis* woodland and bush land occur (Loth, 1999). *Acacia tortilis* has been said to be the most characteristic tree species of the semi arid areas (Mwalyosi, 1991). In lake Manyara area, *Acacia tortilis* have been identified as the most important species contributing to the overall role in plant-animal interactions (Greenway and Vesey-Fitzgerald, 1969; Mwalyosi, 1991; Loth, 1999). *Commiphora* bush thickets occur on the steep slopes some times in the valleys.

On the uplands where fire incidences are common *Themeda triandra* and *Pennisetum mezianum* are predominant (Greenway and Vesey-FitzGerald, 1969). Towards the southern part of the lake near the southern boarder of the National Park on the basement complex plateau (Loth, 1999), the Marang forest reserve occurs. However the south part of the lake is said to be dominated by swamp vegetation (Greenway and Vesey-FitzGerald, 1969)

The natural forest and woodland within the National Park are completely protected from harvesting. Damage is caused mainly by overgrazing by wild animals in some years (Mwalyosi, 1991; Mugasha *et al.* 1993). Residents harvest trees in the forest and woodland outside the park in order to meet various wood needs. In most places there are very few or no trees remaining in these unprotected area.

When one studies any vegetation type, differences in pattern in the land scape which are visible are the plant communities (Kent and Coker, 1992). Plant communities can be defined as the collection of the plant species that grow together in a particular location that show a definite association or affinity with each other (Kent and Coker, 1992). Slingsby and Cooker (1986) defined an ecological community as an assemblage of organisms in a particular place. Some species tend to occur together, because they tend to share certain environmental requirements. Some species are found growing together in certain locations and environments more frequently than would be expected by chance. This comes out in the view that species must have similar requirements for their existence in terms of environment factors such as light, temperature, water,soil nutrients etc. Some times these species do share other parameters for example, tolerance to activities of animals and human, grazing, burning, or trampling (Kent and Coker, 1992).

1.2 Classifications and Ordination

Multivariete techniques are normaly employed to study the complex nature of plant communities with the general objectives of summarising large complex data sets obtained from community samlpes, aiding in the interpretation of the data and the generation of hypothesis about community structure and variation (Gauch, 1982; Gauch and Whittaker, 1972; Økland, 1990). The descriptive nature and functional characteristics of vegetation results from the interaction between the properties of the plant species it contain and the environment in which they occur.

Recently there is a wide variety of multivariate technique available to study the complexicity nature of the plant communities (Gauch, 1982). In any of the Ecological studies, Multivariete techniques have shown an increase in developmet and application since few decades (ter Braak, 1987, 1988).

Many studies have pointed out that among the multivariety methods in studying the complex nature of communities, ordination and classification are the two main and basic strategies (Mueller-Dombois and Ellenberg 1974; Gauch and Whittaker, 1972; Whittaker, 1973, 1975; Digby and Kempton, 1987; ter Braak, 1986,1987,1988; Økland, 1990). Both ordination and classification continue to contribute materially to the elucidation of the complexities within communities. Therefore the choice of the method to be used depends on the ecological question to be answered (Gauch and Whittaker, 1972; Whittaker, 1975; Gauch, 1982).

1.2.1 Classification.

Classification methods aim at analysing the ecological communities, grouping the individuals stands into categories by producing final groups, which are homogeneous (Whittaker, 1973, 1975). Those stands which are closely similar with one another they normally form one class. More over the properties common to a group of similar stands are used to describe that class.

Classification of ecological communities usually provides a useful summary of large data matrices (Gauch and Whittaker, 1981; Digby and Kempton, 1987), particularly when complemented by ordination methods. When classifying the communities, the cluster analysis techniques are useful tools for data analysis (Everitt, 1980). These techniques can be used to simplify the description of large set of data, to generate hypotheses and to search for natural grouping (Everitt, 1980; Digby and Kempton, 1987).

Classification can be hierarchical or non hierarchical (Whittaker, 1973; Everitt, 1980; Hill, *et al.* 1975; Gauch and Whittaker, 1981; Økland, 1990). The non-hierarchical approach used to assign each item to a group while the hierarchical methods used to arrange the groups into a hierarchical (Everitt, 1980; Gauch and Whittaker, 1981). In the hierarchical classification first data are separated into a few broad classes, each of which further divided into smaller classes, then each of these are further subdivided until the terminal classes are generated which are not further subdivided. The final result from any clustering depends on both the initial choice of the similarity measure used to and the criterion for defining group similarity.

1.2.2 Ordination.

Ordination used to summarise the continuous variation, which is often present in classification data, but it ignores details of the pattern and composition of under growth species giving more weight to quantitative aspect (ter Braak, 1987; Økland, 1990). Ordination provides a view of the data and should be used at the outset even when classification is the objective (Whittaker, 1973; Hill, *et al* 1975; Hall and Swine, 1976).

Mueller-Dombois and Ellenberg (1974), describe ordination as a way (technique), which aims at description through the arrangement of samples and stands in order of similarity or environmental gradients. Ordination is a series of techniques that graphically represent similarity between stands species and environmental variables (Gauch, 1982).

Gauch, (1982) argue that the result of ordination is the arrangement of species and samples in a low-dimensional space such that similar entities are close by and the dissimilar entities far apart. Plant species experience the conditions provided by many environmental variables therefore one might analyse their joint effects (ter Braak, 1987).

Canonical correspondence analysis (CCA) aids in examining relationships between species distribution and the distribution of the associated environmental factors and gradients (ter Braak, 1987, 1988). CCA differs from other multivariate analysis techniques in the way that it incorporates the correlation and regression between vegetation data and environmental factors within the ordination analysis itself. The input to CCA consist both data matrix of species and quadrats but also a second data matrix of environmental factors and quadrats. Based in the above advantage, CCA is best defined as the direct method of ordination with out puts being the variability of the environmental data as well as the variability of the species data (ter Braak, 1987,1988, Slingsby and Cook, 1986; Økland, 1992).

The resulting ordination diagram of the CCA usually expresses both patterns of variation in floristic composition and gives out the principal relationship between the species and each of the environmental variables recorded in that particular area. CCA thus used to display the distribution of organisms along gradients of important environmental factors. According to Gauch, (1982), the purpose of direct gradient analysis is to gather and organise community and environmental data in trying to answer different questions, such as which environmental factor in a complex of factors is principally affects the distribution of organisms and community?

In CCA ordination techniques, biplots principle is greatly enhance the interpretations of environmental gradients and allows individual species to be related to all major environmental factors. Thus in CCA diagram the length of the arrow is proportional to the magnitude of change in that direction (Slingsby and Cook, 1986). The environmental variables with long arrows are more closely correlated in the ordination than those with short arrows.

1.3 Background to the study

Patterns of species diversity are much more influenced by physical and historical factors that change along different environmental gradients. Spatial variation in soil conditions can influence the pattern of diversity. A soil gradient on the scales of continents always contributes to patterns of the species diversity thus variation in soil water; nutrients or texture has an influence on patterns of plant diversity (Wild, 1993). Patterns of species diversity have been complemented by effort to explain how so many species can coexist and why more coexist in some areas than in others.

The vegetation of the Lake Manyara region has been extensively modified by drainage system within the area (Mwalyosi, 1991). The drainage variations of the area have an influence on the physical and chemical properties of soil, which in turn affect qualitative and quantitative distribution of the species. The whole valley environment is subjected to cyclic variations of flood and drought. In determining the patterns of plant species diversity, soil conditions and other environmental variables should be well understood.

Mugasha *et al.* (1993) documented that, the lake is an internal drainage with very high saline water of Electrical Conductivity (E.C) as high as 94 dsm^{-1} and a pH between 9-11. Due to high salinity and pH, precipitates usually develop white crusts of salts on the mud flats adjacent to the lake.

The occurrence of volcanic lava and ash also accounts for the high alkalinity of the area. Since the drainage system of the lake is closed, the alkalinity of the water becomes so high by evaporation that soda crystals form on the lake bed (Loth, 1999) this results into high physical and chemical variations of the soils.

Lake Manyara basin represents one of the most challenging areas in terms of conservation programmes. That is it supports a wide range of flora and fauna. The area supports considerable population of pastoral group and their livestocks which adds the need for more attention in the coservation aspect.

Land use activities taking place in the area have a direct impact on the plant patterns and their diversity. Most areas outside the park have been subjected to fire and grazing for a long time creating a very open vegetation.

Lake Manyara National park has been an atraction area to a number of zoologist, botanists, and ecologists. Many studied have been conducted in lake Manyara National Park (Greenway and Vesey-FitzGerald, 1969; Makacha and schaller, 1969; Mwalyosi, 1977, 1981, 1987, 1990, 1991,1995; Mwalyosi and Yanda, 1989; Mwalyosi and Mohamed 1992; Mugasha *et al.* 1993; Loth , 1999).

All the studies in the area have been much concentrated within the National park (western side of the lake). More over many scientists have been interested in the study of *Acaia tortilis* (Mwalyosi, 1987, 1990; Loth, 1999). Thus the corresponding work in the other side of the lake have been lacking. In addition to that there is limited scientific informations on the patterns of the plant species diversity and their relation to environmental factors that have been carried out in the area. Therefore the present study aimed at an ecological study of the pattenrs of plant species diversity around lake Manyara area. Thus informations obatined will contribute towards the coservation and sustainable utilization of the ecosystems (i.e lake Manyara area and its sorounding environment).

1.4 Objectives

1.4.1 General objective

To identify and describe the plant communities and plant species diversity around Lake Manyara area.

1.4.2 Specific objectives

- To identify the plant communities and document the species diversity around Lake Manyara.
- To relate some environmental factors and plant communities.
- To suggest possible conservation measures for the area.
- To establish a species list for the area.

2.0 THE STUDY AREA

2.1 Site description

Lake Manyara is located in Northern Tanzania along the base of the Eastern branch of the East African Rift valley system in the Maasai steppe, about 125 kilometres south-west of Arusha town (Mwalyosi 1990). The lake has approximately 40 km long and 13 km wide, having area of $413km^2$ and a maximum depth of 3.7m when filled to its maximum (Mugasha *et al.* 1993). The lake extends from 35^0 44'-35^0 54'E and 03^0 25'-03^0 48'S (Fig. 1), at 945 ma.s.l. The lake is oriented almost due to N-S direction. Between the lake and the escarpment is a narrow strip of land that forms lake Manyara National park. The park covers 330km^2 of which 229 km^2 is within the lake (Mwalyosi, 1981; Mugasha *et al.* 1993). Game controlled area and agricultural lands make up the remeinder of the land bordering the lake. It has been pointed out that Lake Manyara is among the lakes with very high sodium carbonate (Walter, 1971), and is among the internal drainage lakes within the East African Rift valley lakes (Loth, 1999).

Lake Manyara area receives increasing interest among tourist (Mwalyosi, 1991; Loth, 1999; Mugasha *et al.* 1993). It is very farmous for its birdlife, more than 350 bird species have been recorded (Loth, 1999). The lake offers a very good feeding ground for Flamongoes which are said to increase year after year (Mwalyosi, 1991; Mugasha, *et al.* 1993; Loth, 1999). It has been pointed out that the presence of large flocks of the lesser Flamingoes is related to high salinity of the lake (Mwalyosi and Yanda, 1989; Loth, 1999).

Moreover Manyara is well known for its large mammals. The total biomass is estimated at 177 kg ha^{-1}, this is among the highest herbivoure biomass in the world (Douglas-Hamilton, 1972; Loth, 1999). There is also varieties of canvores have been recoreded in lake Manyara national park. The most important are the Lions, Leopards, Spotted hyena, black-jaccked jackal and bat-eared fox (Douglas-Hamilton, 1972).

