STURE MANAGEMENT IN SELECTED ASALS
OF KENYA

By

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Declaration

This dissertation is my original work and has not been presented for a degree in any other University.

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Abstract

The objective of this study was to monitor phenological stages of grassland in selected ASALs of Kenya, so as to provide information for sustainable pasture management. NDVI data obtained by the VEGETATION instrument onboard SPOT satellite was extracted over three selected ASAL districts of Kenya namely, Kajiado, Garissa and Baringo. Extraction points were based on a land cover map that showed the location of grassland in the three districts.

Piecewise logistic functions were applied on the extracted NDVI data in order to identify phenological stages. Rainfall estimate data was then used to relate the identified phenological stages to rainfall using lagged correlation. Curves of the correlated lagged rainfall and NDVI from the determined phenological stages were plotted to compare their temporal patterns. Spatial patterns of length of the growth period were also determined.

Interannual phenological stages appeared to follow a clear growth – senescence temporal pattern. Two growth periods were identified in all the districts studied, consistent with known cycles of different grass and browse species in the districts. Peak growth was seen to occur during the short rains in Kajiado district and during the long rains in Baringo district. Growth in the two seasons was almost the same in Garissa district. Phenological stages were significantly correlated to different lags of rainfall, with response to a longer lag observed during the March to June growth period. Patterns of lagged rainfall were also found to be similar to those of NDVI at the different phenological stages. The length of both growth periods showed spatially coherent patterns that signified the distribution of different pasture species.

Given these results, logistic functions were able to model grassland phenological stages in the ASALs. However, further investigations are needed using a longer time series of NDVI data and more spatial points, as well as validation using *in situ* data. The results can give useful information for sustainable pasture management in the ASALs of Kenya.

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Abbreviations

ALRMP: Arid Lands Resource Management Project

ASAL: Arid and Semi-arid Lands

DLPO: District Livestock Production Officer

DOY: Dekad of the year

FAO: Food and Agriculture Organization

IIRR: International Institute of Rural Reconstruction

JF: January-February season

JJAS: June-July-August-September season

KARI: Kenya Agricultural Research Institute

LCCS: Land Cover Classification System

MAM: March-April-May season

NDVI: Normalized Difference Vegetation Index

NIR: Near Infrared

OND: October-November-December season

RFE: Rainfall Estimates

SDRN: Environment and Natural Resource Service

SPOT: Satellite Pour l'Observation de la Terre

VIS: Visible

CHAPTER ONE

INTRODUCTION

1.0 Background

Arid and semi-arid lands (ASALs), comprising approximately over 80% of Kenya's landmass, are fragile ecosystems. These ecosystems are characterized by low annual rainfall and high levels of evapotranspiration, which are climatic conditions that make it difficult to engage in rain-fed agriculture. Due to the inability to practice rain-fed agriculture, 90% of the inhabitant population, an estimated 7.2 million people (GoK, 2002 cited in Davies, 2007), rely on livestock as their main, and sometimes only, source of livelihood.

To feed their livestock, nomadic pastoralism is widely practised in these areas as a system of pasture management, because it is thought to make optimal use of the available pasture resources. Nomadic pastoralism is a system that relies on naturally occurring vegetation and hence it is sensitive to variations in climatic conditions. This reliance on natural vegetation makes pastoral communities vulnerable to climatic variability and extremes, and adverse climate change impacts, especially droughts that prolong for a year or more due to failure of the rainfall season.

Past recurrent droughts caused lack of forage in the ASALs, which led to diminished animal production, livestock deaths and consequently loss of income for the pastoralists. These adverse effects call for close monitoring of natural vegetation cycles. Further, understanding how these cycles are related to climate (specifically, changes in rainfall) would provide vital information for early warning systems in the face of climatic shocks.

Vegetation phenology is the study of seasonal plant cycles and how these cycles are related to climate (White *et al.*, 1997). These seasonal cycles are closely associated with rainfall and temperature conditions in the lower atmosphere (Reed *et al.*, 1994), and have been known to be affected by short-term and long-term climate variability (Badeck *et al.*, 2004). With climate change there is a likelihood of shifts in rainfall patterns and hence shifts in timing of phenological events of vegetation that constitutes the source of forage for livestock in the ASALs. The dependence of vegetation dynamics on climate makes the pastoral communities vulnerable to changes in climate and subsequently, to changes in vegetation cycles. Close monitoring of growth cycles of natural vegetation is therefore necessary so as to understand its occurrence, predict its future changes and hence help pastoral communities to cope with the changes.

This study undertook to identify key phenological stages of grasslands (in terms of onset of greenness and senescence, and length of growing seasons) using NDVI data in selected ASALs of Kenya. It is aimed at providing information for natural pasture management.

1.1. Problem Statement

Past droughts have caused the drying up of water sources and decreased forage for livestock in the ASALs. These have led to higher livestock mortality rates, low or zero calving rates, reduced production of milk and weight loss in animals (Orindi, Nyong and Herrero, 2007). Both direct and indirect impacts of droughts resulted in reduced productivity of livestock and consequently, the loss of income for pastoralists. This diminishes their capacity to support themselves and effectively raise the minimum herd numbers required to maintain their households (Orindi, Nyong and Herrero, 2007).

There have been intervention measures to deal with droughts, such as encouraging pastoralists to sell a large number of their livestock. This is done so that they remain with few that they could manage to feed. However, such measures have encountered resistance from pastoralists who find it difficult to sell their livestock, as it is their way of life. Livestock provides them with milk, blood and meat; they are a sign of wealth, are used for bride price as well as to settle disputes (Mundy, 2004). Further, sale of livestock has been short term reactive measures (Orindi, Nyong and Herrero, 2007) aimed at dealing with crisis situations. With the possible increased frequency of droughts under a changing climate, it is vital to implement longer term proactive strategies that would help pastoralists to become more resilient to recurrent droughts. Provision of information on the spatial availability of forage, following seasonal or annual rainfall and temperature patterns, is an important component in developing long term strategies for livestock production in the ASALs.

Traditionally, pastoral management systems included setting aside pasture for dry season grazing. However, this strategy has been threatened in recent times by encroachment of farmers, land grabbers, growth of urban areas, amongst other issues. This has had negative effects on the quality and quantity of pasture accessed by pastoralists in the ASALs. Pastoralists are forced to move to more marginal areas resulting in overgrazing and further deterioration of pasture (Baringo district Vision and Strategy: 2005-2015, 2005; Garissa district Vision and Strategy: 2005-2015, 2005).

Delineation and preservation of reserve grazing areas is thus important in enhancing the resilience of pastoralists. Failure to set aside reserve grazing zones and allowing vegetation to regenerate before exploitation makes pastoralism to become environmentally destructive, despite being the only suitable system for survival of livestock in the ASALs. In addition, the rapid population growth in the ASALs has prompted increased pressure on the natural resource base and occasional conflicts arising from accessibility of the diminishing pasture and water resources. This poses a great challenge for sustainability of pastoral activities in the ASALs. Thus, conservation, sustainable use and management of natural resources (including pasture) are essential in the planning and development of these areas.

In light of the aforementioned problems, this study proposed a means for monitoring phenological stages of natural vegetation (grasslands) that constitute pasture, with the aim of describing pasture cycles in selected ASALs of Kenya. Further, the study sought to gain an understanding of the relationship between pasture cycles and rainfall with a view to aiding in better pasture management, leading to improved livestock productivity. The information generated forms a basis for climate change adaptation strategies for pastoralists in the ASALs of Kenya.

1.2. Objectives of the study

The overall objective of this study was to monitor grassland phenological stages in selected ASALs of Kenya, with a view to guiding improved pasture management for enhanced livestock productivity.

Specific objectives of the study were to:

i. Identify the phenological stages of pasture from NDVI data.
ii. Relate the identified phenological stages of pasture to rainfall.
iii. Determine the spatial distribution of the length of growing period for the pasture species.

1.3. Justification

Pastoralism depends on naturally occurring vegetation (grasslands) for pasture. The phenological cycles of this vegetation determines the availability of forage for their livestock. The appearance and timing of these phenological events are highly sensitive to changes in climatic conditions. However, not much research has been done in Kenya, and specifically in the ASAL areas, towards monitoring the phenological stages of grasslands based on satellite derived information, and relating the timing and duration of phenological events to key climatic variables such as rainfall. Perhaps this has been hampered by lack of *in situ* data due to the high cost of setting up and maintaining monitoring stations, and the vastness of the ASALs which cover an estimated 80% of Kenya's landmass. Remotely sensed data from satellite platforms and phenological events versus rainfall relationships therefore provide useful approaches in monitoring vegetation dynamics in the ASALs.

NDVI is a common index used to monitor vegetation conditions and productivity from satellite derived data. Vegetation phenological events such as the start of the growing season have been derived from NDVI with varying success. Derivation has been done using different proposed methods including moving averages (Reed *et al.*, 1994), use of thresholds (White *et al.*, 1997) and logistic functions (Zhang *et al.*, 2003). The first two methods generally do not account for ecosystems characterized by multiple growth cycles in a year such as those of the ASALs of Kenya. In view of this limitation, this study used logistic functions to identify the phenological stages of grasslands, making it the first of this kind of study to be undertaken in the ASALs of Kenya.

Logistic functions have been used in other researches (Zhang *et al.*, 2004, 2006; Fisher *et al.*, 2007; Fisher and Mustard, 2007; Richardson *et al.*, 2006) with reasonable agreement between observations and model predictions. The results of these studies have also been found to be ecologically meaningful. However, these researches were carried out in parts of the world where temperature was the major limiting climatic factor. It was therefore of interest in this study to investigate the performance of logistic functions in environments where vegetation growth is principally limited by rainfall. Although it is known that the seasonality of grasslands is affected more by the variation in rainfall than in temperature in low rainfall areas (Boonman, 1997; Hermann *et al.*, 2005), the nature of this relationship yet remained to be established especially in ASALs using satellite derived data.

Of importance would be initiatives aimed at providing information on the spatial spread of vegetation phenological stages. This information could aid in delineating and reserving grazing areas, hence guide better management of pasture in the vulnerable ASALs of Kenya. This could in turn alleviate the environmental degradation that results from poor pastoral systems as well as help the communities become resilient and adapt to the changing climate. Development of such a monitoring tool would inform pasture early warning systems so that necessary intervention measures can be taken. It would also form a basis for the incorporation of rainfall into phenological development prediction models.

1.4. Study Area

This study was conducted in three selected ASAL districts of Kenya, namely, Baringo, Garissa and Kajiado (Figure 1 below).

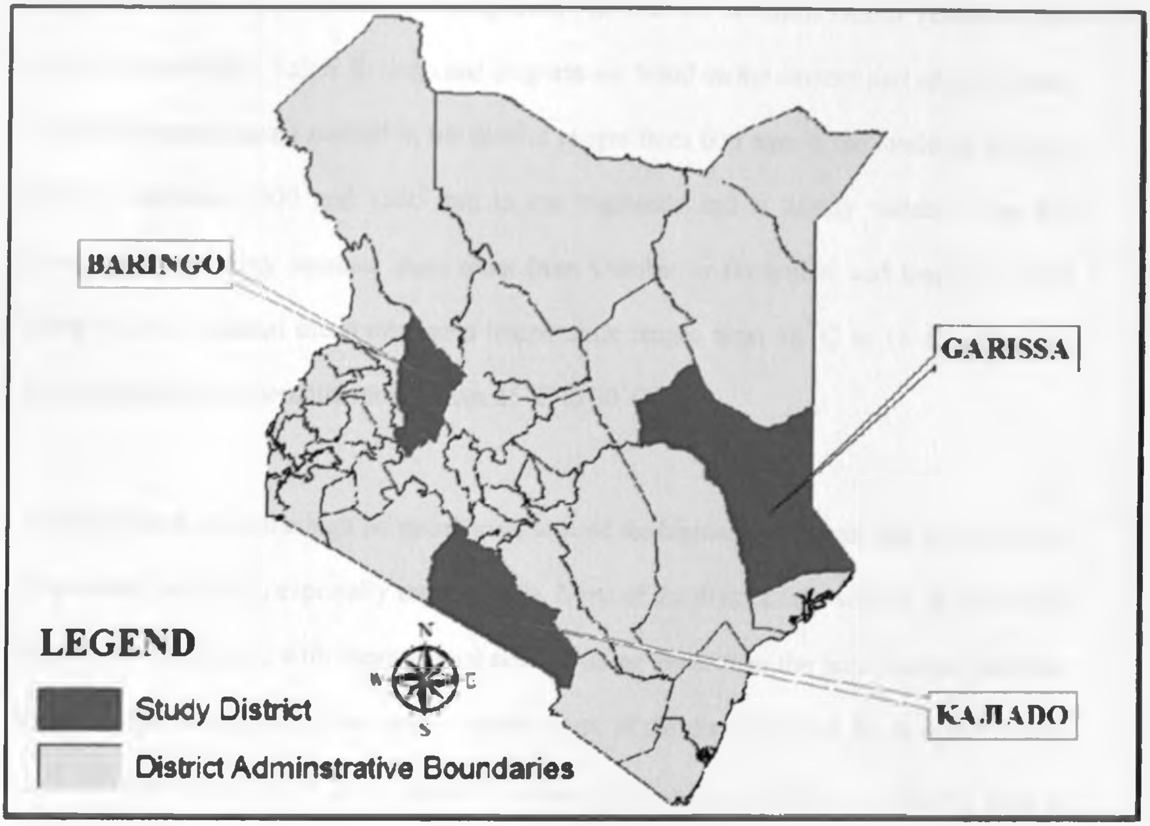

Figure 1: Location of the study districts in Kenya. Districts were based on administrative boundaries in the year 2004.

These districts were chosen to represent the Northern Rift Valley, North Eastern and Southern rangelands/ ASAL regions of Kenya respectively. Cited among the key natural resources in the three districts are livestock, pasture and water. Livestock keeping is a major socio-economic activity in these districts and thus a major (and sometimes the only) source of livelihood. The study considered livestock areas comprising of both grazers (cattle, sheep and goats) and browsers (camels and goats). The background profiles of the study districts are presented in the sub-sections that follow herein under.