2.2 Vegetation

The vegetation is heterogeneous varying from swamp to short grassland, bush land, woodland and forest. Generally, savannah vegetation is predominant (Grandin, 1991, Solbring, *et al.* 1996). The level of the lake, which is subjected to cyclic extremes, conditions the vegetation of the lake basin. Grasslands are characteristic of the lowland alkaline flats. Marshes and alkaline flats border the lake (Mwalyosi, 1981). Northern third of the Park is covered with evergreen forest (under ground water forest) made possible by low precipitation but high water table. Swampy glades of *Typha* and *Cyperus* species (Makacha and Schaller, 1969) break the continuity of the forest. The vegetation types and distribution is strongly associated to soil type which inturn is associated to topography (Loth, 1999). Woody vegetation mainly occupies the well drained hill and ridge tops. The prevalent woody vegetation is *Acacia* woodlands in the drainage channels and *Comiphora combretum* decidous woodlands in upland areas (Mwalyosi 1991, Mwalyosi and Mohamed 1992). Generally the Northern and South-west of the lake is characterised by forest and wood lands, Northern and North west is ground water forest, to the Southern part, the lake is dominated by a swamp while the grasslands dominates the eastern side of the lake.

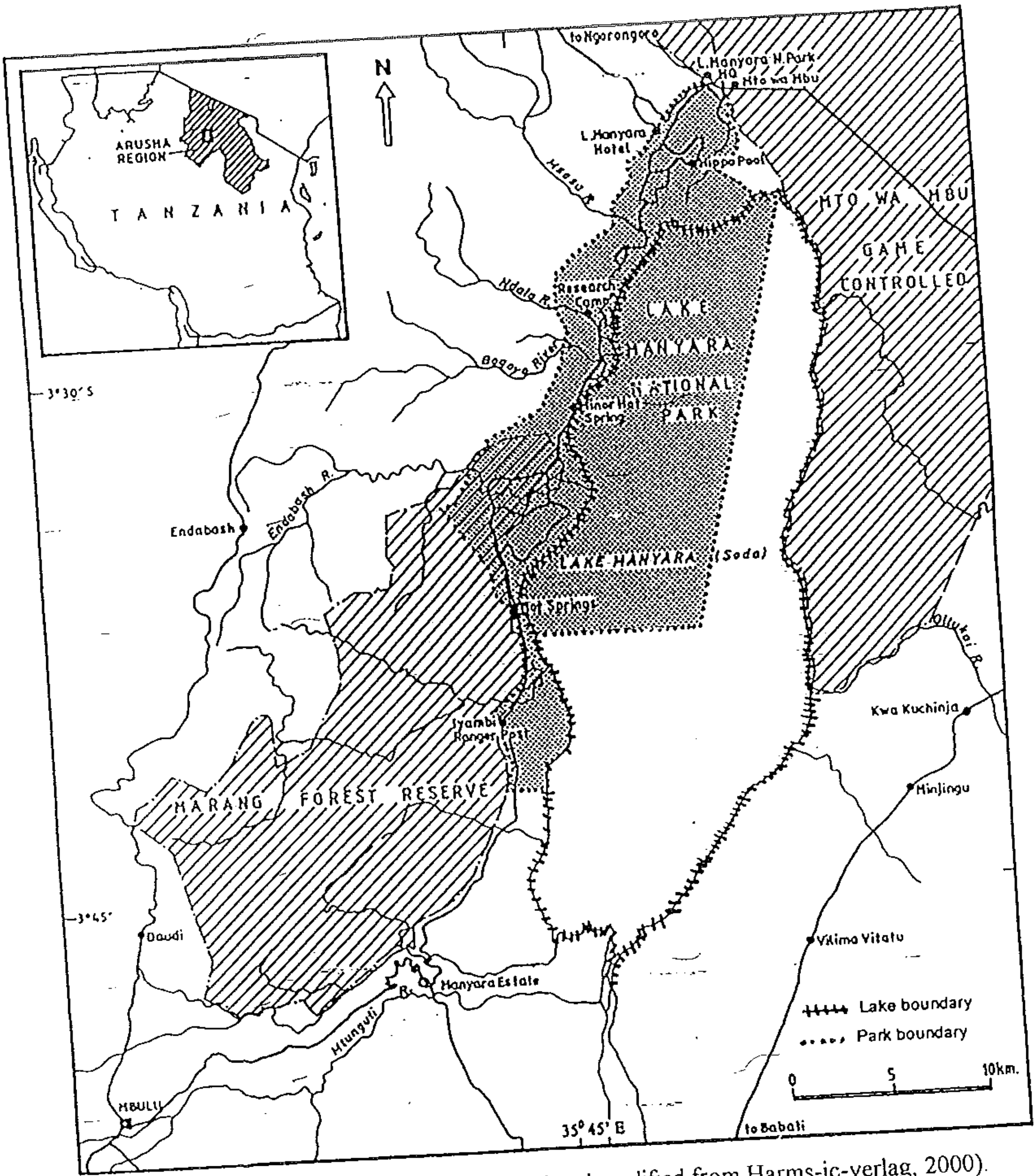

Figure 1. Location of the study area (Adapted and modified from Harms-ic-verlag, 2000).

2.3 Climate

Lake Manyara is found around the Maasai dry lands of East Africa. Rainfall is bimodal and completely restricted to rain season from November to May, with peaks in March to April (Mwalyosi, 1981). The rainfall regime is between 508 to 725 mm per annum. However, in the southern regime it is about 1130mm per annum, twice as much as received in the northern part (Mugasha *et al.* 1993). More over the rain season is divided into short rains from December to January and the long rains from February to May. The mean monthly temperature is almost uniform ranging from 22^{0}C-25^{0}C and the mean annual temperature is around 22°C. July is always recorded as coldest month while November to December are the hottest months (Bauer, *et al.*1993). Rainfall and temperature data that were recorded from Lake Manyara National Park weather station for ten years (1990-1999) are presented in figure 2.

2.4 Soils and Geology

The underlying rocks belong to the Mozambique Belt, which is a part of the crystalline basement rocks in which a wide variety of sedimentary and volcanic rocks have been subjected to metamorphic events (Greenway and Vesey-Fitzgerald, 1969; Bauer *et al.*1993; Loth, 1999). Volcanic activities have played a significance role in the overall soil type of Lake Manyara area. The Oldonyo Lengai, which is an active volcano mountain in Tanzania is approximately 100km from lake Manyara (Loth, 1999) was slightly active in 1983 and in 1995. Lake Manyara has been among the affected areas by these volcanic activities (Loth, 1999). Soils have been developed on the mixture of colluvial and alluvial deposits (Bauer *et al.*1993). The coarser deposits are situated nearer to the escarpment and nearer to the river and natural flood plains. Soil texture is constantly clay-loam (Bauer, *et* *al.*1993) this is probably due to earlier lakedeposits and salinity increases drastically towards the lake. Thus in the lake basin, saline soils are common (Loth, 1999).

Mto wa Mbu/ LMNP (960ma.s.l.) [10] 25 ^{0}C, [725] mm

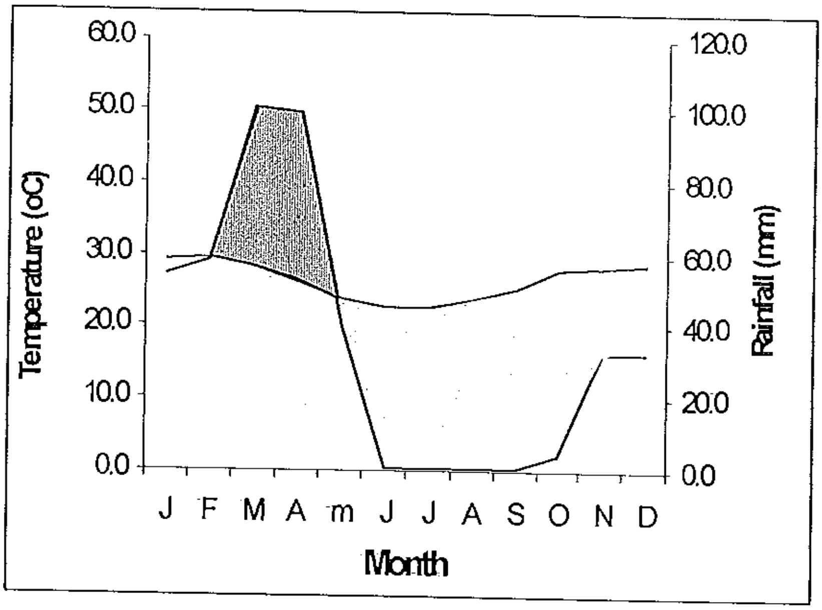

Figure 2. Climate diagram of the study area

3.0 MATERIALS AND METHODS

3.1 Vegetation sampling

A reconnaissance survey of the study area was done on 23 October 2000. Six study sites (T1-T6) were established in the study area (Fig.3) out of which (T1, T3, T5, T6) were established inside the park and two (T2, T4) outside the park. The former four (T1, T3, T5, and T6) extended from the lakeshore to the foot of the escarpment, while the later two (T2 and T4) extended from the lakeshore to the open land. Sample plots 1-14 were laid along T1 (mahali pa nyati); 15-22 along T2 (Jangwani area); 23-32 along T3 (southern boarder of the park); 33-44 along T4 (Kwakuchinja); 45-52 along T5 (Endala); and sample plot 53-62 along T6 (ground water forest). A transect starting from the lakeshore was established at each site and sampling points were located at intervals of 100m. Vegetation sampling was done by using nested plot (Mueller-Dombois and Ellenberg, 1974) technique where by (1x1) m plot were used for herbs and grasses, (5x5) m plots for shrubs and (20x20) m plots for trees. Following Mueller-Dombois and Ellenberg (1974), trees were identified as plants taller than 5 m height and shrubs were identified as plants between 50cm to 5m height.

A total of 62 sample plots were analysed through out the study area. The cover abundance values of all herbs, grasses, sedges, shrubs and trees were estimated using a 1-9 Braun-Blanquet (1932) scale as modified by Van der Maarel (1979). The scale used was: 1 = rare; 2 = few; 3 = < 5% cover; 4 = 5-12.2%; 5 = 12.5-25%; 6 = very abundant but < 5% cover; 7 = 25-50%; 8 = 50-75% and 9 = 75-100%. Where possible plants were identified in the field and in the case where this was not possible specimens were collected for identification and verifications at the University of Dar es Salaam herbarium. The identification and naming of the species was based on the work done by Brenan and Greenway 1949; Turrill and Milne-Redhead, 1952; Agnew, 1974; Hedberg and Edwards. 1989; Lock, 1989; Brumitt, 1992; Edwards *et al.* 1995; Beentje, 1994; Kokwaro, 1994 and available herbarium specimens. Voucher specimens are stored at the Botany Department Herbarium University of Dar es Salaam.

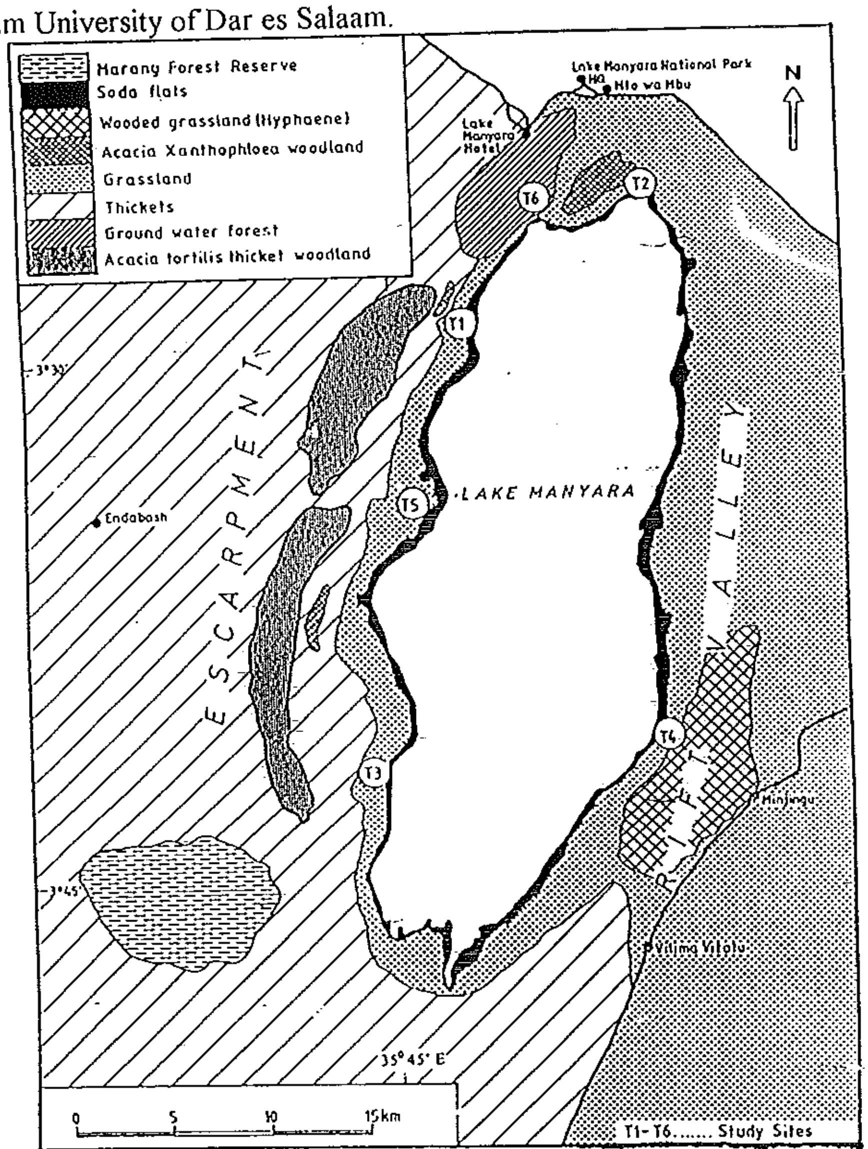

Figure 3. Map of Lake Manyara area showing the study sites (Adapted and modified from Harms-ic-verlag, 2000).

3.2 Environmental data

Altitude was recorded using Everest altimeter at each location. The degree of trampling effect was visually estimated for all quadrates, a scale from 1-3 was used where 1 denotes no trampling effect to plants, 2 trampling effect is less and does not cause severe damage to plants and 3 means the trampling effects is high and cause severe damage to plants.

3.2.1 Soil sampling and analysis

At each sample plot, soil samples were collected at the depth, 0-20 cm depths using a soil auger. Soil samples were kept in polythene bags and properly sealed to prevent contamination and moisture loss, and transported for laboratory analysis to the soil laboratory at the Department of Botany, University of Dar-es-Salaam.

The following physical and chemical properties were analysed for each sample.

- Soil texture: The percentage of sand, clay and silt was determined by hydrometer method as described by Juo (1978).
- Soil pH: Soil pH was determined electrometrically by using the standard electrode procedure in a 1:1 soil water suspension as described by Allen (1989).
- EC: Electrical Conductivity of the soil samples was analysed electrometrically as described by Juo, (1978). The readings were taken as ms/m.
- CEC: Cation Exchange Capacity (CEC) of the soil was determined by Ammonium Acetate (pH 7) method and the readings were taken as meq. /100g (Juo, 1978).
- OM: The determination of organic matter (OM) was done using the Walkley-Black methods as described by Allen (1989), as % dry weight.

- Available P: Available phosphorus was determined by using Bray No.II method and readings recorded as meq. /100g.
- Total N: The determination of total Nitrogen involved two steps, the first stage involved Kjeldahl method where the soil samples were digested to convert organic N to NH^{+}_{4}., and the second step was the determination of ammonia using the indophenol's blue method as described by Juo (1978). Readings were taken as % Nitrogen.
- Exchangeable Bases: The exchangeable bases such as Sodium (Na) and Potassium (K) were determined by flame photometry method as described by Allen (1989), and readings were taken as meq. /100g. Calcium (Ca) and Magnesium (Mg) were determined using atomic absorption method Allen (1989) and recorded as meq. /100

3.3 Data analyses

3.3.1 Classification

Plant community types were analysed following the hierarchical agglomerative clustering technique a computer program SYNTAX (Podani, 1988). Similarity ratio was used as the resemblance index and the average linkage was used as the clustering technique. In this technique the pairs of stands were fused together on the basis of their similarities being the highest and the dissimilarities being the lowest (Podani, 1988). The process continued until all the stands were fused to form one common single group showing a hierarchy from the bottom.

3.3.2 Ordination

Direct ordination is normally performed where the aim is to see how much the measured variables actually account for the variation in data. Canonical correspondence analysis (CCA) was applied to the data using the computer program CANOCO version 4 (ter Braak, and Smilauer, 1998). This program was selected taking into consideration that it is believed to constitute methods that will sufficiently handle and explain the variation in the collected data. The aim was to define the environmental gradients along with the floristic data. CCA reveals the linear combination of the environmental variables measured and explains variations in the species along the ordination axes. For the generation of ordination diagrams CANODRAW in CANOCO program was used (ter Braak, 1987, 1988).

3.3.3 Statistical treatment

The relationships between environmental variables were analysed using Pearson's product–moment correlation coefficients available in the statistical analysis systems using a computer program SPSS. Analysis of variance (ANOVA) was carried out to detect significant differences among the means of the environmental variables of each plant community type. (Thus Tukey's family error rate was performed using the computer program statistical package for social sciences i.e. SPSS)

3.3.4 Species diversity

The species diversity was determined using the Shannon -Wiener diversity index (Magurran, 1988), as follows,

$H' = -\sum pi \ln pi.$

Where, H' =Shannon's diversity index,

Pi = Proportion of the abundance of the i^{th} species as

a proportion of the total cover.

ln = log $base_n$

Species evenness were calculated using the Shannon's evenness index,

$E = H' / H_{max}$, where, E = Evenness, H_{max} = Lns. S = numbers of species in that community,

H' = Shannon's diversity index.

4.0 RESULTS

4.1 Community classification

A total of 84 plant species were identified representing 40 families. A list of all plant species and their families is presented in appendix 1. The number of species per sample plot ranged from one individual species in sample plots found close to the lakeshore to seventeen species in those sample plots found in areas away from the lake (Appendix 2).

Plant communities were characterised by sociological species group resulting from the classification-analysis SYNTAX. In this study the term community is defined as the group of plants, which typically occur together in respective of associated plants (Mueller-Dombois and Ellenberg, 1974). SYNTAX classification resulted in a satisfactory separation of clusters. The dissimilarity levels at which ecologically meaningful major clusters showed up is determined at dissimilarity level above 0.8.

Seven major plant community types (i.e. clusters) have been identified and designated as I, II, III, IV, V, VI and VII (Fig.4). Plant communities have been named based on dominant species. Whittaker (1975) suggested that classifying plant communities using dominant species is the easiest way. One or two species with the highest mean cover-abundance values as shown in Table 1 have been used in naming the plant communities. Species and their plots in which they occurred are presented in appendix 3. Normally more than one plant species dominate a particular community. In the present study cluster numbers (Fig.4) correspond to the number of community types described below.

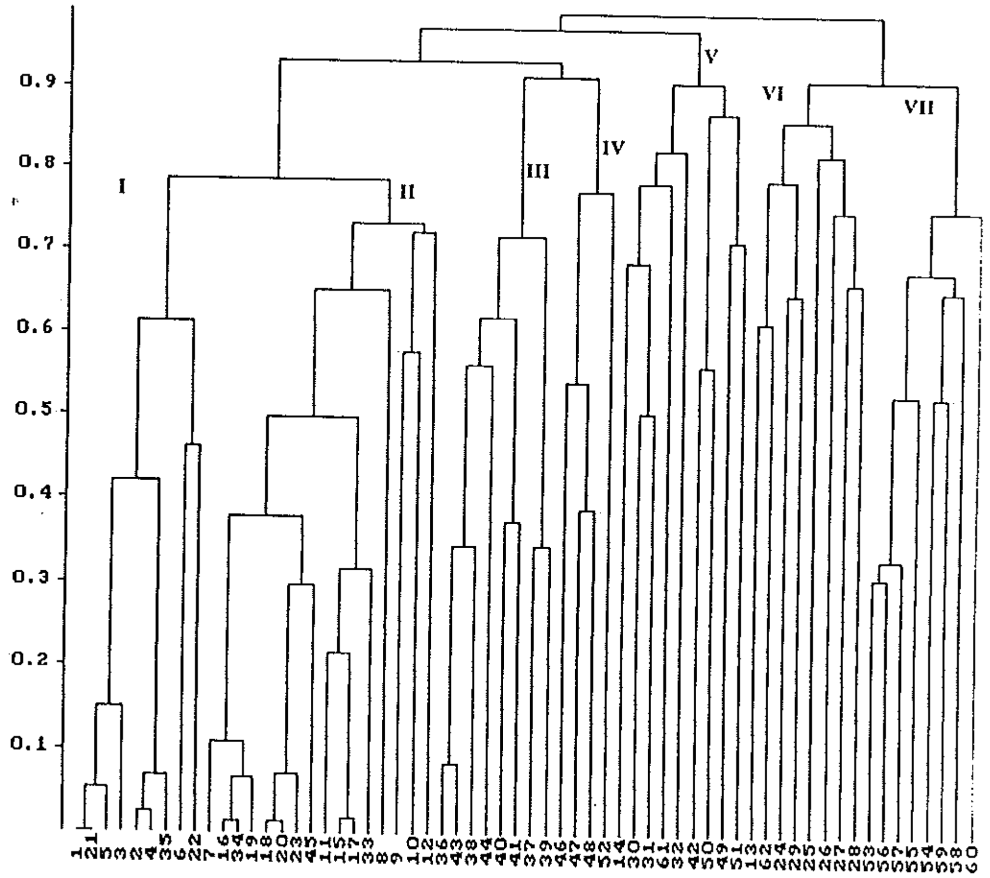

Figure 4. Dendrogram of stand groups of vegetation composition around Lake Manyara Y- axis represent the dissimilarity levels, X-axis represents stands (sample plots)

4.2 Plant community descriptions

Type I. *Sporobobolus spicatus-Cyperus laevigatus* community

The community is mainly dominated by *Sporobobolus spicatus* and *Cyperus laevigatus* in the field layer. Associated species in this community are, shrubs of *Acacia xanthophloea* and *Vernonia myriantha*. Tree layer is not found in this plant community type.

Type II. *Cynodon dactylon-Sporobolus spicatus* community

This community is mainly dominated by *Cynodon dactylon* and *Sporobolus spicatus* in the field layer. Other important but less abundant field layer species are *Sphaeranthus bullatus, Cyperus laevigatus, Sporobolus consimilis, Melochia corchorifolia, Ehretia ameona, Hypoestes forsskalei, Ocimum gratissimum* and *Cassia mimosoides. Tabernaemontana usambarensis, Pluchea dioscoridis* and *Vernonia myriantha* are the species in shrub layer while *Trichilia emetica, Rauvolfia caffra, Croton macrostachyus,* and *Cordia goetzei* are species in tree layer.