1.4.1. Baringo District

Baringo is one of the ASAL districts in the Rift Valley province of Kenya and lies between latitudes 0°12' N and 1°36' N and longitudes 35°36' E and 36°30' E. The district covers an area of 8,655 km^2, with elevation varying from 752 m in the lowlands (Kerio Valley) to 2600 m in the Tugen Hills. Lakes Baringo and Bogoria are found on the eastern part of the district. Long-term mean annual rainfall in the district ranges from 600 mm in the lowlands (Njemps Flats) to between 1000 and 1500 mm in the highlands and is highly variable. The area experiences two rainy seasons; short rains from October to December and long rains from March to May. Annual mean minimum temperature ranges from 16° C to 18° C and annual mean maximum temperature ranges from 25° C to 30° C.

Although there are some high potential areas around the highlands, a larger part of the district is classified as ASAL, especially the lowlands. Most of the district falls within agro-climatic zone V (i.e. semi-arid, with mean annual rainfall being lower than the mean annual potential evapotranspiration), except the south western parts of the district which lie in agro-climatic zones II (sub-humid) to IV (semi-humid to semi-arid) (Braun *et al.*1980). In the dry areas of the district, livestock such as goats, sheep and cattle are kept; bee keeping is also practised. Figure 2 gives information on livelihoods in Baringo district.

With regard to pasture, *Cenchrus ciliaris* and *Eragrostis superba* are the most common grass types found in the dry areas of Baringo district, whereas *Chloris gayana* is common in the high potential rangeland parts of the district. Browsers (goats) feed on the leaves of *Acacia*; the ripened *Acacia* pods that drop to the ground on the other hand are a source of fodder for cattle as well. The *Acacia* species are widespread within the dry parts of Baringo. Livelihood systems are mainly pastoral, followed by agro-pastoral and mixed farming systems. However there are also small patches of irrigated crop areas (Figure 2).

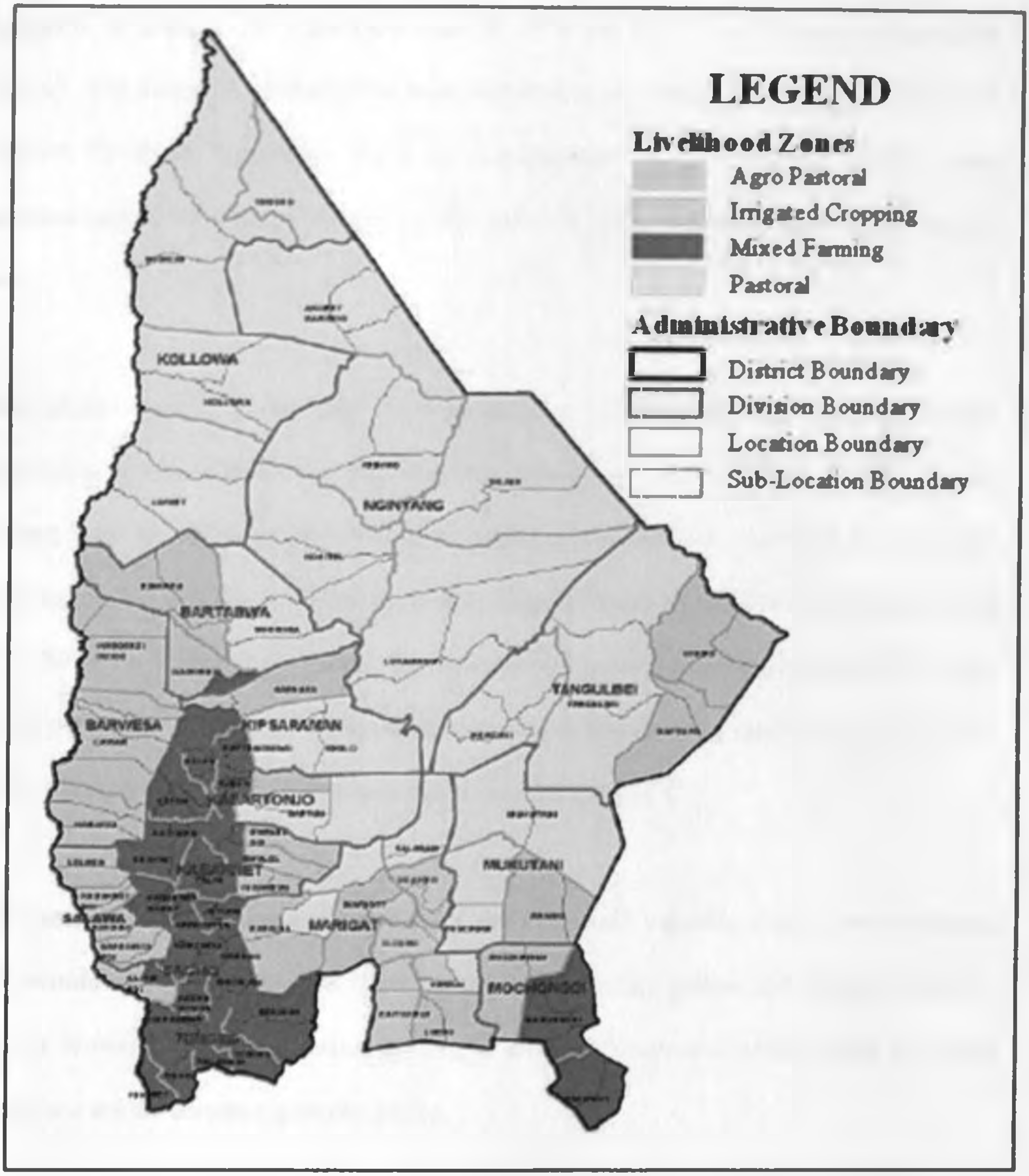

Figure 2: Livelihoods in Baringo district (Adapted from Baringo district profile, Arid Lands Resource Management Project)

1.4.2. Garissa District

Garissa is one of the ASAL districts of North Eastern province of Kenya and lies between latitudes 0° 58' S and 1° 38' S and longitudes 38° 34' E and 41° 05' W. It covers an area of 33, 620 km^2. The district is generally flat, with altitude ranging from 70 m to 400 m above mean sea level. The River Tana passes along the Western boundary of the district, and is the only permanent source of water. During the rains, seasonal rivers (known locally as *laghas*) also flow.

Mean annual rainfall in the district varies between 150 mm and 550 mm. The district experiences two rainy seasons; the short rains are received from October to December while the long rains are received from March to May. Garissa district is classified as arid in the south and very arid in the north, falling in agro-climatic zones VI and VII respectively (Braun *et al.*1980). Throughout the district, the mean annual rainfall is always less than the mean annual potential evapotranspiration. Annual maximum temperatures range from 30° C to 36° C while annual minimum temperatures range from 18° C to 24° C.

Important grasses for pasture in the district are *Eragrostis superba*, *Chloris roxburghiana*, and *Aristida* species. *Aristida* are, however, the most common pasture species in the district. For the browsers (goats and camels), *Acacia tortilis*, *Comiphora africana* and *Balanites aegyptiaca* are the common pasture species.

Livelihoods are dependent on livestock, mostly camels which are drought resistant, as well as cattle and goats. Figure 3 presents a distribution of livelihood types in Garissa district.

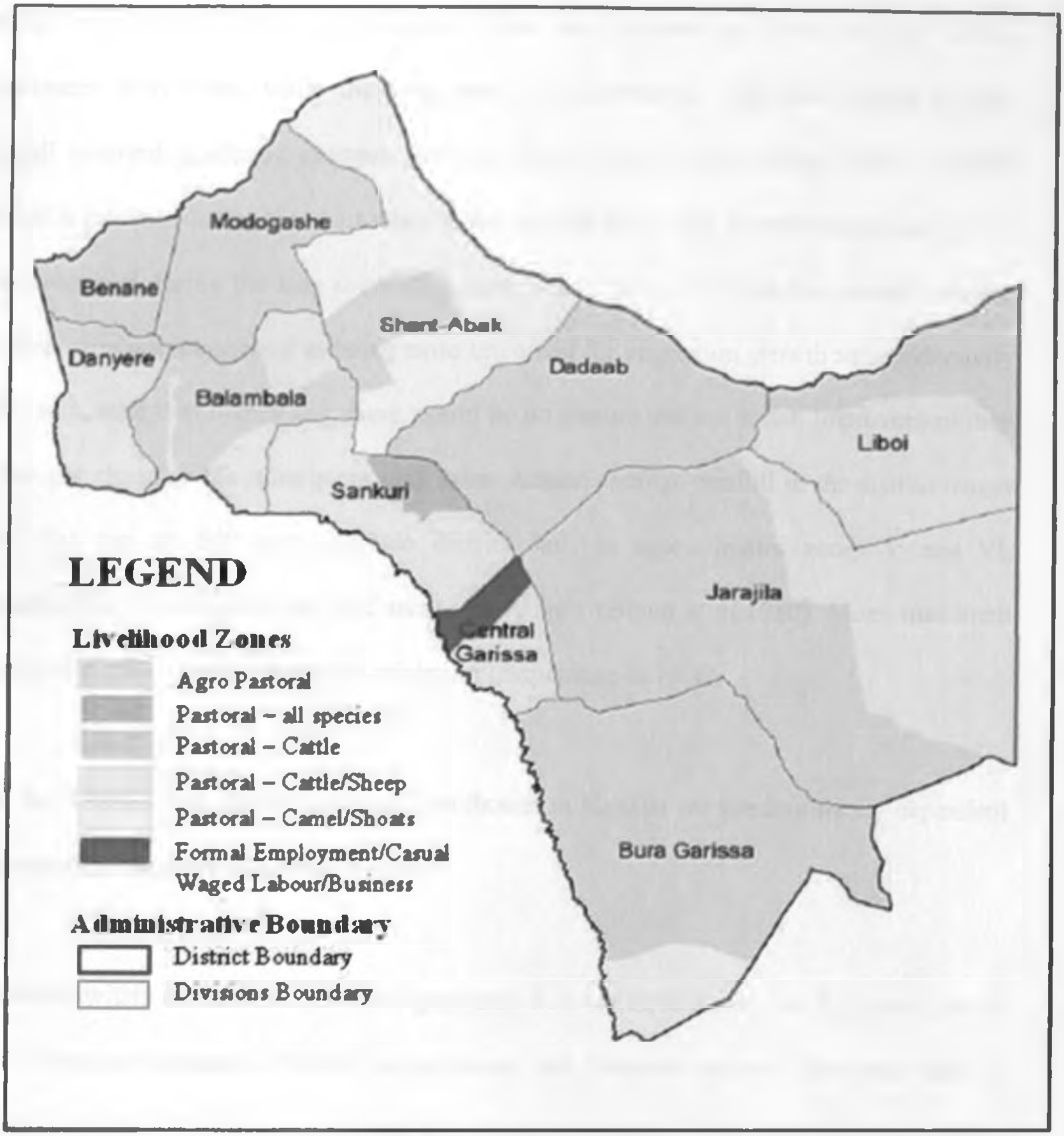

Figure 3: Livelihood types in Garissa district (Adapted from kenyafoodsecurity.org)

1.4.3. Kajiado District

Kajiado district is located in the Southern Kenya rangelands, between latitudes 1°0' S and 3°0' S and between longitudes 36°5' E and 37°5' E. It covers an area of approximately 21,902.9 km^2. Altitude varies from 500 m above mean sea level in Magadi Division to 2,500 m in the Ngong Hills.

Rainfall in Kajiado district is bimodal. From late October to December the district experiences short rains, while the long rains are experienced from mid March to May. Rainfall received gradually changes from the eastern part of the district where a higher amount is received during the short rains, to the western part of the district where much of the rain is received during the long rains (de Leeuw *et al.*, 1991). Of these two rainfall seasons, the short rains are recognized as being more important for vegetation growth and productivity in the area, such that if they fail, there would be no pasture and not much improvement may be brought about by the subsequent long rains. Annual average rainfall in the district ranges from 400 mm to 600 mm. Kajiado district falls in agro-climatic zones V and VI, corresponding to semi-arid and arid areas respectively (Braun *et al.*1980). Mean maximum temperature is 30° C while the mean minimum temperature is 19° C.

Like for Baringo and Garissa districts, livelihoods in Kajiado are predominantly dependent on pastoralism as shown in Figure 4 below.

Vegetation within the district is bushed grassland with scattered trees. The dominant grasses are *Pennisetum meziunum*, *Chloris roxburghiana* and *Cenchrus ciliaris*. The community in Kajiado considers *Chloris roxburghiana* and *Cenchrus ciliaris* as the more important pasture grasses (Mnene, 2006).

Land adjudication and sub-division of group ranches has lead to increased sale of medium and high potential land to people from other parts of the country. This has moved land tenure from being communally held to individual ownership, pushing pastoralists further into the drier areas of the district (Kajiado District Development Plan 2002-2008).