Type III. *Hyphaene petersiana-Digitaria velutina* community

Hyphaene petersiana constitute the dominant tree layer species in this community while the shrub layer is mainly dominated by *Digitaria velutina.* Other associated species in tree layer includes, *Acacia zanzibarica, Commiphora africana* and *Acacia xanthophloea. Abutilon bidentatum, Achyranthes aspera, Sporobolus consimilis, Sphaeranthus bullatus, Cynodon dactylon* and *Cynodon nlemfuensis* form a group of species in field layer.

Type IV. *Sporobolus consimilis* community

The field layer in this plant community type is well defined and is dominated by *Sporobolus consimilis.* Other important but less abundant associated field layer species are *Sporobolus spicatus, Pluchea dioscoridis, Eragrostis paten, Heliotropium longiflorum, Ehretia ameona* and *Boerhavia diffusa. Balanites aegyptiaca* is the characteristic species in the shrub layer. Species in the tree layer includes *Kigelia africana, Acacia tortilis,* *Acacia xanthophloea, Triumfetta rhomboidea, Harrisonia abyssinica,* and *Terminalia brownii.*

Type V. *Acacia tortilis* community

This community type is characterized by *Acacia tortilis* as the dominant tree species. The associated trees and shrubs in this type include *Acacia zanzibarica, Cordia sinensis, Cordia ovalis, Balanites aegyptiaca, Gardenia jovis-tonantis, Maerua triphylla, Solanum incanum* and *Hibiscus micranthus. Hypoestes forsskalei, Chloris gayana, Boerhavia diffusa, Eragrostis patens, Conyza pyrrhopappus, Cyperus erectus, Commelina africana, Digitaria velutina, Euclea schimperi, Heliotropium longiflorum, Blepharis maderaspatensis, Ocimum gratissimum, Cynodon nlemfuensis* and *Lindackeria bukobensis* are common species in the field layer.

Type VI. *Hypoestes forsskalei- Clausena anisata* community

The community is mainly dominated by *Hypoestes forsskalei* and *Clausena anisata.* Other important but less abundant associated species in the shrub and field layer includes *Hibiscus micranthus, Sphaeranthus bullatus, Achyranthes aspera, Acacia mellifera, Acacia brevispica, Digitaria velutina, Ipomea hildebrandtii, Maerua triphylla, Capparis fascicularis Tabernaemontana usambarensis, Vernonia myriantha, Euclea schimperi, Acalypha fruticosa, Rhus longipes, Chassalia parvifolia, Xylopia parviflora, Flacourtia indica, Opilia amentacea* and *Allophylus africanus. Trichilia emetica, Strychnos mitis, Maerua angolensis, Cordia sinensis, Kigelia africana, and Ziziphus mucronata,* common species in the tree layer.

Type VII. ***Trichilia emetica- Tabernaemontana pachysiphon*** **community**

This type has a well-developed tree and shrub layer. *Trichilia emetica* is dominant in the tree layer and *Tabernaemontana pachysiphon* is dominant in the shrub layer. Other associated tree and shrub species include *Bridelia micrantha, Cordia sinensis, Balanites aegyptiaca, Hibscus micranthus, Cordia ovalis, Ficus thonningii, Tabernaemontana usambarensis, Croton macrostachyus, Cordia goetzei, Flacourtia indica, Cordia africana* and *Maerua angolensis. Achyranthes aspera, Sphaeranthus bullatus, Acalypha fruticosa, Celtis africana, Drypetes natelensis, Panicum infestum, Oncinontis tenuiloba, Sporobolus spicatus, Whitfieldia elongata, Sida acuta, Rhus longipes, Antiaris toxicaria, Acalypha fruticosa, Xylopia parviflora*, and *Trema orientalis* are species in the field layer.

Table 1. List of species with mean cover abundance values. Species names used for community types naming their mean cover abundances values are given in bold.

Communities	I	II	III	IV	V	VI	VII
Abutilon bidentatum	0	0	0. 6	0	0	0	0
Acacia brevispica	0	0	0	0	0	1.38	0.25
Acacia mellifera	0	0	0	0	0	0.75	0
Acacia tortilis	0	0	0	1	**6.8**	0	0
Acacia xanthophloea	1.22	0.59	0.63	1	0	0	0
Acacia zanzibarica	0	0	0.38	1	1.67	0	0.08
Acalypha fruticosa	0	0	0	0	1.22	0.13	0.88
Achyranthes aspera	0	1.29	0.75	0	0	2.5	3
Allophylus africanus	0	0	0	0	0	0.75	0
Antiaris toxicaria	0	0	0	0	0	0	0.38
Asparagus falcatus	0	0	0	0	0	0	0.75
Balanites aegyptiaca	0	0	0	1.25	0.56	0	0.75
Boerhavia diffusa	0	0	0	1.25	0.67	0	0
Blepharis maderaspatensis	0	0	0	0	0.89	0	0
Bridelia micrantha	0	0	0	0	0	0	0.63
Blighia unijugata	0	0	0	0	0	0	0.25
Capparis fascicularis	0	0.29	0	0	0	0.63	0.25
Cassia mimosoides	0	0.41	0	0	0	0	1.3
Celtis africana	0	0	0	0	0	0	3.63
Chassalia parvifolia	0	0	0	0	0	1.5	3.63
Chloris gayana	0	0	0	0	1.33	0	0
Clausena anisata	0	0	0	0	0	**2.63**	0
Commelina africana	0	0	0	0	1.22	0	0
Commiphora africana	0	0	0.75	0	0	0	0
Conyza pyrrhopappus	0	0	0	0	0.56	0	0
Cordia goetzei	0	0.35	0	0	0	0	1
Cordia ovalis	0	0	0	0	0.44	0	1
Cordia africana	0	0	0	0	0	0	1.63
Cordia sinensis	0	0	0	0	1.22	0.63	1.63
Croton macrostachyus	0	0.24	0	0	0	0	4.25
Cynodon dactylon	0	**5.12**	0.88	0	0	0	0
Cynodon nlemfuensis	0	2.24	1.75	0	0.89	0	0
Cyperus erectus	0	0	0	0	0.89	0	0
Cyperus laevigatus	**2.78**	0.88	0	0	0	0	0
Dalbergia bracteolate	0	0	0	0	0	0	0.13
Digitaria velutina	0	0	**4.25**	0	0.78	0.5	0.13
Drypetes natalensis	0	0	0	0	0	0	0.25
Ehretia amoena	0	0.18	0	0.25	0	0	0.25
Eragrostis patens	0	0	0	0.25	0.56	0	0

...Table 1 continue

Euclea schimperi	0	0	0	0	0	1.25	0
Ficus thonningii	0	0	0	0	0	0	0.63
Flacourtia indica	0	0	0	0	0	0.63	0.63
Gardenia jovis-tonantis	0	0	0	0	0.67	0.75	0
Harrisonia abyssinica	0	0	0	0.25	0	0	0
Heliotropium longiflorum	0	0	0	1.25	0.11	0	0
Hibscus micranthus	0	0	0	0	0.44	2.60	0.88
Hyphaene petersiana	0	0	**6.25**	0	0	0	0
Hypoetes forsskalei	0	0.35	0	0	1.44	**3.13**	0
Ipomea hildebrandtii	0	0	0	0	0	0.5	0
Kigelia africana	0	0	0	1.25	0	1.38	0
Lippia javanica	0	0.71	0	0	0	0	0
Lindackeria bukobensis	0	0	0	0	0.56	0	0
Maerua angolensis	0	0.24	0	0	0	1.88	0
Maerua triphylla	0	0	0	0	1.22	1	0
Mascarenhasia arborescens	0	0	0	0	0	0	0.13
Melochia corchorifolia.	0	0.41	0	0	0	0	0.13
Ocimum gratissimum	0	0.18	0	0	2	0	0
Opilia amentacea	0	0	0	0	0	0.13	0
Oncinotis tenuiloba	0	0	0	0	0	0	0.5
Panicum infestum	0	0	0	0	0	0	0.5
Pluchea dioscoridis	0	0.24	0	1.6	0.67	*0*	0.5
Portulaca quadrifida	0	0	0.01	0	0.01	0.01	1.75
Rauvolfia caffra	0	0.71	0	0	0	0	0.01
Rhus longipes	0	0	0	0	0	0.25	1.75
Scutia myrtina	0	0	0	0	0	0	1.38
Sida acuta	0	0	0	0.25	0	0	1.38
Solanum incanum	0	0	0	0	1.89	0	0
Sphaeranthus bullatus	0	0.24	0.63	0	0	1.13	1.25
Sporobolus consimilis	0	0.29	1.88	7	0.78	0	1.25
Sporobolus spicatus	**6.22**	**2.59**	0	1.5	0	0	0
Strychnos mitis	0	0	0	1.5	0	2.38	0
Tabernaemontana pachysiphon	0	0	0	0	0	0	**4.75**
Tabernaemontana usambarensis	0	0.53	0	0	0	1.13	1.25
Tephrosia villosa	0	0	0	0	0.22	0	1.25
Terminalia brownii	0	0	0	1.5	0	0	0
Trema orientalis	0	0	0	0	0	0	0.38
Trichilia emetica	0	0.12	0	0	0	2.1	**8.75**
Trichodesma zeylanicum	0	0	0	0.25	0	0	0
Triumfetta rhomboidea	0	0	0	1.5	0	0	0
Vangueria madagascariensis	0	0	0	0	0	0.63	0.25

...Table 1 continue

Vernonia myriantha	1.22	0.35	2.13	0	0	0.63	0.25
Whitfieldia elongata	0	0	0	0	0	0	0.63
Xylopia parviflora	0	0	0	0	0	1.25	0.63
Ziziphus mucronata	0	0	0	0	0	1.38	0

4.3 Relationship between environmental variables

Changes among environmental variables differ from one place to another. The correlation coefficients between environmental variables (Table 2) show a significant strong negative correlation between altitude, soil pH, and trampling effects ($p < 0.01$). The reason for negative correlation between altitude and trampling can be related to the reason that animal movements are higher in areas close to the lake as it was compared to areas away from the lake, that is as distance from the lake increases the trampling effect decrease.

There is a strong positive correlation between soil pH and cation exchange capacity, clay, electrical conductivity, potassium, magnesium, sodium and total nitrogen, while organic matter was negatively correlated. Soil organic matter is a very important soil fraction as it supplies many nutrients especially nitrogen and phosphorus. More over it imparts a favourable structure to the soil's microbial activities (Russell, 1973). When the soil pH becomes high as a result of accumulation of soluble salts (such as sodium carbonate) the microbial activities slow down and hence low soil fertility (Russell, 1973).

Cation exchange capacity and electrical conductivity show a strong positive correlation with potassium, magnesium, and sodium. High sodium content has been found in those areas close to lake where electrical conductivity and cation exchange capacity is high. During the prolonged drought accumulations of salt remain on the surface soils. Therefore it can be revised that high amount of soluble salts within the soil increases the electrical conductivity of the soil (Russell, 1973; Hucle *et al.* 2000). Clay content revealed a strong positive correlation with pH while it revealed a strong negative correlation with silt content, organic matter and sand content. Sodium and Clay show negative correlation with most of the environmental variables but the two are correlated. Organic matter is strongly positively correlated with total nitrogen and available phosphorus but negatively correlated with soil pH. It have been pointed out that nitrogen contents and phosphorus tend to bind themselves in high quantities in high organic matter contents, however there is low organic matter content in soils with high pH values (Russell, 1973).