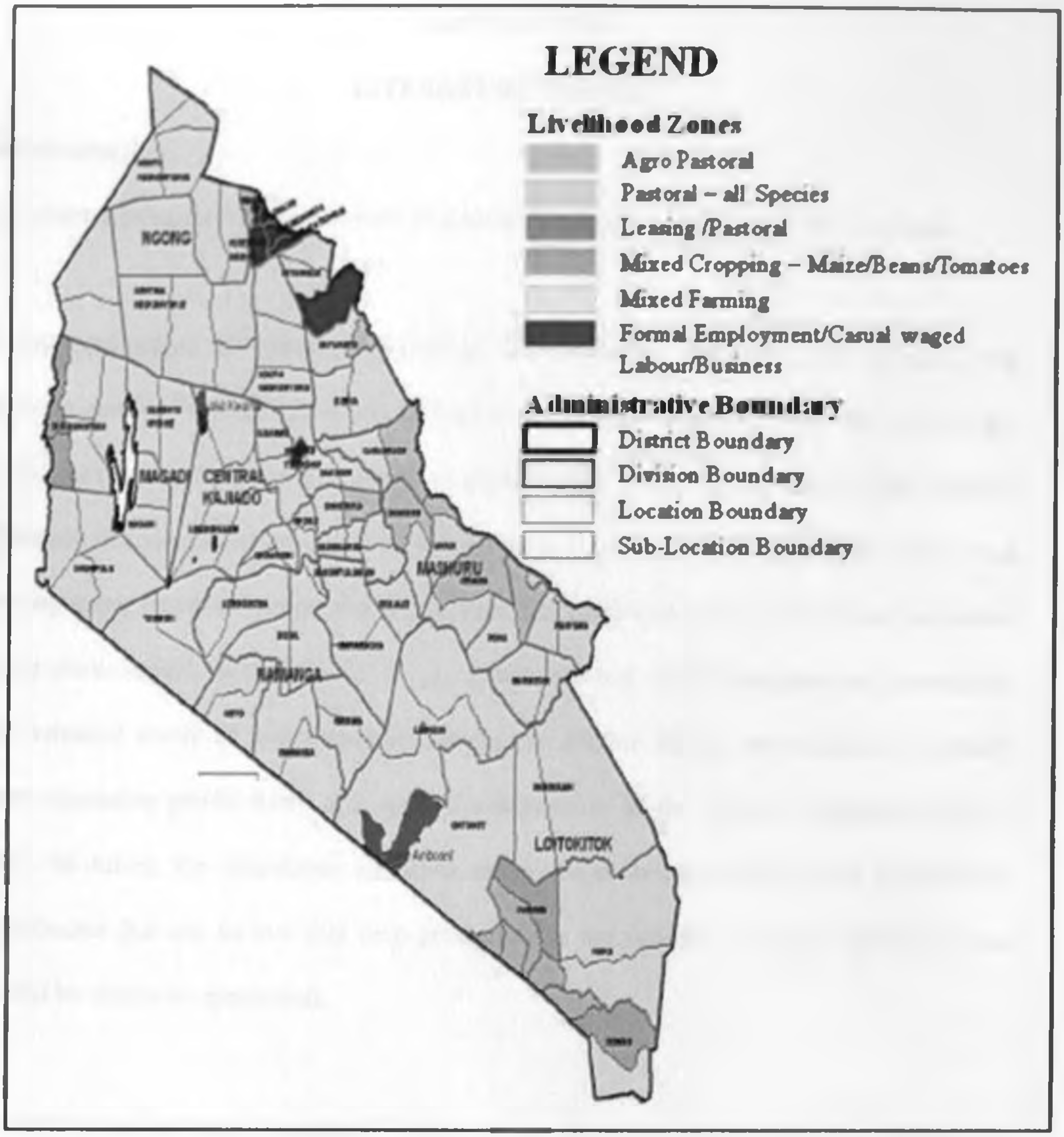

Figure 4: Livelihoods in Kajiado district (Adapted from Kajiado District Annual Progress report, June 2008-July 2009, Arid Lands Resource Management Project)

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter presents literature review of similar works that were carried out in the past.

Phenological stages of vegetation including leaf unfolding, flowering, fruit ripening, leaf colouring and leaf fall are important biological indicators of climate variability and change. On the short-term, the recurrent cycles of phenological events are affected by and respond differently to seasons due to climate fluctuations and/or anthropogenic forcings; whereas on the long term, climate change and anthropogenic disturbance may cause annual and inter-annual phenological shifts (Bradely *et al.*, 2006). Altered rainfall amounts and seasonality, and increased levels of evapotranspiration due to climate change are expected to greatly affect vegetation productivity and species composition in the tropical rangelands (IPCC, 1997). In Africa, the rangelands are ASAL areas that experience poor rainfall distributions and amounts that are so low that crop production is not possible. As such, these areas are covered by extensive grasslands.

In a strict sense, the term "grassland" is used for any plant community which has herbaceous species and includes savannah, with conspicuous grass cover, but also containing woody plants (Humphreys, 1993). However, this study uses grasslands to imply grazing land in the ASALs. This is indeed the type of land to which pastoral communities are relegated in order to feed their livestock (Reid *et al.*, 2005). This makes pastoral systems highly vulnerable to a change in climate, since their livelihoods are almost solely dependent on natural vegetation (grasslands) to provide pasture for their livestock.

Despite the risk that the pastoral communities are exposed to in the ASALs, there is emerging consensus that pastoral systems are best suited (as compared to other land use practises) for maintaining the integrity of rangelands (Reid *et al.*, 2005). However, benefits from pastoral systems can only be realized if there is sustainable management of the available natural resource. Sustainable management calls for quality information on the state of grasslands, which would come from an understanding of the growth dynamics of this vegetation type in a natural environment. Monitoring the growth cycle dynamics of grasslands is a challenge due to the vastness of the ASALs and the lack of *in situ* data. In this regard, data derived from satellites has proven useful in vegetation monitoring.

2.1. Identification of Vegetation Phenological Stages

Satellite data has been used to derive phenological stages of vegetation in a number of studies, with varying success. This has been through the use of the Normalized Difference Vegetation Index (NDVI), an index which earlier studies have linked to vegetation productivity (Goward and Dye 1987; Prince *et al.*, 1995; Wang *et al.*, 2004) due to its sensitivity to photosynthetically active radiation in the visible range of the electromagnetic spectrum. NDVI is calculated as in equation 1 below.

$$NDVI = \frac{NIR-VIS}{NIR+VIS} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(1)}$$

where NIR and VIS are the near infrared and visible bands of the electromagnetic spectrum, respectively.

Reed *et al.* (1994) is one of the commonly referred to studies that attempted to derive phenological stages of vegetation from NDVI. They generated a smoothed NDVI time series curve and a moving averages curve, then took the intersection points between the two curves to indicate the onset or start of greenness. Although this method entailed a quantitative and automated approach, the method depended on the length of time used to generate the moving averages, which could be different for different vegetation types. Further, the method relies on the abrupt increase of NDVI to detect the onset, which assumes there can be only one such increase within a year. However, more than one increase per year may occur due to multiple growth periods in a year. Thus, this approach is not suited to areas where there is multi-modal growth in a year, such as in the Kenyan grasslands.

Another method that has been used to identify phenological stages is the transformation of NDVI into a ratio that indicates what percentage of the maximum greenness that has been attained (White *et al.*, 1997). The inputs, comprising of daily NDVI and annual maximum and minimum NDVI, would have made the ratio an objective approach except that the ratio then required a definition of thresholds to mark different phenological stages. The challenge in using thresholds is that there cannot be standard values, as the values depend on vegetation type, species and geographical location, amongst a number of other factors. The same goes for other threshold methods such as those by Myneni *et al.* (1998) and Yu *et al.* (2004).

The limitations associated with these earlier methods led Zhang *et al.* (2003) to develop a method that did not require arbitrary assignment of thresholds. Zhang *et al.* (2003) used simple logistic functions of time fitted to NDVI data in a piecewise manner. Piecewise fitting approach was such that a logistic function with different parameters was developed for each phenological stage. This kind of subdivision made the method flexible enough to accommodate multiple growth cycles within any one year. By calculating the rate of change of curvature of the logistic curve and checking the points where the curve changed signs, transition dates for onset of greenness and senescence of vegetation could be determined.

Richardson *et al.* (2006) used a logistic function similar to Zhang *et al.* (2003) to detect spring and autumn phenological stages of a forest in North America that was composed of different tree species. They compared the performance of a model based on time (day of the year) with that of a model based on accumulated temperatures i.e. Heating Degree Day (HDD). It was found that the time based function performed as well as the HDD model, and that both could adequately describe development of greenness and senescence. Although the HDD model may be thought of as a better predictor of phenological stages since it incorporates a parameter (temperature) that affects the internal processes of plant (such as photosynthesis, respiration, among others), Fisher *et al.* (2007) suggested that the HDD model does not give significant improvement to the time based model.

Fisher and Mustard (2007) used the logistic model as well, but rather than the rate of change of curvature, they used half-maximum (a value derived from the total amplitude and background greenness) to determine transition NDVI values. According to these authors, the transition value corresponds to the steepest point on the symmetric sigmoid curve. The transition NDVI values were taken to mark the onset of growth or senescence/dormancy of vegetation. Since the half-maximum was constrained by the entire shape of the phenological curve, the value was minimally affected by noise. Comparison of results from this method with *in situ* data indicated that the model could successfully predict 70% – 86% of the variance in phenological stages over two forested areas. The half-maximum method is considered to be stable and consistent across ecosystems (Bradely *et al.*, 2007). Further, the logistic method has been found to produce realistic estimates of transition dates for green up, maturity, senescence and dormancy stages (Zhang *et al.*, 2006) while being spatially coherent in describing inter-annual vegetation phenological stages (Fisher and Mustard, 2007).

All these studies were however conducted in regions of the world where vegetation phenological stages are more sensitive to seasonal changes in temperature. It was therefore of interest in this study to find out if the logistic model performed as well in regions where rainfall is the limiting factor, such as in the tropical ASALs of Kenya.

2.2. Relating NDVI derived Vegetation Growth to Rainfall

The annual cycle of plant growth and development is expected to be altered by changes in precipitation patterns due to climate change in water limited ecosystems (Badeck *et al.*, 2004). It is for this reason that a number of studies have been conducted to investigate the relationship between satellite derived vegetation productivity and rainfall. In the ASALs, rainfall is considered to be the dominant factor affecting vegetation greenness (Herrmann *et al.*, 2005). For example, precipitation extremes arising from El Niño events have been shown to have had significant effects on vegetation productivity in the ASALs of East and Southern Africa (Assaf *et al.*, 2002).

A number of studies have also demonstrated the relationship between NDVI and lagged rainfall (Wang *et al.*, 2003; Herrmann *et al.*, 2005; Chandrasekar *et al.*, 2006). Wang *et al.* (2003) found that biweekly NDVI was correlated with rainfall from 2 to 4 weeks before the biweekly period, whereas the growing season NDVI was correlated with rainfall over 15 month duration. The study differentiated vegetation types, whereby, this response was observed in grasslands as well. Indeed, discriminating the various vegetation types is seen as important in understanding vegetation response to rainfall. Fisher *et al.* (2007) observed that information on species composition and spatial location are necessary for satellite observations to be linked to climate data. While it was a study that indicated the relationship between NDVI and rainfall, it is not clearly known how Wang *et al.* (2003) determined the growing season, which is a phenological metric. In addition, coarse resolution data from AVHRR was used and some vegetation responses may therefore have been smoothed out within the biweekly (14day) NDVI periods used.

In a study conducted in three semi-arid regions of Africa (South Sahel in West Africa, Tsavo-Garissa in East Africa and Karoo in South Africa), Martiny *et al.* (2005) found that annual NDVI was related to rainfall in the concurrent and previous years. This study further suggested that on an annual time scale there was a "memory" effect where vegetation productivity remained high following a wet year and a "recovery" effect where vegetation experiences difficulty in recovering from a dry year. It is therefore of interest to find out if the same effects are replicated on seasonal time scales as dictated by phenological stages.

In another study over semi-arid Africa, it was suggested that the distribution and concentration of the rainy season has more influence on the regional differences of NDVI response to rainfall, than vegetation cover, soil type and potential evapotranspiration (Martiny *et al.*, 2006). This implies that different phenological patterns would be expected over different rainy seasons such as the long and short rains that occur in the Kenyan ASALs. This needs to be investigated. Camberlin *et al.* (2007) also found one year lag relationships between annual rainfall and NDVI, but the spatial pattern of this relationship was difficult to interpret. Perhaps the interpretation would be easier if the NDVI time series was broken down into phenological stages.

The studies mentioned in section 2.2 attempted to link rainfall to vegetation productivity from satellite data using NDVI on time scales that did not acknowledge the plants' varied need and use of available moisture depending on the growth stage involved. Furthermore, while

AVHRR data set offers a longer time period for study as compared to other satellite instruments, this data has a course resolution such that some small scale responses may not be observable. This study, therefore, sought to counter the limitations associated with previous studies.

2.3. Grass and Browse Species of the ASALs of Kenya

The grass and browse species mentioned in the profiles of the study districts (Sections 1.4.1 to 1.4.3) are described in this section.

Commonly known in Kenya as African foxtail, *Cenchrus ciliaris* is a perennial grass found in open and bushed grasslands in tropical Africa. It is a drought resistant type of grass with deep roots and can grow in areas with 250 mm to 300 mm of rainfall. Its growth cycle occurs between 120 and 180 days with the growth season being in austral summer, between December and February (FAO, http://www.fao.org/ag/Agp/AGPC/doc/gbase/).

Chloris roxburghiana, also known as Horsetail grass, is a perennial grass that naturally occurs in East Africa in open or bushed grasslands (Mnene, 2006). The grass optimally requires one rainfall season of 500 mm to 625 mm but it is drought tolerant; the grass grows in austral summer (FAO, http://www.fao.org/ag/Agp/AGPC/doc/gbase/).

Eragrostis superba is commonly known as Maasai love grass and naturally occurs in the East African grasslands. It is a perennial grass that optimally requires rainfall between 500 mm and 874 mm. However, it grows well in ASALs as it is drought resistant. The grass' growth cycle takes 90 to 150 days (FAO, http://www.fao.org/ag/Agp/AGPC/doc/gbase/).

Chloris gayana is a grass species native to Africa that grows in austral spring (September to November) and austral summer. It is found in areas with 500 mm to 2000 mm of rainfall but has been known to be suited to dry areas of Kenya. *Chloris gayana* has deep roots and is good in tolerating droughts. It can be considered as an annual or perennial species, with a growth cycle of 150 to 210 days (FAO, http://www.fao.org/ag/Agp/AGPC/doc/gbase/).

Known in Kenya as the common needle grass, *Aristida adscensionis* grows well in areas with annual rainfall of 300 mm to 400 mm. It is an annual species that grows in austral summer, but can develop out of season if moisture and temperature conditions are favourable. The species escapes drought if it has enough moisture to germinate. The growth cycle of this species takes 90 to 150 days (FAO, http://www.fao.org/ag/Agp/AGPC/doc/gbase/).

Acacia tortilis is the most widespread acacia species in dry parts of Africa. In Kenya it is found in the lowland ASAL in dry bushland, bushed and wooded grassland and along laghas. It can grow where annual rainfall is between 150 mm to 900 mm (Maundu and Tengnäs, 2005). *Acacia tortilis* has enormous deep roots that help to access underground water, hence making it semi-evergreen, though it behaves as a deciduous tree. It is a perennial tree species with a growth cycle occurring between 90 and 180 days (FAO, http://www.fao.org/ag/Agp/AGPC/doc/gbase/).

Commiphora africana is a perennial tree species that is commonly found in dry parts of Kenya, in Acacia-commiphora bushland. It grows in areas with annual rainfall of 400 mm to 1000 mm (Maundu and Tengnäs, 2005). The species is deciduous and grows throughout the year (FAO, http://www.fao.org/ag/Agp/AGPC/doc/gbase/).

Another perennial tree or shrub, *Balanites aegyptiaca* grows in the ASALs, with annual rainfall of 200 mm to 800 mm. It is found in bushed, wooded and open grasslands (Maundu and Tengnäs, 2005). It is a semi-evergreen, deciduous species whose growth cycle occurs between 90 and 180 days (FAO, http://www.fao.org/ag/Agp/AGPC/doc/gbase/).

CHAPTER THREE

MATERIALS AND METHODS

3.0 Introduction

This chapter describes each of the datasets that were used to achieve the study objectives and the data sources. A full exposition of the methods used in analysing the data is also presented.

3.1. Data Types and Sources

3.1.1. Remotely Sensed Data

Remotely sensed data was obtained from VGT4Africa, a project that aims to distribute satellite data to an African user community. The data was acquired using the VEGETATION instrument on board SPOT 4 and 5 satellites. The instrument provides accurate measurements of basic condition and development of vegetation canopies.

SPOT satellites are at an average altitude of 830 Km and have a ground swath of 2200 Km. VEGETATION is specially designed for land surface monitoring providing near real time images at a spatial resolution of 1 km. Its temporal resolution is 5 times over 6 days around the equator, while once a day over the globe. The instrument measures radiation reflected by the earth's surface in four spectral bands as given in Table 1 below.

Table 1: Spectral bands used by the VETETATION instrument on board SPOT satellite

Spectral bands	Specified (µm)	VEGETATION1 (actual values) (µm)	VEGETATION 2 (actual values) (µm)	Surface reflectance range
BLUE (B0)	0.430 - 0.470	0.437 - 0.480	0.438 - 0.475	0.0 - 0.5
RED (B2)	0.610 - 0.680	0.615 - 0.700	0.615 - 0.690	0.0 - 0.5
NIR (B3)	0.780 - 0.890	0.772 - 0.892	0.782 - 0.890	0.0 - 0.7
SWIR (MIR)	1.580 - 1.750	1.600 - 1.692	1.582 - 1.685	0.0 - 0.6

Data acquired from VEGETATION undergoes geometrical processing, radiometric and atmospheric corrections and synthesis composition before the final products are delivered to the users. Geometrical processing involves georeferencing each pixel in the raw image and projection on to a map. Radiometric correction computes the Top of Atmosphere (TOA) reflectance taking into account the solar irradiance, sun angles, and sun-earth distance. Atmospheric processing includes the identification of clouds, snow, ice and shadow.

NDVI data for the whole African continent is available for download (www.vgt4africa.org) from April 1998 to current. The data is delivered every ten days (dekad) of a month, i.e., three dekads per month from 1st to 10th, 11th to 20th and 21st to the end of the month. The dekads are numbered 1 to 36, counting from the first ten days in January to the last ten days in December. A five year period from 1999 (the first year with complete data) to 2003 was used. This was because the method for identifying phenological stages was computer time intensive, taking about two weeks to have one complete year. Thus, five years were what could be processed within the time required for this study.

NDVI is based on the comparison between reflectance of the visible (VIS) and near infrared (NIR) bands of the electromagnetic spectrum. Healthy vegetation absorbs more of the VIS and reflects the NIR, while the converse is true for unhealthy vegetation. As such, using measurements from the VEGETATION instrument (refer to Table 1), NDVI is calculated as:

$$NDVI = \frac{B3 - B2}{B3 + B2}$$

Specifically, the S10 NDVI product from the VEGETATION instrument was used in this study. It is a ten-day synthesis product (hence the S10). Synthesis involves coming up with a pixel-to-pixel mosaic of daily atmospherically corrected reflectance data. During the process, the "best" measurement for a given pixel among the available set of dekadal measurements was chosen. A single dekadal image was then produced using the Maximum Value Composite (MVC) algorithm, where the selected value corresponds to the view with the highest ground reflectance. Views that were cloudy, of bad quality or interpolated were excluded. Each run of the algorithm then results in a single dekadal image of NDVI over the whole globe. Typical NDVI values decoded from this product are between 0.1 and 0.92, referring to areas with little vegetation and those with dense vegetation respectively.

3.1.2. Rainfall Data

Rainfall estimates (RFEs) produced by NOAA's Climate Prediction Centre and downloaded from FEWSNET (http://earlywarning.usgs.gov/adds/datatheme.php) were used over the period corresponding to the NDVI data. RFEs were chosen because the data covered the whole area of the study districts, as opposed to the sparse station data which was not available at all the points where NDVI was extracted. Validation of RFEs has been done using Ethiopia as a case study where it was found that the estimates were highly correlated ($r = 0.6$ to 0.9) with *in situ* rainfall data (Ouma *et al.*, 2005). In a similar exercise conducted over western Kenya, simple regression analysis showed good agreement between RFEs and station data, with $r^2 = 0.8$ and a bias of ~5mm per dekad (Funk and Verdin, 2003).

RFEs are based on Meteosat infrared data that is obtained every 30 minutes at a resolution of 0.05°. The infrared data gives an estimate of convective rainfall based on cloud top temperatures. This estimate is incorporated with data from about 1000 rain gauge stations of WMO's Global Telecommunication System (GTS) to produce a gridded rainfall map. The resultant RFEs are in form of images with a spatial resolution of 8 Km. From 2001, RFE 2.0 came in to replace the earlier version (RFE 1.0). In order to get better rainfall estimates, the algorithm used in developing RFE 2.0 obtained data from the Special Sensor Microwave/

Imager (SSM/I) on board the Defence Meteorological Satellite Program satellites, and the Advanced Microwave Sounding Unit (AMSU) on board NOAA satellites, in addition to Meteosat infrared data.

The algorithm in RFE 2.0 follows the Xie and Arkin (1995) methodology, which proceeds in a two-step merging process. Firstly the three satellite data sets (Meteosat, SSM/I and AMSU-B) and GTS data are linearly combined using a maximum likelihood method in order to reduce the random error in the individual data sets. Maximum likelihood produces weighted linear combination coefficients that are inversely proportional to the square of local random errors from individual data sources. Secondly bias in the merged data is removed using gauge based data from GTS which is assumed not to have bias in areas where enough observations are available. Finally, the daily estimates from the merging process are summed up to dekadal rainfall estimates. Xie and Arkin's (1995) method produced an improved global rainfall field compared to that when using individual sources and the quality was found to be reasonable both in the tropics and extra-tropics.

3.1.3. Land Cover Map

A land cover map was obtained from Africover for masking the NDVI images, so as to pick out grassland areas. Africover was a programme of the Environment and Natural Resources Service (SDRN) whose objective was to develop a common land cover classification system.

The Africover land cover maps were generated based on the Land Cover Classification System (LCCS). LCCS is a comprehensive standardized *a priori* method, which can be used to describe, characterize, classify and compare any land cover identified anywhere in the world, at any scale (Jansen and Di Gregorio, 1998). The system is such that it is able to describe enough classes to deal with the real world but at the same time adhering to strict class boundaries so that classes are unambiguous. Classes are defined using a set of independent diagnostic criteria (known as classifiers) which are hierarchically arranged so that a high level of geographical accuracy (i.e. mapability) is achieved. LCCS then proceeds in two phases: the dichotomous phase and modular-hierarchical phase.

Classifiers used in the dichotomous phase are the presence of vegetation, edaphic conditions and artificiality of cover, in that order. The phase results in eight major classes at the third level as shown in Figure 3. The modular-hierarchical phase involves selecting classifiers tailored to the eight major land cover classes from the dichotomous phase (Figure 4). These classifiers are hierarchically arranged as per their mapability. At this phase, environmental attributes that influence land cover (such as climate) and specific technical attributes (such as crop type) can be included.

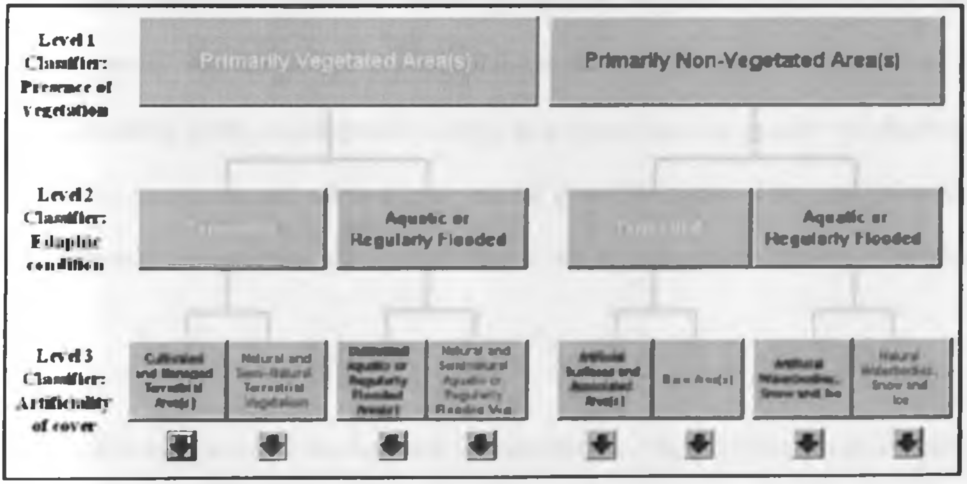

Figure 5: Dichotomous phase of the Land Cover Classification System

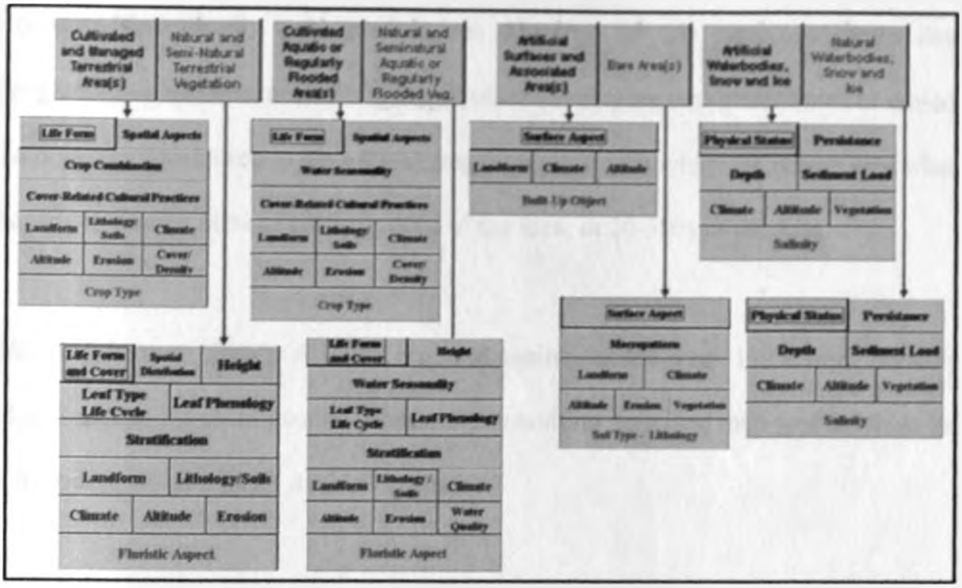

Figure 6: Modular hierarchical phase of the Land Cover Classification System. Classifiers are in dark blue, environmental attributes in purple and technical attributes in green

In this study, the land cover map focussed on pasture within the study areas. Pasture meant that the selected map showed only the location of grasslands. Thus, classifiers used in the dichotomous phase were (in order of hierarchy) primary vegetated areas, terrestrial, natural and semi-natural vegetation. For the modular-hierarchical phase, the life form was first defined depending on the physiognomic aspect; in this case the physiognomy was herbaceous i.e. referring to grasses and other narrow-leaved grass-like plants. This was followed by determination of the dominant life form, leading to the definition of its cover as closed, open or sparse.

When considering grasses as the dominant vegetation type, other life forms such as trees and shrubs may be present though with sparse cover. It led to three categories of grasslands: (1) herbaceous with sparse trees (2) herbaceous with sparse shrubs (3) herbaceous with sparse trees and shrubs. This, together with the Africover cartographic standard where there is a Minimum Mappable Area (MMA), brings about the concept of mixed units. Mixed unit were used to produce thematically aggregated classes whereby, for this case, land cover data relating to grasslands was enhanced while that of other cover types was generalized or erased. Hence, an area was considered to have the aggregation class occupying: the whole area when it was the only life form; 60% of the area; 40% of the area; or 20-30% of the area.

LANDSAT TM images (Bands 4, 3, 2) acquired mainly in the year 1999 were digitally enhanced and used in the classification process. The resulting grassland map was downloaded from the Africover website as an *ArcView* shapefile.

3.2. Methods of Data Analysis

3.2.1. Quality Control

Quality Control was undertaken to check for inconsistencies in the observed NDVI and RFE data. RFE data was inspected for errors that may have resulted from change of instrumentation between RFE 1.0 (up to year 2000) and RFE 2.0 (from year 2001). NDVI data was examined for errors in observations by the VEGETATION instrument, which may have arisen from wobbling of SPOT 4 and 5 satellites. Double mass curves were used to check for inconsistencies in both datasets, as extracted from the different points in the three study districts. The mass curves were constructed as follows.

Let x be one of the points in the study districts where data was extracted. Data from point x was cumulated over the entire 5 year study period ($\sum D_x$), starting from the most recent year (2003). Average data of three points neighbouring point x was obtained and cumulated ($\sum D_{av}$) over the study period, beginning with the most recent year as well. $\sum D_x$ was then plotted against ($\sum D_{av}$), resulting in a double mass curve.

A break in the slope of the double mass curve indicates change in data at point x at a particular time, in relation to the neighbouring stations. In the event of a change in data at any point in time, an adjustment was made based on slope of the mass curve. The adjusted data was computed as shown in Equation 2 below.

$$D_{cx} = D_x \frac{S_c}{S_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where D_{cx} is the adjusted data at point x, D_x is the observed data at point x, S_c is the adjusted slope of the double mass curve and S_o is the original slope of the double mass curve. The ratio S_c/S_o is the correction factor.