Table 2. Pearson's product moment correlation coefficients for correlation between environmental factors. CEC = Cation Exchange Capacity, EC = soil Electron Conductivity. ** = P< 0.01; * = P< 0.05; ns= =not significant.

Altitude	-														
Ca	-0.29 *	-													
CEC	-0.26 *	0.38 **	-												
EC	-0.14 ns	0.12 ns	0.5 **	-											
Potassium	-0.22 ns	0.14 ns	0.58 **	0.71 **	-										
Magnesium	-0.24 ns	0.17 ns	0.42 *	0.74 **	0.6 **	-									
Sodium	-0.31 *	0.01 ns	0.59 **	0.57 **	0.73 **	0.47 **	-								
Organic matter	0.24 ns	0.51 **	-0.09 ns	-0.14 ns	-0.13 ns	0.02 ns	-0.27 *	-							
Phosphorus	0.06 ns	-0.21 ns	-0.15 ns	-0.13 ns	-0.26 *	-0.15 ns	-0.15 ns	0.48 **	-						
pH	-0.36 **	-0.05 ns	0.36 **	0.36 **	0.51 **	0.46 **	0.7 **	-0.35 **	-0.01 ns	-					
Clay	-0.01 ns	-0.12 ns	-0.01 ns	0.01 ns	0.01 ns	-0.04 ns	0.21 ns	-0.36 **	0.34 **	0.34 **	-				
Sand	0.19 ns	0.08 ns	-0.25 *	-0.05 **	-0.17 ns	0.02 ns	-0.31 *	0.31 *	-0.16 ns	-0.21 ns	-0.45 **	-			
Silt	-0.22 ns	0.27 *	0.21 ns	0.12 ns	0.19 ns	0.11 ns	0.16 ns	0.19 ns	-0.37 **	-0.02 ns	-0.39 **	-0.31 ns	-		
Total Nitrogen	0.01 ns	0.16 ns	-0.12 ns	-0.26 ns	-0.46 **	-0.17 ns	-0.52 **	0.56 **	-0.1 ns	-0.49 **	-0.31 *	0.32 *	-0.01 ns	-	
Trampling	-0.57 **	0.28 *	0.37 **	0.24 ns	0.36 **	0.29 *	0.43 **	0.45 **	-0.46 **	0.18 ns	-0.43 **	0.01 ns	0.44 **	0.05 ns	-
	Altitude	Ca	CEC	EC	K	Mg	Sodium	OM	P	pH	clay	Sand	Silt	TN	Tramp

4.4 Relationship between plant community types and environmental variables

In order to obtain the relation between the community types and environmental variables, Tukey's family error rate test (Anon. 1990) was performed. The results are presented in Table 3. Community types showed significant variations in almost all environmental variables except for potassium and calcium.

Table 3. Tukey's family error rate test between environmental variables and plant community types. Different letters notations in each row indicates significance differences at p> 0.05.

Communities	I	II	III	IV	V	VI	VII
Trampling	2.8	2.6	3.0	2.5	1.7	1.2	1.1.
	a	a	a	a	b	b	b
Altitude	977	986	987	991	1034	1062	997
	b	b	b	b	a	a	a
sand	7.3	19.9	22.6	50.0	37.3	34.6	4.4
	b	ab	ab	a	ab	ab	c
Silt	57.1	59.5	70.1	48.5	47.4	43.0	38.0
	ab	ab	a	.abc	abc	b	b
Clay	36.1	29.1	3.3	31.5	23.6	25.8	59.9
	b	ab	c	ab	d	d	a
pH	8.5	9.0	6.8	7.3	7.2	7.1	7.7
	a	a	b	b	b	b	b
Organic matter	1.7	1.7	2.2	1.8	2.5	1.3	2.6
	ab	ab	ab	abc	a	c	a
Total Nitrogen	0.2	0.1	0.6	0.4	0.4	0.1	0.2
	c	abc	a	ab	ab	abc	c
Phosphorus	21.7	21.0	21.0	17.3	18.0	21.5	37.3
	b	b	b	b	b	b	a
Cation exchange capacity	63.7	64.9	49.6	45.9	37.0	39.6	39.1
	a	a	ab	ab	c	c	c
Electrical conductivity	2.7	4.9	0.2	0.7	0.3	0.5	0.6
	b	a	c	abc	c	abc	abc
Sodium	59.6	43.7	2.40	0.8	2.8	4.9	1.3
	a	ab	abc	c	abc	abc	abc
Potassium	4.8	6.3	1.3	2.5	1.6	1.9	1.9
	ns	ns	ns	ns	ns	ns	ns
Calcium	19.4	21.9	16.3	26.7	16.6	13.4	19
	ns	ns	ns	ns	ns	ns	ns
Magnesium	17.5	26.6	17.3	16.9	16.4	14.4	15.5
	b	a	b	b	b	b	b

Two plant groups have been obtained based on the effect of trampling; plant community types I, II, III and IV (*Sporobolus spicatus-Cyperus laevigatus*, *Cynodon dactylon-Sporobolus spicatus* and *Hyphaene petersiana-Digitaria velutina*, *Sporobolus consimilis* respectively) are found in those areas which have been highly affected by trampling, while community types V, VI and VII (*Acacia tortilis*, *Hypoestes forsskalei-Clausena anisata and Trichilia emetica-Tabernaemontana pachysiphon* respectively) form the second group, which are found in the less affected areas. Generally the group represents plant community types that have been found away from the lake in the National park (i.e. Western part of the lake).

Based on the altitudinal range, two community categories have been observed from the result: community type I to IV, distributed below 995ma.s.l. (i.e. *Sporobolus spicatus-Cyperus laevigatus*, *Cynodon dactylon- Sporobolus spicatus*, *Hyphaene petersiana-Digitaria velutina* and *Sporobolus consimilis* community types). The second group is plant community types V to VII (*Acacia tortilis*, *Hypoestes forsskalei- Clausena anisata* and *Trichilia emetica-Tabernaemontana pachysiphon* community types) that are distributed above 995 ma.s.l.

With respect to soil pH two community categories have been detected. Those that are found within mean pH values greater than 8.0; it includes; *Sporobolus spicatus-Cyperus laevigatus* community type and *Cynodon dactylon-Sporobolus spicatus* community type. The second category is those community types that are present at mean pH values less than 8.0 (Table 3). This group includes *Hyphaene petersiana-Digitaria velutina*, *Sporobolus consimilis*, *Acacia tortilis*, *Hypoestes forsskalei-Clausena anisata* and *Trichilia emetica-*

Hyphaene petersiana –Digitaria velutina and *Sporobolus consimilis*) occupy areas with moderate organic matter content.

4.5 Ordination

Canonical correspondence analysis has been used aiming at identifying the relationship of community distributions along the environmental gradient. Initial results indicated high constraints in the CCA output as, a result of insignificance of some environmental variables in explaining their influence on community distribution. Thus calcium, sodium, magnesium and potassium were omitted due to their less effectiveness in describing the plant communities in relation to environmental gradient. The four variables were omitted during the ordination analysis because environmental variables with less effectiveness in explaining the distribution of species usually show very short arrows in the CCA output (ter Braak, 1987; Kent and Coker, 1992), and thus they usually cause constraints in the CCA out.

Environmental variables with long arrows are more strongly correlated with the ordination axes than those with short arrows and have much more influence on community distribution. It has been pointed out that for the CCA out put to be clear, insignificant variables should be omitted (ter Braak, 1987; Økland, 1990; Kent and Coker 1992). As a result only eleven environmental variables have been used in ordination (altitude, organic matter, total nitrogen, sand percent, trampling effect, silt percent, cation exchange capacity, electrical conductivity, soil pH, phosphorus and clay).

The results of the ordination with canonical correspondence analysis shown in Figure 5 Trampling effect, clay percent, silt percent, cation exchange capacity (CEC) and available phosphorus, are the most important variables that determine variations along axis 1. To a lesser extent sand percent and total Nitrogen contributes to this variation. Organic matter, soil pH and altitude, are the most significant variables along the axis 2. More over the electrical conductivity of the soil to a lesser extent also contribute to this variation.

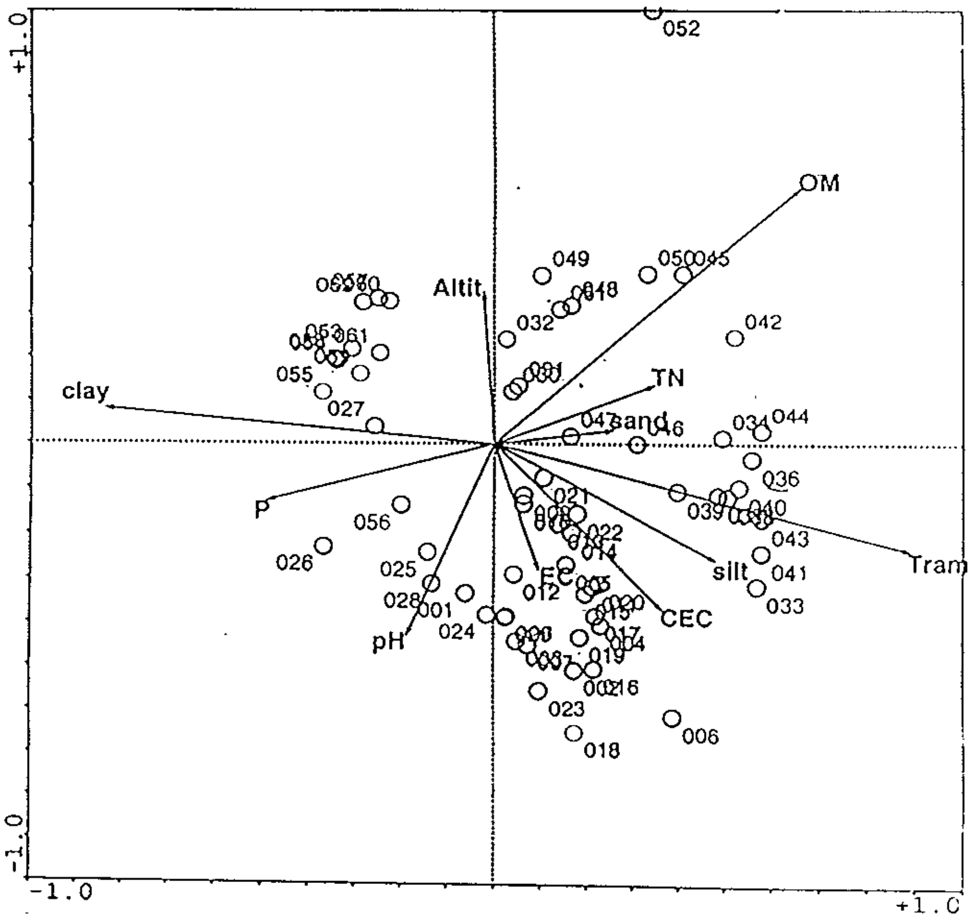

Figure 5. Ordination diagram of a canonical correspondence analysis of all sample plots and environmental variables of the Lake Manyara area. Alt = Altitude; OM = Organic matter; Tram = Trampling; CEC = cation exchange capacity; EC = electrical conductivity; TN = total nitrogen; P = available phosphorus. Arrows represent environmental variables, numbers represents sample plots.

Sample plots taken in the alkaline grasslands are observed to be much more influenced by high soil pH, high cation exchange capacity, high silt content and high electrical conductivity. These sample plots represents plant community type I and II (*Sporobolus spicatus-Cyperus laevigatus* and *Cynodon dactylon– Sporobolus spicatus* community types).