3.2.2. Identification of Phenological Stages of Grasslands

Since the study focused on pasture dynamics, it was necessary to extract values of NDVI in areas categorized as grasslands within the study districts. As such, an overlay of a land cover map, Kenya district boundaries map and dekadal NDVI images was carried out using *ArcMap*. Ten spatially distributed points constrained by the location of grasslands were selected at random within each study district for extraction of NDVI values, throughout the study period. The choice of points was an attempt to capture different grassland species expected to exhibit differences in phenological stages.

The NDVI values extracted in this way were in terms of digital numbers (DN) that ranged from 0 to 255. This called for conversion of the digital numbers to real NDVI values. Conversion was done using Equation 3 as given by VGT4Africa program, the data supplier (http://www.vgt.vito.be).

$$Real\ NDVI = g \times DN + h \quad \text{..............................} (3)$$

where $g = 0.004$, DN is the digital number and $h = -0.1$. These coefficients have no physical meaning; they constitute an equation used to convert the NDVI values into integers between 0 and 255, so that they could be stored as byte data in the raster image files.

The method used to identify grassland phenological stages was that developed by Zhang *et al.* (2003). Consequently, annual NDVI values were subdivided according to the wet and dry seasons i.e. the dry seasons in January to February (dekads 1 to 6) and June to September (dekads 16 to 27), and the wet seasons in March to May (dekads 7 to 15 and October to December (dekads 28 to 36). Logistic functions were then fitted to the subdivided NDVI data in a piecewise manner. Piecewise fitting was such that a logistic function with different parameters was developed for each phenological phase. The logistic function used was of the form given in Equation 4.

$$y(t) = \frac{c}{1+e^{a+bt}} + d \quad \text{..............................} (4)$$

where $y(t)$ is the NDVI at time t, c is the potential maximum NDVI in a season, d is the initial background value of NDVI, and a and b are fitting parameters.

In view of the findings by Fisher *et al.* (2007), this study used a model based on day of the year (DOY). Since the NDVI data was dekadal, DOY here referred to dekad of the year (t), numbered 1 for the first dekad of January to 36 for the last dekad of December.

The four parameters a, b, c and d were determined separately for each subdivision of NDVI data (January – February, March – May, June – September and October – December) using the Levenberg – Marquardt (LM) algorithm. The LM algorithm is a method of non-linear least square estimation of parameters. It obtained parameter estimates based on the maximum likelihood of the model data being a good fit to the observed data. This was achieved through a linear approximation of a function f in the neighbourhood of the parameter matrix p. The function f (in this case it is the logistic function in Equation 4) mapped the estimated to the observed data when a small change, δ_p, was applied to the initial guess of the parameter matrix. By Taylor series expansion f could be approximated as:

$$f(p + \delta_p) \approx f(p) + J\delta_p \quad \text{..............................} \ (5)$$

where J is the Jacobian matrix, formed by the first partial derivative of f with respect to p i.e. $\partial f(p)\partial p$

A value of δ_p was sought in order to find an optimal parameter matrix p* which when applied to the function f resulted in a minimum error between observed and predicted values. The minimum occurred when $J\delta_p - \varepsilon$ was orthogonal to the column space of J, such that

$J^T(J\,\delta_p - \varepsilon) = 0$, where ε is the sum of errors between observed and estimated values and J^T is the transpose Jacobian matrix. This led to the normal equation $J^TJ\,\delta_p = J^T\varepsilon$.

However, the LM algorithm solved a variation of the normal equation, called the augmented normal equation (Equation 6).

$$N\delta_p = J^T\varepsilon \quad \text{..............................} \ (6)$$

N is a matrix whose off-diagonal elements are the same as J^TJ while the diagonal elements are given by $N_{ii} = \mu + [J^TJ]_{ii}$ for some $\mu > 0$. μ is termed as the damping term.

The LM algorithm was thus an iterative process where the damping term was increased or decreased in order to find δ_p that led to a reduction of the error (Lourakis, 2005). By use of the damping parameter, the algorithm used slow descent if the initial parameters given were far from the minimum, while there was quick convergence if initial parameters were close to the minimum. *Matlab* 6.1 was used to run the algorithm by calling the *lsqnonlin* subroutine.

Once the parameters from Equation 2 above had been determined, the half-maximum (and in this case, half-minimum) method of Fisher *et al.* (2007) and Fisher and Mustard (2007) was employed to discriminate the phenological stages. This involved determining the transition NDVI values by use of the potential maximum (parameter *c*) and background minimum (parameter *d*) as given in Equation 7 below.

$$Transition\ NDVI = \frac{c+d}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

By checking where the transition NDVI values lay within the fitted smoothed curves, different phenological stages were identified.

3.2.3. Relating the Identified Phenological Stages to Rainfall Patterns

NDVI values from the identified phenological stages were correlated, first with concurrent rainfall, and then with lagged rainfall (up to 6 dekads prior to the beginning of each stage). This lag period was in line with a study by Wang *et al.* (2003) who indicated that biweekly NDVI values were correlated with precipitation received in the preceding 2 to 4 biweekly periods. Lagged rainfall that had the highest positive correlation with NDVI at the different stages was noted. Standardized values of the correlated rainfall were then plotted on the same graph as standardized values of NDVI from the corresponding phenological stage. This was done to compare the temporal patterns of the resultant two curves.

3.2.4. Assessing the Spatial Pattern in Length of Growth Period

After the identification of transition dates using logistic functions, the length of each phenological stage was computed from the difference between the DOY corresponding to the starting and ending dekads. This was computed for each sample point within the study districts and for each year within the study period. The five year average for the length of the growth period was then computed. The average length of growth period values were plotted on maps of the districts using *ArcMap*.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents results from the analysis of data sampled in this study according to the methodology described in chapter three. A detailed discussion of these results is also presented.

4.1. Consistency of NDVI and RFE Data

Figures 7 a) to 7 c) show the double mass curves that were plotted to check for consistency of the extracted NDVI data over Kajiado, Garissa and Baringo districts.

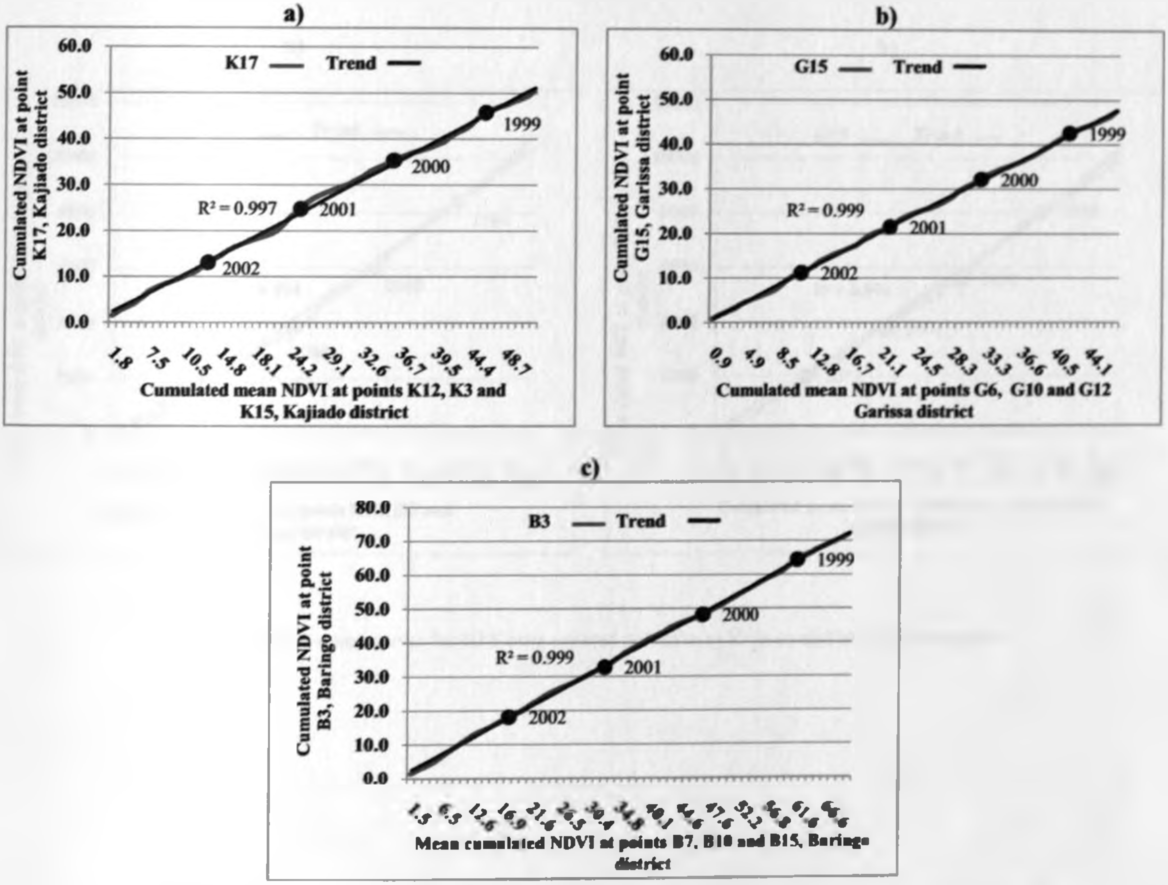

Figure 7: Double mass curves for NDVI over selected points in a) Kajiado, b) Garissa and c) Baringo districts.

Figures 7 a) to 7 c) show that curves of NDVI followed a near straight line, as seen from the linear trends. In each of the study districts, the linear trends had high values of r^2 (~0.99), meaning that the trends explained a large percentage of the variance in the NDVI data. Near linear NDVI curves implied that data extracted from different points in the three study districts was consistent, hence no adjustments were necessary. Consistency of the NDVI data was both in time (i.e. from one year to the next) and in space (i.e. from one point to another) over each of the study districts.

Double mass curves were also plotted to check for consistency of the extracted RFE data in Kajiado, Garissa and Baringo districts. These curves are shown in Figures 8 a) to 8 c).

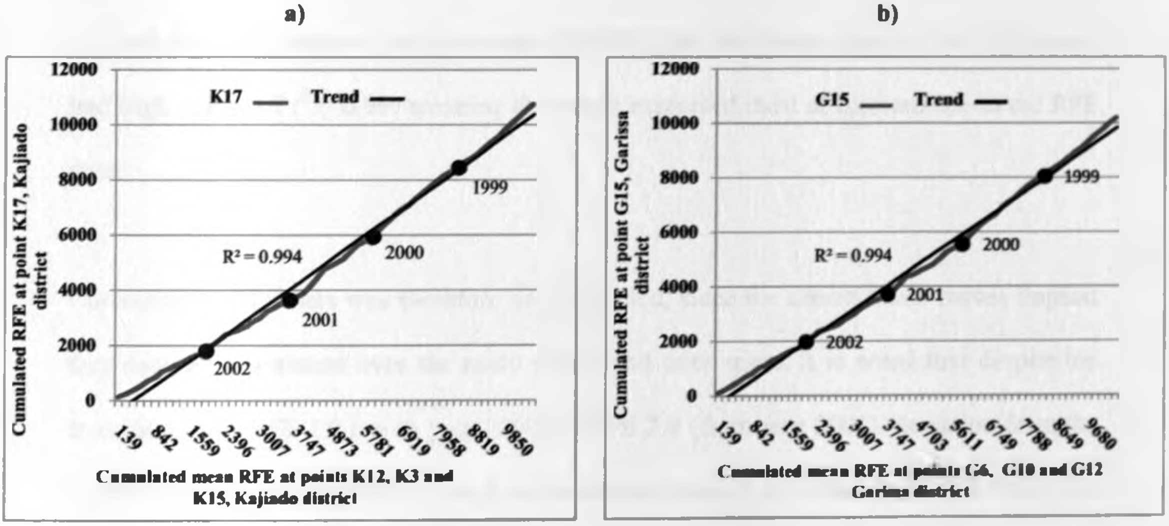

Figure 8: Double mass curves for RFE over selected points in a) Kajiado and b) Garissa districts.

c)

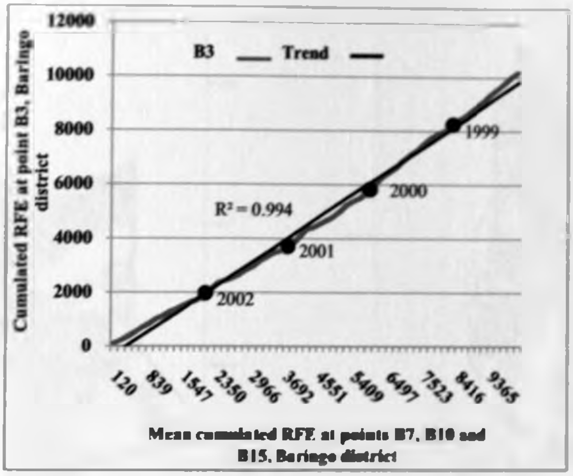

Figure 8c: Double mass curve for RFE over selected points in c) Baringo district.

The double mass curves for RFE data were also observed to follow an almost straight line over all the study districts. As in the case of NDVI data, the linear trends of the RFE curves had high values of r^2 (~0.99) meaning the trends explained most of the variance in the RFE data.

Correction of RFE data was therefore not conducted, since the almost linear curves implied that data was consistent over the study period and over space. It is noted that despite the transition from RFE 1.0 (up to year 2000) to RFE 2.0 (from year 2001), deviation from the linear trend was not significant enough to warrant adjustment, i.e. consistency of the data was still maintained.

4.2. Spatial Variability of NDVI

Figures 9 a) to 9 c) show the points in each study district where NDVI values were extracted, after an overlay with the land cover map of areas covered by grasslands.

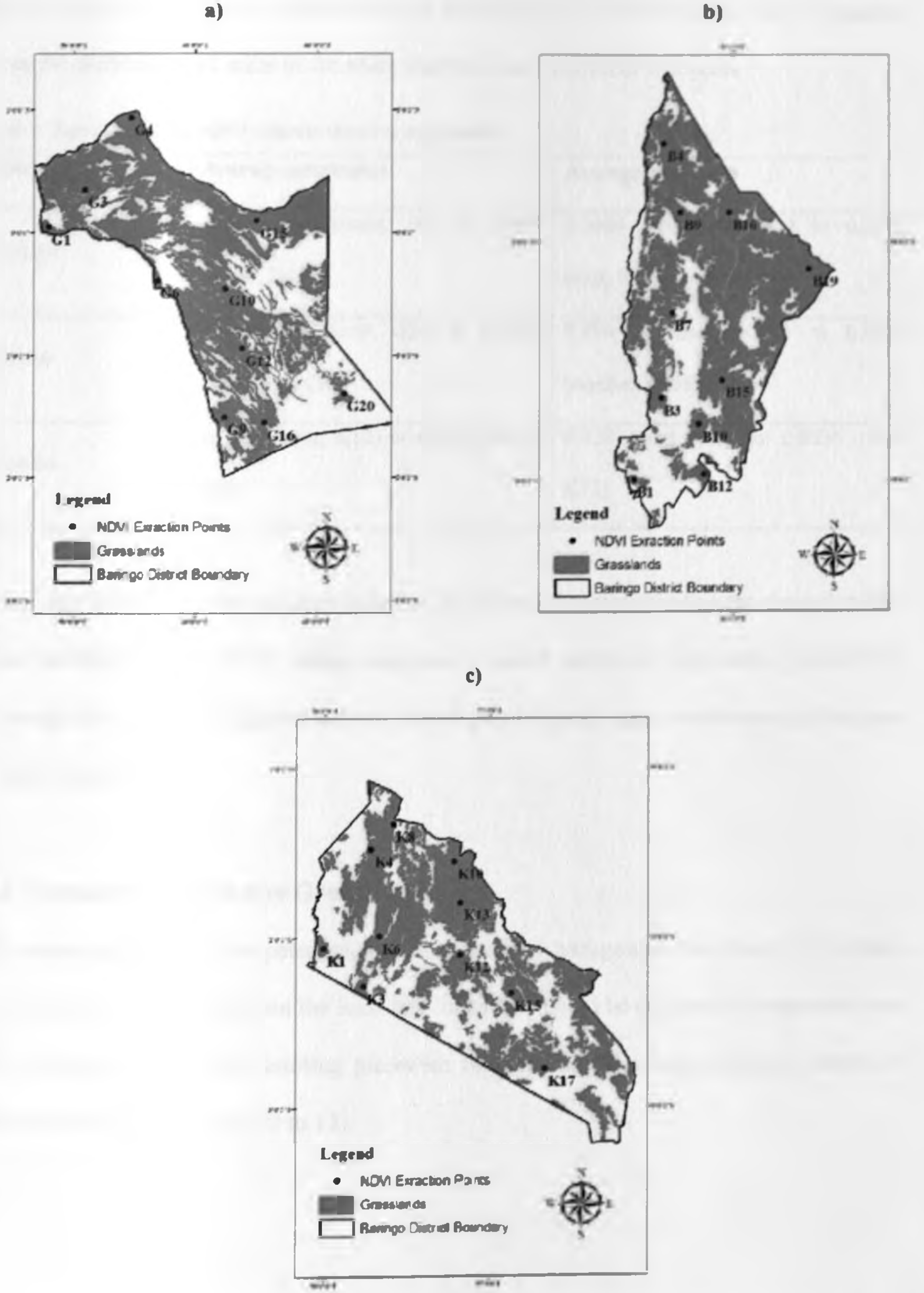

Figure 9: Points where NDVI was extracted in a) Garissa b) Baringo and c) Kajiado districts.

Table 2 below shows the average maximum and minimum NDVI values that were extracted from the different point areas in the study districts over a period of five years.

Table 2: Five year average NDVI values in the three study districts

District	Average maximum	Average minimum
Baringo	0.7328 (southwest, B1) to 0.484 (north, B4)	0.3064 (southwest, B1) to 0.1576 (east, B19)
Garissa	0.7064 (southeast, G20) to 0.2952 (northeast, G4)	0.184 (southeast, G20) to 0.0512 (northeast, G4)
Kajiado	0.6736 (east, K12) to 0.4992 (west, K6)	0.228 (west, K1) to 0.0936 (east, K13)

From this table, it is observed that values of NDVI varied spatially within the three districts. The variability in the NDVI values suggests a spatial pattern in vegetation productivity. Consequently, it was anticipated that the derived phenological stages would also exhibit some spatial pattern.

4.3. Phenological Stages over Grasslands

The initial guesses for the potential maximum and the background minimum lay between 0.01 and 0.6, which was within the boundary limits that would be expected for vegetation in a dry area (grassland). The resulting piecewise fitted logistic functions produced smoothed NDVI curves data (Figures 10 to 12).

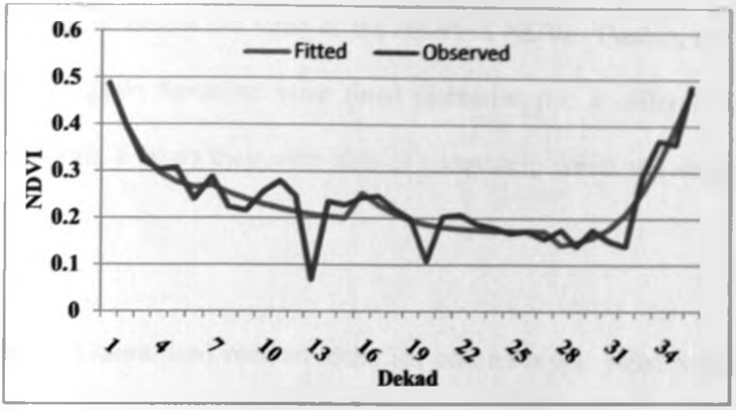

Figure 10: Observed and modelled NDVI curves in Kajiado, 2002

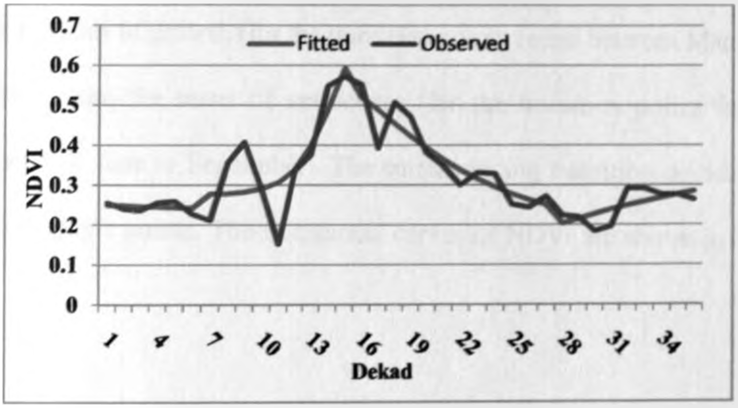

Figure 11: Observed and modelled NDVI curves in Baringo, 2002

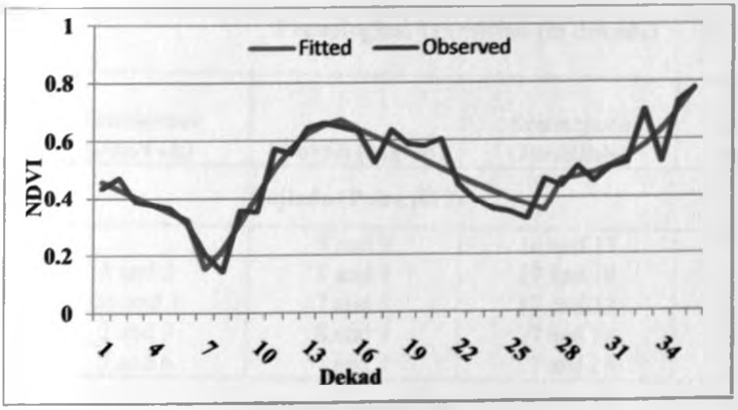

Figure 12: Observed and modelled NDVI curves in Garissa, 2002

These curves tended to follow the trend of the observed NDVI. Further, the Figures show that although the logistic functions were fitted piecewise (i.e. a different function for a different period within a year) they were able to adequately depict the annual NDVI time series.

The half-maximum (-minimum) method identified one transition point within each of the periods considered (January-February, March-May, June to September, and October-December). Phenological events identified by the transition NDVI values signified the onset of greenness or the start of growth (for the transition points found between March – May and October-December) and the onset of senescence (for the transition points found between January-February and June to September). The corresponding transition dekads are given in Table 3 for some sample points. The interannual curves of NDVI are shown in Figures 13 to 15.

Table 3: Dekads when transition between phenological stages occurred over some sample points in each study district. The points K17, G15 and B3 are as shown in figures 9c, 9a and 9b respectively.

Year	Phenological Transition (in dekads)			
	Senescence (Jan/Feb)	Growth (March)	Senescence (June/July)	Growth (November/ December)
	Kajiado (Point K17)			
1999		8 and 9	16 and 17	33 and 34
2000	2 and 3	8 and 9	17 and 18	33 and 34
2001	36 and 1	7 and 8	17 and 18	32 and 33
2002	2 and 3	8 and 9	17 and 18	33 and 34
2003	5 and 6	7 and 8	17 and 18	33 and 34
	Garissa (Point G15)			
1999	5 and 6	7 and 8	23 and 24	33 and 34
2000	3 and 4	8 and 9	20 and 21	33 and 34
2001	3 and 4	7 and 8	20 and 21	31 and 32
2002	5 and 6	11 and 12	18 and 19	29 and 30
2003	1 and 2	8 and 9	17 and 18	29 and 30

Year	**Phenological Transition (in dekads)**			
	Senescence (Jan/Feb)	**Growth (March)**	**Senescence (June/July)**	**Growth (November/ December)**
		Baringo (Point B3)		
1999	5 and 6	7 and 8	19 and 20	29 and 30
2000	4 and 5	14 and 15	17 and 18	31 and 32
2001	1 and 2	8 and 9	18 and 19	29 and 30
2002	2 and 3	12 and 13	27 and 28	32 and 33
2003	4 and 5	11 and 12	18 and 19	33 and 34

Results in Table 3 show that growth during the short rains season was detected to have consistently begun around dekad 33 (November) over the study period in Kajiado district. In Garissa district, the start of growth in the years 1999 and 2000 was found, on average, in dekad 33. Thereafter, there appears to have been a progressive shift toward an earlier occurrence of growth. An inter-annual cycle was observed in Baringo district between 1999 and 2002, where growth begun earlier in the season in one year then later in the next year.

During the long rains, growth began on average around dekad 8 (March) in Kajiado and Garissa districts. 2002 was, however, an anomalous year in Garissa district with growth starting in the middle of the season (i.e. in April). Much like in OND, growth in Baringo district occurred earlier in one year and later in the next.

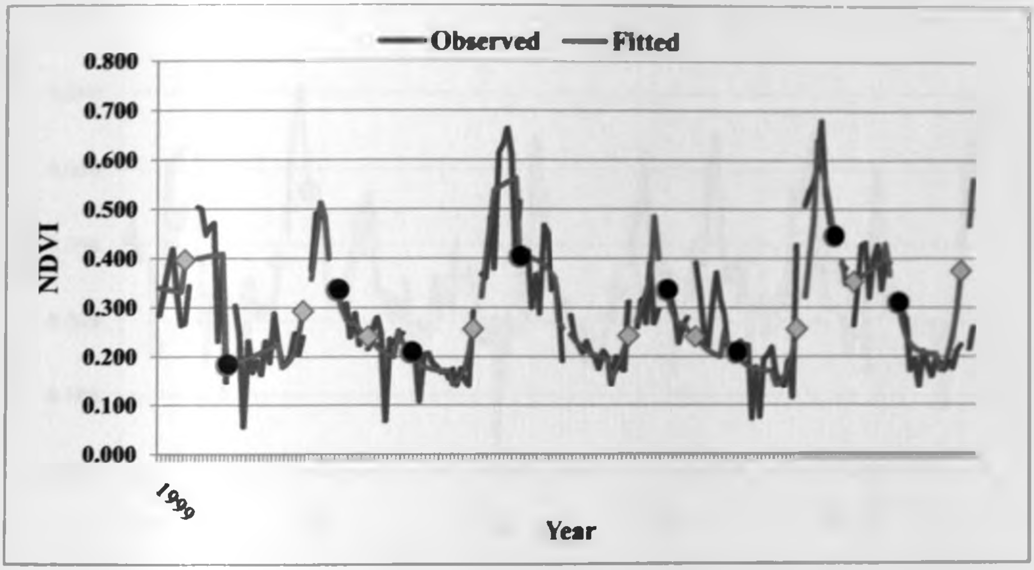

Figure 13: Inter-annual phenological stages in Kajiado (K17).◇Shows the onset of greenness, while● indicates the onset of senescence.

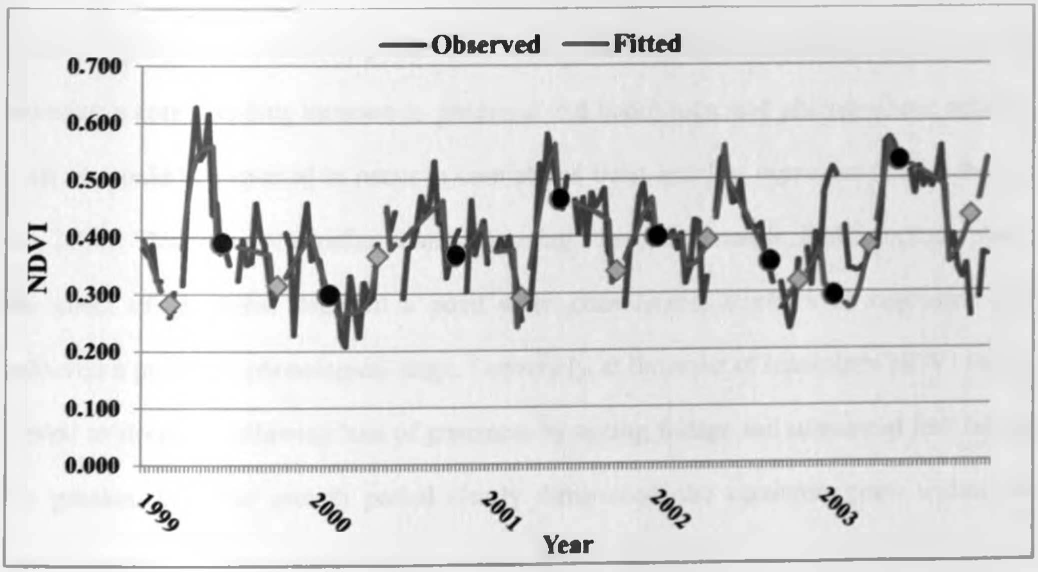

Figure 14: Inter-annual phenological stages in Baringo (B3).◇Shows the onset of greenness, while● indicates the onset of senescence.