Sample plots taken from outside the park are highly influenced by trampling effect. They represent plant community type III *(Hyphaene petersiana-Digitaria velutina)*. This is probably due to the reason that the area covered with this community is found within the eastern corridor of Lake Manyara National Park where animals do migrate to Tarangire National Park and back to Manyara National Park. More over the area is used for livestock grazing since it is situated outside the National park.

Sample plots which are seen to be highly influenced by organic matter and altitudinal gradient represents plant community type V (*Acacia tortilis)* while plant community type VII (*Trichilia emetica-Tabernaemontana pachysiphon)* is represented by sample plots which are seen to be influenced with altitudinal gradient and clay percentage. Sand content is seen to be of lesser significance in explaining variation in species composition.

Sample plot number 52 is seen to be an outlier since it is isolated from all other sample plots resulting in the overlapping of the information in the CCA out put. In order to get a clear CCA output sample 52 was omitted. Omission of outliers is said to be much related to the elimination of the background noise, which is normally said to be caused by species with rare occurrences (Tamrat, 1994). Sample plot 52 constitutes most of species that were not found in other sample plots. Thus it has been argued that rare species contribute little information to the overall variations in the ordination system (Zerihun and Backeus, 1991). After removing sample plot number 52 a clear separation of type VII is observed. It is thus become clear for the that it is influenced by phosphorus and to the lesser extent by altitude (Fig. 6). Clay content and trampling effect still show a strong correlation with axis 1 of the CCA, while pH, organic matter, total nitrogen, electrical conductivity and sand percentage revealed the strong correlation with second axis

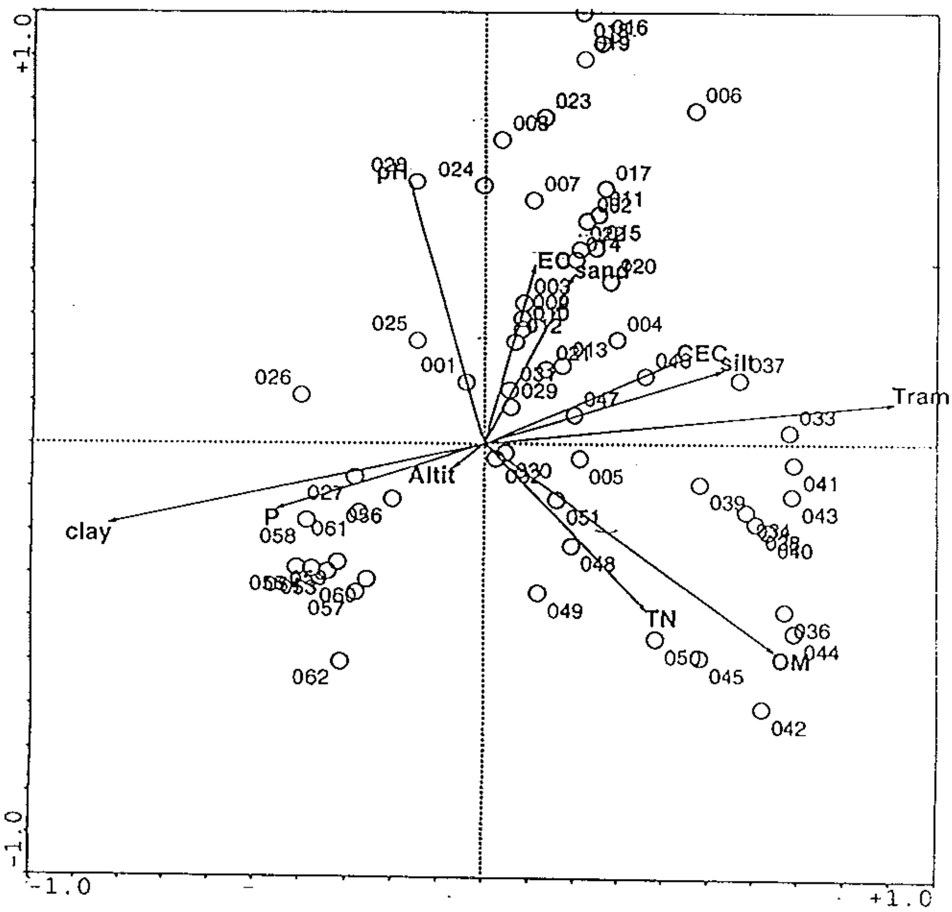

Figure 6. Ordination diagram of a Canonical Correspondence Analysis of sample plots (except sample plot 52) and environmental variables, for environmental variable abbreviations, see Fig.5. Arrows represent environmental variable and numbers represent sample plot.

4.6 Plant species diversity

Results of the analysis of species diversity and evenness for plant community types are given in Table 4. Plant community type I (*Sporobolus spicatus-Cyperus laevigatus* community type) show the lowest species diversity and the lowest species richness however the evenness is high indicating that species are evenly distributed. Low species diversity and low species richness can be probably due to the fact that the community is found within an area of very high soil pH which hinders most of the microbial activities which in turn affects the growth of most plants. It has been observed that few species tend to tolerate the unfavorable condition of the areas close to lakeshore (Walter, 1971). The results agree with Cole (1973) that, in those areas where plant species tend to dominate due to wide range of environmental tolerance always have less species diversity and less species richness. More over plat community type III (*Hyphaene petersiana-Digitaria velutina*) forms the second community with the lowest species diversity and species richness. On the other hand although plant community type II (*Cynodon dactylon-Sporobolus spicatus*) have high species diversity compared to plant community type I, III and IV (*Sporobolus spicatus-Cyperus laevigatus, Hyphaene petersiana-Digitaria velutina* and *Hypoestes forsskalei-Clausena anisata* respectively) but it show the lowest species richness compared to all other plant community types.

On the other hand the highest diversity index (H') and evenness are high in plant community type V (*Acacia tortilis* community type). This can be related to the reason that this type is occurring in areas of well-drained soils. Young (1976) suggest that well drained soils permit most of microbial activities that adds fertility in the soil creating fovourable growth conditions for most plants. Muchena (1986) argue that high species diversity is found in those areas with slightly acidic to slightly alkaline soils (6.5 to 7.8). Most associated plant species found in *Acacia tortilis* community type have been recorded in those areas with slightly alkaline soils of pH value between 6.1-7.7.

Table 4. Species diversity indices between communities. S = species richness (number of species), H' Shannon's diversity index, E = Evenness, I – VII = plant community type one to Seven.

Community types	Shannon's diversity index (H')	Evenness (E)	Species richness (S)
I	1.17	0.84	4
II	2.58	0.79	26
III	2.03	0.82	12
IV	2.49	0.86	18
V	3.17	0.93	30
VI	3.15	0.94	29
VII	2.83	0.83	30

In comparing species diversity and evenness in the different communities analysed, results show that community type V (*Acacia tortilis*) and community type VI (*Hypoestes forsskalei-Clausena anisata*) have both high species diversity and high evenness (Fig. 7). Thus plant community type VI (*Hypoestes forsskalei-Clausena anisata*) is highly evenly distributed than other plant community types. However plant community type 1 (*Sporobolus spicatus – Cyperus laevigatus*) shows less diversity but it is evenly distributed compared to plant community type II, III and VII (*Cynodon dactylon- Sporobolus spicatus, Hyphaene petersiana-Digitaria velutina* and *Trichilia emetica-Tabernaemontana pachysiphon* community types respectively). In terms of species richness plant community V (*Acacia tortilis* community type) and plant community type VII (*Trichilia emetica-Tabernaemontana pachysiphon* community type), show high number of species.

Based on species diversity, results show that there is an increase of species cover and abundance as you move away from the lakeshore. This is because close to the lake most of the environmental conditions are unfavourable to the growth of most plants (Hucle *et al.* 2000).

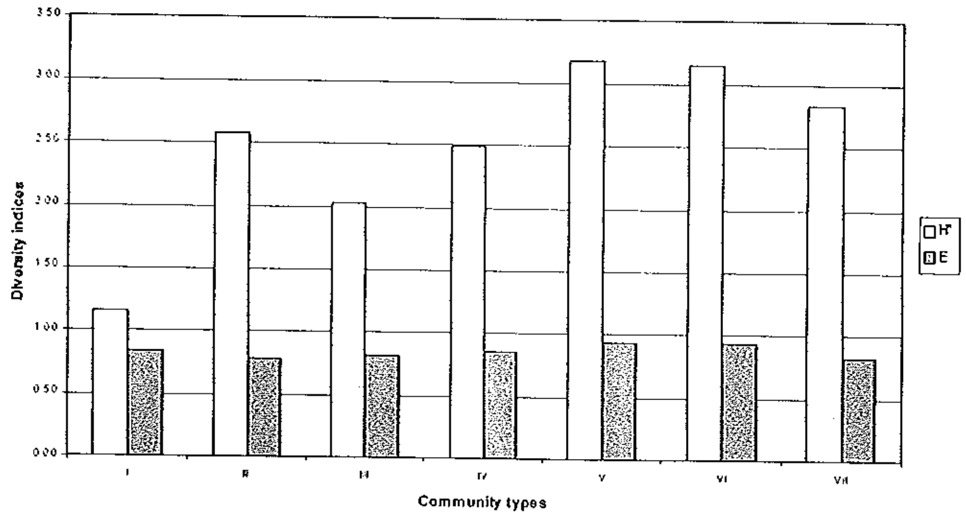

Figure 7. Relationship between Shannon's diversity index and Shannon's evenness index for the plant communities.

5.0 DISCUSSION

5.1 Distribution of plant community types

In the present study vegetation composition and vegetation cover are observed to change gradually with a gradual change in edaphic and other environmental gradients such as trampling effects.

A clear pattern of species distribution has been detected around the lake. The lakeshore is primarily covered with grasslands of which the *Sporobolus spicatus* –*Cyperus laevigatus* community type 1 and *Cynodon dactylon* – *Sporobolus spicatus* community type II are predominant. The two community types forms good pasture land for grazing animals. As a result the trampling effect has been acceraleted within these areas. These communities with their related species are seen to be dominating areas with high soil pH (i.e. > 7.5). The mean pH values under which the communities are dominant are 8.5 and 10.0 respectively (Table 3). Their pattern is also much more influenced by the presence of high salt concentration, which can be observed as white crystals on the surface soils. According to Russell (1973) soluble salts such as sodium carbonate, sodium chloride and sodium sulphate usually accumulates on the surface soils where water table is high. This usually occurs in natural conditions such as flood plains of rivers, low laying of lakeshores and in depressions. Generally the areas are covered with salt crusts during the dry periods, salts then dissolves in the soil water each time when the soil becomes wet, this in turn has an effect on the electrical conductivity of the soil (Muchena, 1986). The pattern on the distribution of *sporobolus spicatus, Cyperus laevigatus,* and *Cynodon dactylon* then depends much on soil texture and its ability to tolerate high pH.

The previous study by Vesey-FitzGerald, (1970) indicates that within the alkaline grasslands the distribution of grass species depends much on soil texture and on the way species recolonize the lake bed after recession of lake water recede following flooding by lake.

Hyphaene petersiana-Digitaria velutina community is dominant in the Southeast of the Lake outside the National Park. Generally the community is prevalent in areas of slightly alkaline to neutral soils, with pH values ranging from 6.1-7.2. The community is found to be much affected by tramping effect. Thus the community forms the second group with low species diversity (H'= 2.03) next to type I (*Sporobolus spicatus - Cyperus laevigatus* community type).