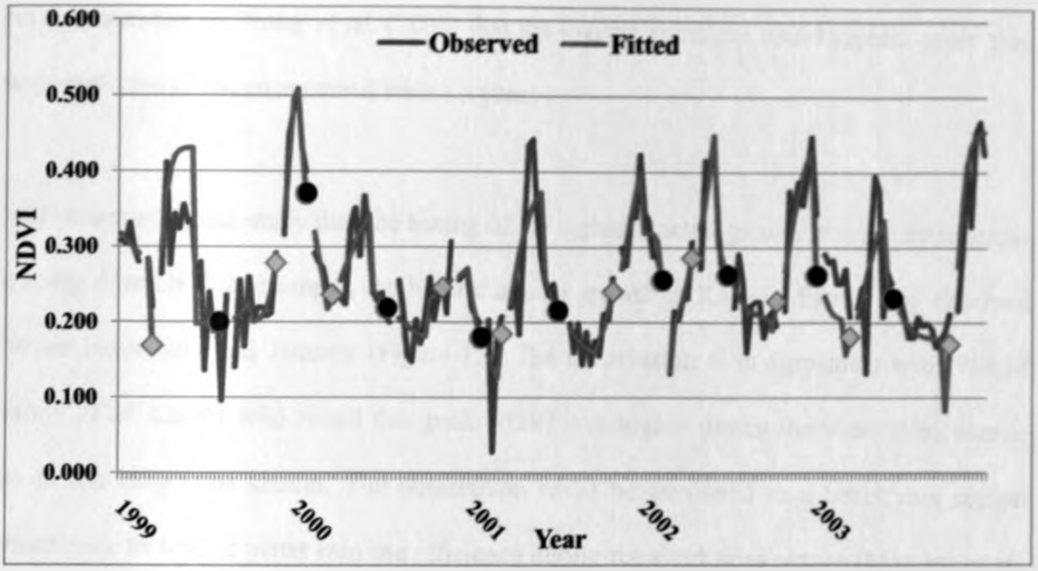

Figure 15: Interannual phenological stages in Garissa (G15). ◇Shows the onset of greenness, while ● indicates the onset of senescence.

Onset of greenness marked a point when there was persistent increase of NDVI values, meaning a corresponding increase in greenness and hence increased photosynthetic activity, such as would be expected to occur in case of bud burst and leaf expansion (Richardson *et al.*, 2006). This meant that rather than pinpointing when, for example, bud burst took place, the onset of greenness depicted a point when considerable numbers of vegetation had achieved a particular phenological stage. Conversely, at the onset of senescence NDVI values tended to decrease following loss of greenness by ageing foliage and substantial leaf fall by the grasses. With the growth period clearly demarcated, the maximum point within the growth period could reasonably imply maturity of the vegetation.

All the three study districts showed inter - annual patterns comprising of growth – senescence – growth – senescence. Two growth periods per year were, therefore, observed in the three districts i.e., between March and early June, and late November to January. This was in line with the assertion of Zhang *et al.* (2003) that the logistic functions could capture more than one growth and senescence period within a year.

It was observed in this study that the timing of the highest annual growth was different across the study districts. For example, the highest annual growth in Kajiado district was observed between November and January (Figure 13). The observation is in agreement with that of Martiny *et al.* (2006) who found that peak NDVI was higher during the short rains season than in the long rains season. The observation could be attributed to a better rain season performance as well as better rain use efficiency during the short rains season (Martiny *et al.*, 2006). For Baringo district, the highest annual NDVI peak occurred between March and May (Figure 14), while in Garissa district, the magnitude of NDVI in the two growth periods was comparable (Figure 15).

The shape of the curves (Figures 13 to 15 above) implied that growth and development of pastures appeared to occur more rapidly than the senescence phase, which was more gradual. The rapid growth of pastures suggests quick response of perennial grasses to the rainfall onset through breakage of their vegetative buds that survive throughout the year (Humphreys (1993). On the other hand, the gradual senescence of the perennial pastures would be due to their continued abstraction of soil moisture through their deep root systems long after the cessation of rainfall.

Length of the growing and senescence periods were determined from subsequent transition (onset) points as shown in Table 4 below.

Table 4: Annual length of phenological stages for some sample points in the study districts

Year	Length of phenological stages (in dekads)			
	Senescence (Jan/Feb)	Growth (March)	Senescence (June/July)	Growth (November/ December)
	Kajiado (Point K17)			
1999		8	17	5
2000	6	9	16	3
2001	7	10	15	6
2002	6	9	16	8
2003	2	10	16	5
	Garissa (Point G15)			
1999	2	16	10	6
2000	5	12	13	6
2001	4	13	11	10
2002	4	7	11	7
2003	7	9	12	
	Baringo (Point B3)			
1999	2	12	10	11
2000	10	3	14	6
2001	7	10	11	9
2002	10	15	5	8
2003	7	7	15	

It was observed that, in general, growth that began during the long rains (March-April-May, MAM) season extended over a longer period than that which began during the short rains (October-November-December, OND) season. On average, growth during the MAM season was longer than that during the OND season by 3 dekads in Kajiado district, 4 dekads in Garissa district and 1.5 dekads in Baringo district. The pronounced disparity in Kajiado and Garissa districts implied that the response of grasslands to rainfall received is season-dependent. For all the three study districts, the period of senescence that occurred between January and March was shorter than that during June-July-August-September (JJAS) period owing to the longer dry period in JJAS.

The five year average length of growing period during March - June and November - January are given in Tables 5 and 6 below.

Table 5: Five-year averages of the length of growing period between March and June, for different points in the study districts.

March – June					
Kajiado		**Baringo**		**Garissa**	
Point	Average length (Dekads)	Point	Average length (Dekads)	Point	Average length (Dekads)
K1	10.2	B1	10.4	G1	10.6
K3	8.4	B3	11.2	G3	6.8
K4	9.4	B4	8.6	G4	6
K6	9	B7	8.8	G6	8.8
K8	7.8	B9	7.6	G9	10
K10	9	B10	9.2	G10	9
K12	8.2	B12	7	G12	9.4
K13	9	B15	8	G15	11.4
K15	9.2	B16	7.8	G16	11.6
K17	9.2	B19	9	G20	12.2

Table 6: Five-year averages of the length of the growing period between November and January, for different points in the study districts.

November – January					
Kajiado		**Baringo**		**Garissa**	
Point	Average length (Dekads)	Point	Average length (Dekads)	Point	Average length (Dekads)
K1	7.25	B1	6.5	G1	7
K3	8.25	B3	8.5	G3	8.25
K4	6.25	B4	9.25	G4	6.25
K6	6.75	B7	8.25	G6	9.5
K8	7.75	B9	8.5	G9	8
K10	5.5	B10	8.25	G10	9.5
K12	7	B12	8.25	G12	8.25
K13	6	B15	9.25	G15	7.5
K15	8.25	B16	7.25	G16	9.5
K17	7.25	B19	7.75	G20	9.25

It is observed from Tables 5 and 6 that length of the growing period differed across the study districts, and between points within each district. These differences together with the dissimilarity of transition dekads (Table 3) are indicative of different pasture species with different maturation periods within a given season in the grasslands studied.

According to the dominant pasture species and their characteristics in the study districts (see Section 2.3) the pasture species observed to grow in Baringo between November and January (especially B3 to B15) could be *Eragrostis superba* or Acacia. The two species begin to grow around December for about 90 days i.e. 9 dekads. B1, B16 and B19 could be annual shrubs that respond quickly to the onset of rains but die off when the rains cease (Personal communication with District Livestock Production Officer, Baringo).

Between November and January, in Garissa district, vegetation at points G3, G6, G10, G12, G16 and G20 showed a length of growing period that could be associated with *Eragrostis superba*, *Aristida adscensionis*, *Balanites aegyptiaca* and *Acacia tortilis*. The other points could as well be annual plants with shorter life spans.

The length of growth period from November to January in Kajiado did not match the characteristics of perennial grass species found in the area, whose growth cycle takes longer than what was observed in this study. This may be a reflection of poor performance of the short rains, in which case vegetation observed to grow in the area are shrubs and forbs (Personal communication with Deputy Director, KARI Kiboko). The short-lived shrubs and forbs are therefore likely to have dominated the vegetation types of Kajiado district during the short rains.

It is expected that the pasture species that began growing in November in Baringo and Garissa district get into another growth cycle with the advent of the long rains in the month of March. According to Mnene *et al.* (1996), forage vegetation responds quickly to rainfall after a short dry season such as that experienced between January and March. Similar observation was made by Martiny *et al.* (2006) who found that the response of NDVI to rainfall was more rapid for the long rains. Hence the early start of the pasture growth cycle in March would imply the possibility of longer growth periods as suggested by the results of this study. The lengths of growing periods from March to June in Baringo and Garissa (Table 6) are therefore consistent with those of grass and tree species aforementioned in the November to January growth period. Point B3 in Baringo could also mean growth of *Cenchrus ciliaris*. For Kajiado, the length of the growing period in March to June is consistent with the characteristics of *Chloris roxburghiana* although as indicated above, the shrubs and forbs may also be present.

4.4. Relationship between Identified Phenological Stages and Rainfall

Table 7 below gives values of correlation coefficients obtained from correlating NDVI values for the various pasture phenological stages with concurrent and lagged rainfall values for the three study districts over a time period of five years.

Table 7: Coefficients that were obtained from the correlation between rainfall (at different lags) and NDVI (from different phenological stages), for some sample points in each of the study districts. ** indicate instances when the lag period exceeded 6 dekads.

Year	Senescence (Jan/Feb)	Growth (March)	Senescence (June/July)	Growth (November/ December)
Kajiado (K17)				
1999	lag6 0.47	lag4 0.61	lag2 0.36	lag1 0.82
2000	lag4 0.79	lag4 0.36	lag0 0.24	lag4 0.99
2001	lag6 *0.39	lag2 0.19	lag2 0.68	lag6 0.71
2002	lag4 0.47	lag3 0.69	lag3 0.59	lag3 0.47
2003		lag3 0.45	lag0 0.62	lag5 0.98
Baringo (B3)				
1999		lag5 0.39	lag3 0.32	lag2 0.36
2000	lag6 0.48	lag5 0.62	lag4 0.23	lag2 0.54
2001	lag5 0.44	lag5 0.40	lag6 0.42	lag3 0.88
2002	**lag9 0.52	lag6 0.35	lag3 0.90	**lag8 0.55
2003	lag1 0.55	lag6 0.65	lag0 0.28	lag4 0.89

Year	Senescence (Jan/Feb)	Growth (March)	Senescence (June/July)	Growth (November/ December)
Garissa (G15)				
1999		lag6 0.22	lag4 0.57	lag1 0.69
2000	lag6 0.63	lag6 0.60	lag2 0.37	lag2 0.91
2001	lag2 0.84	lag1 0.38	lag1 0.73	lag6 0.69
2002	lag4 0.67	lag4 0.61	**lag9 0.27	lag6 0.40
2003	**lag8 0.69	lag0 0.47	lag4 0.63	**lag9 0.73

Except in a few cases, the correlation coefficients between NDVI for the phenological stages and lagged rainfall up to 6 dekads prior to the phenological stages were statistically significant at $\alpha = 0.1$ (i.e. at 90% confidence level). This observation is consistent with the findings of previous studies that showed a delayed response of vegetation to rainfall over different time scales (Wang *et al.*, 2003; Martiny *et al.*, 2006; Camberlin *et al.*, 2007). In particular, Camberlin *et al.* (2007) found that on an annual scale, semi-arid areas in Africa showed high correlations between NDVI and rainfall.

With regard to the lagged relationships, the observed growth between March and June in Kajiado and Garissa districts was likely due to the contribution of the rainfall received in OND season as well as that received in MAM season, whereas the observed growth in Baringo district could have been in response to rains received in OND season. The observation that growth in March to June was influenced by rainfall in OND season suggests some dependence of this growing period to that in the November to January period. This follows from the fact that rainfall in OND season influences seed production during November to January period and enhances pasture reseeding in the MAM season. If the short rains season allowed a good amount of seed production, then the response to the long rains would not only be rapid but there would also be more germination occurring, which would translate into higher values of NDVI. However, this kind of relationship requires more detailed investigation in other studies.

The year to year differences in lags and correlation coefficients were indicative of a response of the phenological stages to inter-annual rainfall variability. Possibly, there is a pattern of rainfall amount which determines the lag of the phenological response as suggested by Mnene (2006). In a series of controlled trials, this author noted that higher germination of grasses occurred when watering was done every 2 – 3 days with an amount of 500 – 750ml, than when given 250ml of water daily. In relation to rainfall, it means that beginning of growth requires a sizeable rainfall amount that need not occur as frequently. This explains the long lags observed during the growth periods in this study.

Lagged rainfall that had the highest positive correlation with NDVI value of a phenological stage appeared to have a temporal pattern similar to that of NDVI for that phenological stage. This is depicted in Figures 16 to 24 below.