The high trampling effect is associated with high number of animals that migrate through the Eastern corridor from lake Manyara National Park to Tarangire National Park, especially during the dry periods. Not only that, but also high grazing intensity by livestock around this area contributes to this high trampling effect. The previous work by Mugasha *et al.* (1993) pointed out that areas outside the park are susceptible to many changes especially those, which are caused by human activities. Areas outside the park are highly overgrazed by cattle as a result most areas are left bare with very open grasslands. Species diversity in these areas hence becomes low as compared to protected areas. It has been pointed out that, the vegetation of the dry area could take as long as 150 yeas to regenerate when disturbed (Lyaruu *et al.* 2000), hence they need more attention in all conservation practices.

Acacia tortilis community type (Community type V) is seen to be among the most predominant tree species along the western fringes of the lake. This community represented more than 50% of the forest in the study area. The soils under which the community grows well are slightly alkaline with mean pH value of 7.2 (Table3). This community is dominant in well-drained soils. However most *Acacia tortilis* and *Acacia xanthophloea* have been observed dead especially those, which were affected by the 1998 floods (Fig. 8).

Figure 8. A group of dead *Acacia tortilis* and *Acacia xanthophloea* in lake Manyara

The *Trichilia emetica-Tabernaemontana pachysiphon* community type (community type VII) is predominant along the Northeastern part of the lake. The community shows a continuous canopy cover made possible by trees of *Trichilia emetica* and *Croton macrostachyus* and it shows a clear zone from other groups due to its evergreen nature through out the year (Fig. 9). This is due to the fact that there are perennial springs of fresh water that flows from the foot of the escarpment. The springs are the results of volcanic activities (Loth, 1999). There is high content of organic matter and high phosphorus in the area, which can be associated with the decay of leaf litter and roots within the area under canopy cover (Moughalu and Awakunle, 1994).

Figure 9. Evergreen ground water forest in the northeast part of Lake Manyara.

Other community types (type IV and VI) dominated most of the western part of lake Manyara. They were observed along the slightly alkaline soils with a mean pH value of about 7.3 and 7.2 respectively (Table3).

This result is in agreement with the results obtained by Loth (1999) that in Lake Manyara National park the Vegetation between the lake and the escarpment is unmistakably defined by a gradient from very alkaline and saline, poorly to imperfectly drained soils close to the lake, to neutral and salt free, well drained soils higher up the shore.

Cole (1973) argues that generally swamps, and lakes show zonation of the vegetation along micro topographical gradient. He concluded that within savannah regions, the lowest zone of lakes and swamps are occupied by carpet grass, these merges into taller savannah grasses, later on they merge to shrub zone, which finally merges to tree layer.

5.2 Plant communities in relation to environmental variables

The environmental variables such as organic matter, clay content, Silt content cation exchange capacity, electrical conductivity, available phosphorus, soil pH, and trampling effect have been identified to be the most important factors controlling the pattern of plant species distributions in lake Manyara area. Plant community type I, II (*Sporobolus spicatus-Cyperus laevigatus* and *Cynodon dactylon Sporobolus spicatus* community types) are much more influenced by soil pH, cation exchange capacity, silt content, electrical conductivity and trampling effect. High electrical conductivity, cation exchange capacity, soil pH and silt contents have been denoted in areas close to the lake where the community types are predominant. This can be related to the poor drained soils close to the lake which normally have identified constituting high amount of soluble salts which increases the pH of the soil and hence high conductivity of the soils (Muchena, 1986).

There is variation among the community types with respect to environmental variables. As it has been pointed out that the presence of species usually indicate a satisfactory relationship between existing environmental conditions and ecological tolerance of that species (Hucle *et al.* 2000). Only species with wide range of tolerance to disturbance exist under unfavorable conditions (Hucle *et al.* 2000).

Results obtained suggest that soils of lake Manyara close to the lakeshore are probably salt affected soils that have high amount of sodium content and are said to be among the saline soils in Tanzania (Mugasha *et al.*1993). Generally high amount of sodium in the soils is toxic to most plant growth (Muchena, 1986). It has been documented that saline soils are characterized by high amount of soluble salts (Brady, 1984; Edward and Grubb, 1982; Muchena, 1986) sodium being the dominant cation. Some of these soils have high salt content near the surface which becomes toxic to most of plants (Muchena, 1986). Both saline and sodic soils have pH of more than 7.5 (Brady, 1984). Soils of Lake Manyara especially those close to the lake have pH values between 7.8-10.2, and white crystals usually are observed on the surface soils. Excess exchangeable sodium and high pH values have strong influence on the availability and transformation of the essential plant nutrients (Hamilton, 1989; Doubenmire, 1959).

The amount of potassium in the plots close to the lake was low compared to sodium, calcium and magnesium. This indicates that there is likelihood of interference in nutrient uptake and plant metabolism in areas close to the lakeshore(Hamilton, 1989). Any process that encourage the maintenance or build up of exchangeable bases such as Ca, Mg and Na always contributes in the overall reduction of acidity and causes an increase in alkalinity (Young, 1976). Not only that but also any condition that will permit the exchangeable bases to remain in the soil contributes to high pH values and consequently high electrical conductivity (Buckman and Brady, 1969).

Plant community type VII (*Trichilia emetica-Tabernaemontana pachysiphon* community type) is quite different from all other communities with respect to available Phosphorus. This is probably due to the reason that the community is a typical ground water forest with closed canopy with high organic matter content, thus it has been indicated that in high organic matter content, phosphorus is available in high content also (Moughalu and Awakunle, 1994).

In any plant growth mechanisms soil texture is of paramount significance. Soil texture by influencing soil water content is an important environmental factor that determines the concentration of soil mineral nutrients. The results obtained from the textural analysis of soil samples show that clay and silt percentage are high along the lakeshores and nearby places. The dominance of clay particles and silt particles along the lakeshore reflects the effects of weathering and erosion in the upper parts of the Mbulu plateau (Mwalyosi, 1990) where the materials transported becomes deposited in lower parts. Moreover the lake level fluctuation has played an important role on the modification of the soil materials within the area.

It is difficult to make the conclusive deductions about altitudinal effects on the species distributions in the present study. The reason for this is that the area has been affected by various disturbances which includes flooding by the saline lake, drought, and animal distabunces. Moreover the altitudinal range in the present study area is not high enough to enable a great variation. It has been argued that areas with moderate altitudinal ranges (valleys and plain area) does not have an influence on the community distributions (Loth, 1999; Hucle *et al.* 2000) rather community distribution might have been contributed by other environmental gradients.

5.3 Patterns of species diversity.

It has been argued that species diversity varies from one place to another due to spatial and temporal heterogeneity of environmental parameters (Whittaker, 1975; Keddy, 1984). The patterns of species diversity in the present study show that plant community types away from the lake (*Acacia tortilis, Hypoestes forsskalei-Clausena anisata* and *Trichilia emetica-Tabernaemontana pachysiphon*) are more diverse than those community types close to the lake (*Sporobolus spicatus-Cyperus laevigatus* and *Cynodon dactylon –Sporobolus spicatus*). Vegetation composition and species richness increases with distance away from the lake. This can be associated with reason that most favourable growth conditions for plants have been observed in the areas away from the lake (Walter,1971).

It has been observed that areas close to the lake are dominated by *Sporobolus spicatus, Cynodon dactylon*, and *Cyperus laevigatus* which forms parts of the alkaline grassland communities. Under these areas species richness is very low, only four species have been recorded in plant community I (*Sporobolus spicatus-Cyperus laevigatus* commuunty type). Areas with very high levels of species richness normally are those areas with many species per quadrat, however no two quadrates on a transect are alike in their species composition (Magurran, 1988; Huston, 1994). Therefore species diversity varies from one place to another due to spatial and temporal heterogeneity of environmental parameters (Magurran, 1988; Hamilton, 1989; Crawley, 1997). The results obtained agree with observations done by Keddy (1984) on the study of plant zonation on lakeshores in NOVA SCOTIA where he found out that high species diversity was related to the suitable and fovourable edaphic factors in those areas away from the lakeshore while the lakeshore was generally dominated by few species and hence low diversity.

More over the high trampling effect close to the lake contribute to this low diversity and low species richness. This is probably due to high number of grazers that tends to graze in the alkaline grasslands. Not only that but also due to the fact that most animals do drink water from the lake, hence more trampling disturbances have been observed in these areas. At high rates of disturbance, the pool of adapted species is small thus the species richness will be low (Keddy, 1984; Crawley, 1997). Species richness is always greater at moderate levels of disturbance because dominance of one or two species will be prevented. Thus the pool of potential colonists will be relatively large (Crawley, 1997).

6.0 CONCLUSION AND RECOMMENDATIONS

Major community types of the lake Manyara area have been described. Seven plant communities have been distinguished and have been related to the environmental variables analysed. The patterns of species diversity around lake Manyara area is much more reflected to the availability and distribution of the physical and chemical properties of the soils.

The major environmental factors that are seen to affect the patterns of species diversity in the lake Manyara area are organic matter, clay content, available phosphorus, trampling, cation exchange capacity, electrical conductivity of the soil, silt content, soil pH, and to the lesser extent total nitrogen. Trampling effect on the other hand can damage and eliminate the more sensitive species from patches. The changes on the physical and chemical properties of soils are much more influenced by distance from the lake. As distance from the lake increases some of the environmental variables (such as soil pH, cation exchange capacity, electrical conductivity and sodium) decrease and become less harmful to the plant growth.

Therefore general pattern of the species distribution around Lake Manyara is mostly associated with edaphic factors, thus the high saline soils are dominated by grasslands of which *Sporobolus spicatus* and *Cyperus laevigatus* are dominant species. On the other hand well-drained soils have been identified to be occupied by trees and shrubs of which *Acacia tortilis* dominates the area. The distribution of *Acacia* species is related to soil texture and alkalinity of the soils. They are seen to grow well under slightly saline and well-drained soils.

In the North east of the lake the where *Trichilia emetica-Tabernaemontana pachysiphon* community shows a clear pattern is much more influenced by the ground water springs, which emerge from the foot of the escarpment through out the year, and which are free from high concentrations of salts from the alkaline lake.

Lake Manyara area is rich in biological resources. It plays an ecological, economical and socio-cultural role in Tanzania. Thus in order to insure its sustainability, community based conservation strategy is recommended. This comes out in the real sense that community based conservation strategy and the sustainable utilization of the resources around lake Manyara are inseparable. The population around the area is increasing rapidly their needs on plants are also increasing, thus overexploitation of the resources has been observed in the area.

Since the current pattern of resource use in the area is unsustainable, and in order to address the problem of the conservation and resource use, an integrated regional conservation and development program must be developed and implemented. This will enable even the already destructed vegetation to regenerate. The approach will only be successful if the local resource users will be involved at every stage. All conservation strategies should be economically viable, ecologically sustainable, and socially and culturally acceptable.

There is a need for more scientific researches to be conducted not only within the national park as it has been done before but also outside the park. The vegetation around the lake is more in a danger of disappearing, especially those found outside the park where human interference is high. The whole lake Manyara and its immediate surroundings therefore should be included within the national park.

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8.0 APPENDICES

Appendix 1. Species list of Lake Manyara

Species name	Family
Abutilon bidentatum (Hochst.) A. Rich.	Malvaceae
Acacia brevispica Harms	Fabaceae
Acacia mellifera(Vahl) Benth.	Fabaceae
Acacia tortilis (Forssk.) Hayne	Fabaceae
Acacia xanthophloea Benth.	Fabaceae
Acacia zanzibarica (S.Moore) Taub.	Fabaceae
Acalypha fruticosa Forssk.	Euphorbiaceae
Achyranthes aspera L.	Amaranthaceae
Allophylus africanus P. Beauv.	Sapindaceae
Antiaris toxicaria Lesch.	Moraceae
Asparagus falcatus L.	Asparagaceae
Balanites aegyptiaca (L.) Del.	Balanitaceae
Boerhavia diffusa L.	Nyctaginaceae
Blepharis maderaspatensis (L.) Roth	Acanthaceae
Bridelia micrantha (Hochst.) Baill.	Euphorbiaceae
Blighia unijugata Bak.	Sapindaceae
Capparis fascicularis DC.	Capparidaceae
Cassia mimosoides L.	Fabaceae
Chloris gayana Kunth	Poaceae

...Appendix 1 continued

Celtis africana Burm. f.	Ulmaceae
Chassalia parvifolia. K. Schum.	Rubiaceae
Clausena anisata (Willd.) Benth.	Rutaceae
Commelina africana L.	Commelinaceae
Commiphora africana (A.Rich.) Engl.	Burseraceae
Conyza pyrrhopappus Sch. Bip. Ex A.Rich.F.	Asteraceae
Cordia africana Lam.	Boraginaceae
Cordia goetzei Gürke	Boraginaceae
Cordia ovalis R.B.	Boraginaceae
Cordia sinensis Lam.	Boraginaceae
Croton macrostachyus Del.	Euphorbiaceae
Cynodon dactylon (L.) Pers.	Poaceae
Cynodon nlemfuensis Vanderyst	Poaceae
Cyperus laevigatus L.	Cyperaceae
Dalbergia bracteolate Bak.	Fabaceae
Digitaria velutina (Forssk.) P. Beav.	Poaceae
Drypetes natelensis (Harv.) Hutch.	Euphorbiaceae
Ehretia ameona Klotzsch	Boraginaceae
Eragrostis patens Oliver	Poaceae
Euclea schimperi(A.DC.) Dandy	Ebenaceae
Ficus thonningii Blume	Moraceae

...Appendix 1 continued

Flacourtia indica (Burm.f.) Merr.	Flacourtiaceae
Gardenia jovis-tonantis (Welw.) Hiern	Rubiaceae
Harrisonia abyssinica Oliv.	Simaroubaceae
Heliotropium longiflorum (*A.* DC.) Jaub.	Boraginaceae
Hibiscus micranthus L.f.	Malvaceae
Hyphaene petersiana Mart Hist.	Arecaceae
Hypoestes forsskalei (Vahl.) Stand ex Roem & Schult	Acanthaceae
Ipomea hildebrandtii Vatke.	Convolvulaceae
Kigelia africana (Lam.) Benth.	Bignoniaceae
Cyperus erectus (Schum.) Mattf. & Kük.	Cyperaceae
Lindackeria bukobensis Gilg	Flacourtiaceae
Lippia javanica (Burm.F.) Spreng.	Verbenaceae
Maerua angolensis DC.	Capparidaceae
Maerua triphylla A.Rich.	Capparidaceae
Mascarenhasia arborescens A.DC.	Apocynaceae
Melochia corchorifolia L.	Sterculiaceae
Opilia amentacea Roxb.	Opiliaceae
Oncinotis tenuiloba Stapf.	Apocynaceae
Ocimum gratissimum Willd.	Labiatae
Panicum infestum Peters	Poaceae
Pluchea dioscoridis DC.	Asteraceae
Portulaca quadrifida L.	Portulacaceae

...Appendix 1 continued

Rauvolfia caffra Sond.	Apocynaceae
Rhus longipes Engl.	Anacardiaceae
Scutia myrtina (Burm.f.) Kurz	Rhamnaceae
Sida acuta Burm. f.	Malvaceae
Solanum incanum L.	Solanaceae
Sphaeranthus bullatus Mattf.	Asteraceae
Sporobolus spicatus (Vahl) Kunth	Poaceae
Sporobolus consimilis Fresen.	Poaceae
Strychnos mitis S. Moore	Loganiaceae
Tabernaemontana pachysiphon Stapfon.	Apocynaceae
Tabernaemontana usambarensis K.Schum	Apocynaceae
Tephrosia villosa (L.) Pers.	Fabaceae
Terminalia brownii Fresen.	Combretaceae
Trema orientalis (L.) Bl.	Ulmaceae
Trichilia emetica Vahl	Meliaceae
*Trichodesma zeylanicum (*Burm.f.) R.Br.	Boraginaceae
Triumfetta rhomboidea Jacq.	Tiliaceae
Vangueria madagascariensis Gmel.	Rubiaceae
Vernonia myriantha Hook.f.	Asteraceae
Whitfieldia elongata Beauv.	Acanthaceae
*Xylopia parviflora (*A.Rich.) Benth.	Annonaceae
Ziziphus mucronata Willd.	Rhamnaceae

Appendix 2. Number of plant species in each plot recorded from 62 plots

Plots	Number of species
1	2
2	1
3	2
4	1
5	3
6	3
7	5
8	7
9	7
10	12
11	2
12	8
13	7
14	6
15	1
16	2
17	1
18	3
19	2
20	3
21	2

...Appendix 2 continued

22	4
23	3
24	13
25	17
26	11
27	10
28	7
29	8
30	9
31	1
32	9
33	1
34	2
35	2
36	2
37	3
38	3
39	5
40	3
41	5
42	5
43	2

...Appendix 2 continued

44	6
45	3
46	2
47	1
48	5
49	9
50	3
51	7
52	18
53	6
54	9
55	11
56	6
57	9
58	11
59	9
60	9
61	7
62	7

Appendix 3. Plots and plant species present in them

Species name	Plots	Collection number
Abutilon bidentatum	8	JAN & FM 10
Acacia brevispica	24, 29, 25, 26, 27, 54	JAN & FM 38
Acacia mellifera	62	JAN & FM 84
Acacia tortilis	48, 14, 30, 31, 61, 32, 49	JAN & FM 26
Acacia xanthophloea	5, 22, 11, 10, 39, 48	JAN & FM 4
Acacia zanzibarica	57, 44, 49, 31	JAN & FM 52
Acalypha fruticosa	14, 29, 31, 28, 55	JAN & FM 25
Achyranthes aspera	10, 44, 62, 24, 25, 26, 53, 26, 59, 58, 60	JAN & FM 18
Allophylus africanus	54	JAN & FM 69
Antiaris toxicaria	55	JAN & FM 70
Asparagus falcatus	54	JAN & FM 68
Balanites aegyptiaca	52, 51	JAN & FM 64
Boerhavia diffusa	52, 30, 31	JAN & FM 49
Blepharis maderaspatensis	30, 31, 61	JAN & FM 48
Bridelia micrantha	58	JAN & FM 76
Blighia unijugata	58	JAN & FM 75
Capparis fascicularis	28	JAN & FM 41
Cassia mimosoides	60	JAN & FM 79
Chloris gayana	49	JAN & FM 58
Celtis africana	53, 54, 55, 57, 58, 59	JAN & FM 65
Chassalia parvifolia.	25, 26, 27	JAN & FM 37
Clausena anisata	24, 25, 26, 28, 27	JAN & FM 32
Commelina africana	32	JAN & FM 50
Commiphora africana	41, 32	JAN & FM 51
Conyza pyrrhopappus	32	JAN & FM 46
Cordia africana	61	JAN & FM 83
Cordia goetzei	12, 59	JAN & FM 21
Cordia ovalis	61	JAN & FM 82
Cordia sinensis	10, 61, 62	JAN & FM 17
Croton macrostachyus	53, 56, 57, 55	JAN & FM 60
Cynodon dactylon	7, 8, 9, 10, 11, 12, 15, 16, 17, 18, 19, 20, 23	JAN & FM 3
Cynodon nlemfuensis	7, 11, 12, 33, 34, 39, 40, 41, 45	JAN & FM 6
Cyperus laevigatus	1, 2, 21, 5, 3, 6, 22, 18, 20, 34, 39, 40, 41, 45, 49	JAN & FM 2

...Appendix 3 continued

Dalbergia bracteolata.	58	JAN & FM 77
Digitaria velutina	36, 43, 38, 44, 40, 41, 31, 42, 24	JAN & FM 31
Drypetes natelensis	58	JAN & FM 78
Ehretia ameona	8, 52	JAN & FM 9
Eragrostis patens	52, 42	JAN & FM 53
Euclea schimperi	24, 25, 27	JAN & FM 30
Ficus thonningii	60	JAN & FM 80
Flacourtia indica	25	JAN & FM 36
Gardenia jovis-tonantis	30, 32, 51	JAN & FM 47
Harrisonia abyssinica.	52	JAN & FM 60
Heliotropium longiflorum	32	JAN & FM 45
Hibiscus micranthus	14, 13, 62, 24, 29, 25, 26, 54, 60	JAN & FM 22
Hyphaene petersiana.	36, 37, 38, 39, 40, 41, 42, 43, 44	JAN & FM 54
Hypoestes forsskalei.	9, 10, 14, 61, 13, 62, 24, 25, 26, 27	JAN & FM 12
Ipomea hildebrandtii	24	JAN & FM 29
Kigelia africana	24, 29, 52	JAN & FM 28
Cyperus erectus	32	JAN & FM 44
Lindackeria bukobensis	32	JAN & FM 43
Lippia javanica	12	JAN & FM 20
Maerua angolensis	12, 13, 62, 25, 28	JAN & FM 19
Maerua triphylla	49, 51, 52	JAN & FM 57
Mascarenhasia arborescens	57	JAN & FM 74
Melochia corchorifolia	8, 9, 10	JAN & FM 11
Opilia amentacea	28	JAN & FM 40
Oncinotis tenuiloba	55	JAN & FM 72
Ocimum gratissimum	9, 30, 31, 49, 51	JAN & FM 13
Panicum infestum	55	JAN & FM 71
Pluchia dioscoridis	48, 49	JAN & FM 56
Portulaca quadrifida	7	JAN & FM 8
Rauvolfia caffra	9, 10, 12, 55, 59, 60	JAN & FM 14
Rhus longipes	24	JAN & FM 27
Scutia myrtina	54, 59	JAN & FM 67
Sida acuta	52	JAN & FM 62
Solanum incanum	14, 42, 50, 49, 51	JAN & FM 24

...Appendix 3 continued

Sphaeranthus bullatus	13, 60	JAN & FM 23
Sporobolus spicatus	1, 2, 3, 4, 5, 6, 7, 8, 16, 18, 19, 20, 21, 22, 23, 34, 35, 45, 46	JAN & FM 1
Sporobolus consimilis	37, 38, 39, 44, 45, 46, 47, 48, 51, 52	JAN & FM 55
Strychnos mitis	29, 25, 26, 27	JAN & FM 35
Tabernaemontana pachysiphon	53, 56, 57, 55, 54, 59, 58	JAN & FM 66
Tabernaemontana usambarensis	10, 12, 25, 56, 57	JAN & FM 16
Tephrosia villosa	30, 32	JAN & FM 42
Terminaria brownii	52	JAN & FM 61
Trema orientalis	60	JAN & FM 81
Trichilia emetica	9, 10, 12, 13, 25, 26, 29, 53, 54, 55, 56, 58, 59,60	JAN & FM 15
Trichodesma zeylanicum	52	JAN & FM 63
Triumfetta rhomboidea	52	JAN & FM 59
Vangueria madagascariensis	25	JAN & FM 33
Vernonia myriantha	35, 22, 7, 8, 41, 37, 39	JAN & FM 5
Whitfieldia elongata	56	JAN & FM 73
Xylopia parviflora	25, 26	JAN & FM 34
Ziziphus mucronata	26	JAN & FM 39