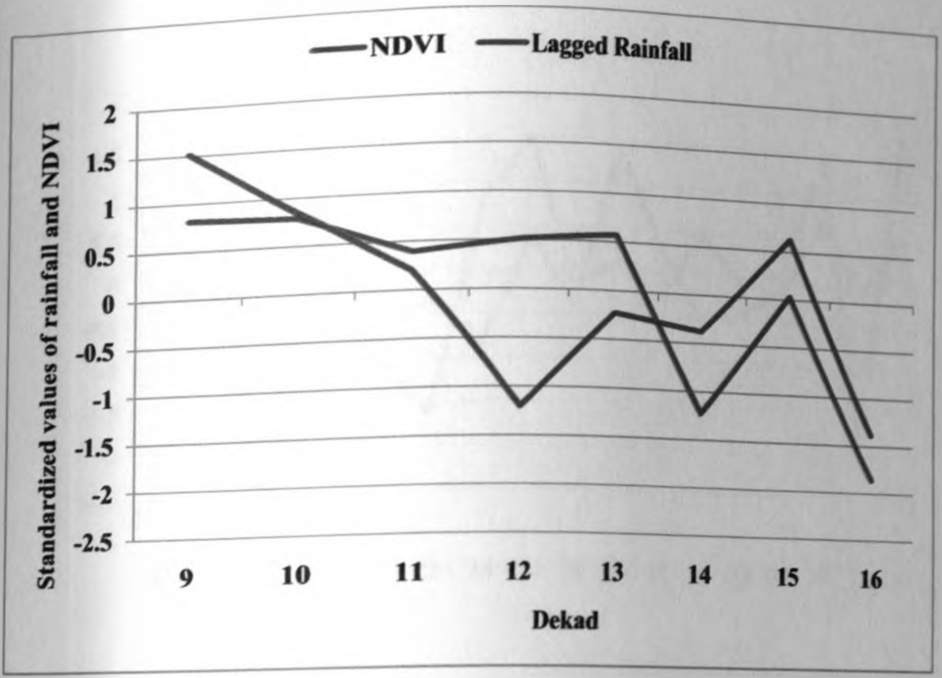

Figure 16: Curves of standardized values of NDVI and rainfall (lag4) in Kajiado district (point K17), during the March to June growing period, in 1999.

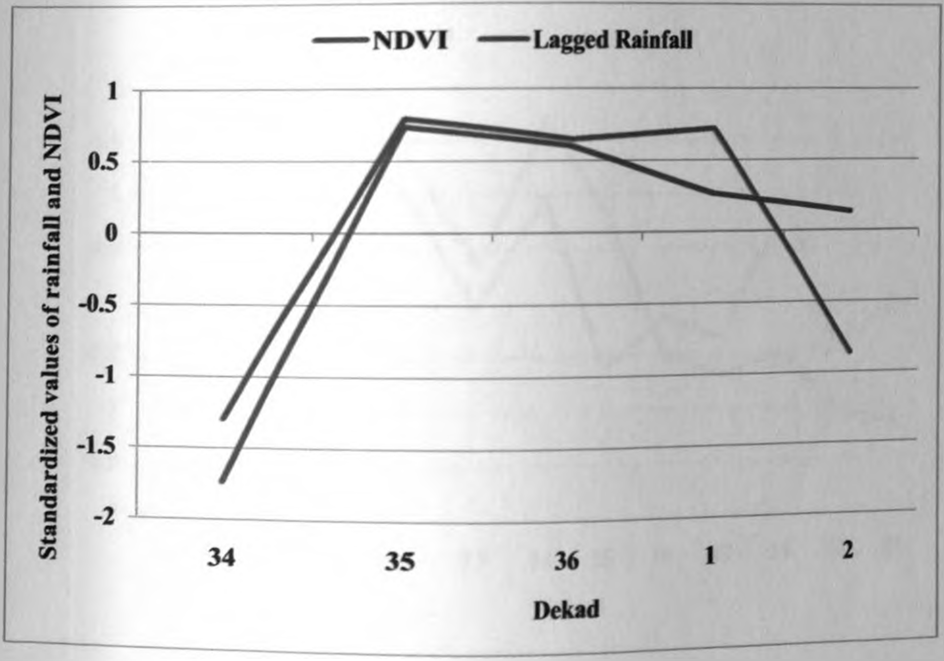

Figure 17: Curves of standardized values of NDVI and rainfall (lag1) in Kajiado district (point K17), during the December to January growing period, in 1999.

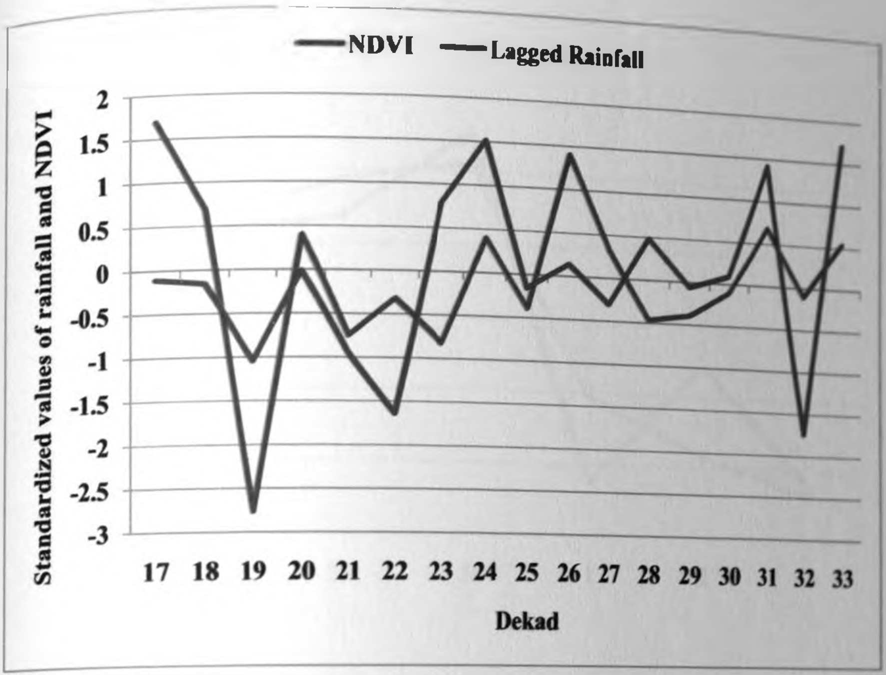

Figure 18: Curves of standardized values of NDVI and rainfall (lag2) in Kajiado district (point K17), during the June to September senescence period, in 1999.

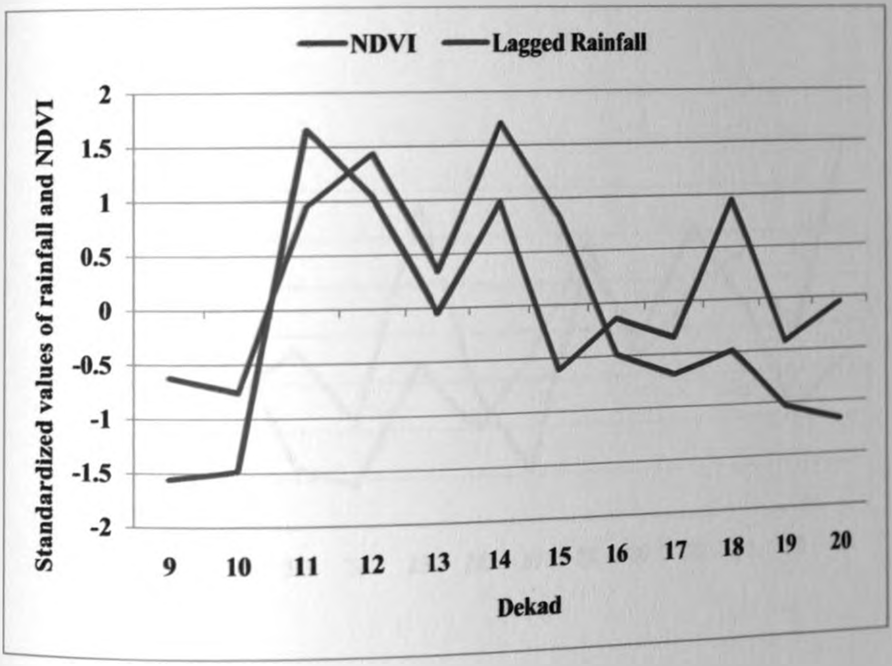

Figure 19: Curves of standardized values of NDVI and rainfall (lag6) in Garissa district (point G15), during the March to June growing period, in 2000.

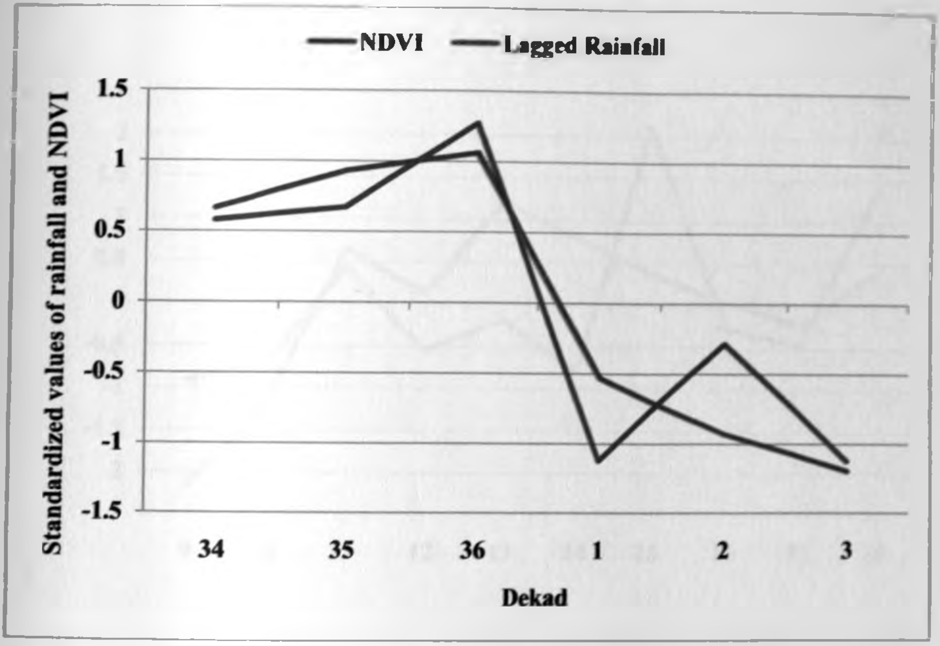

Figure 20: Curves of standardized values of NDVI and rainfall (lag2) in Garissa district (point G15), during the December to January growing period, in 2000.

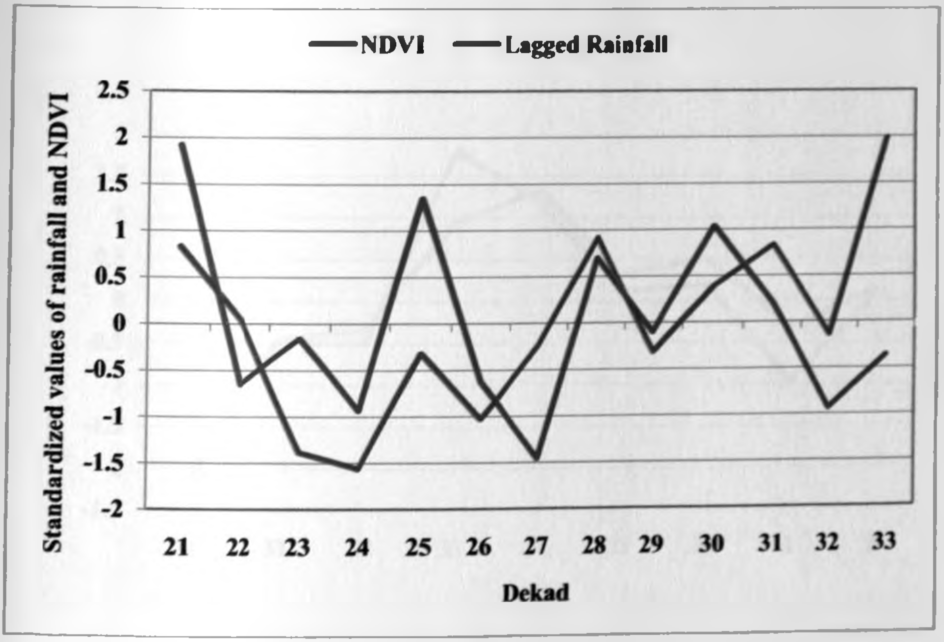

Figure 21: Curves of standardized values of NDVI and rainfall (lag2) in Garissa district (point G15), during the July to October senescence period, in 2000.

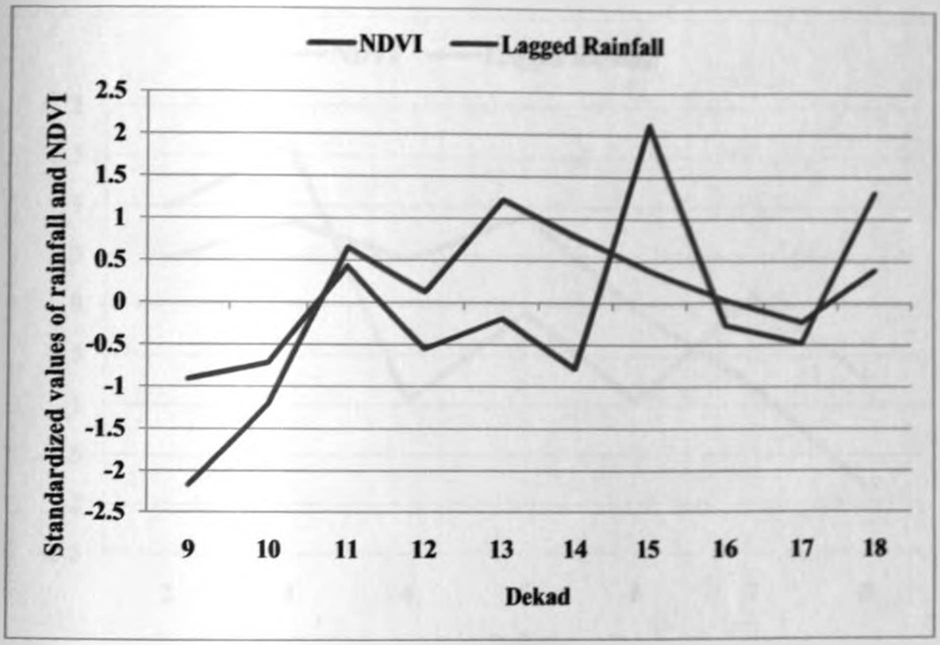

Figure 22: Curves of standardized values of NDVI and rainfall (lag5) in Baringo district (point B3), during the March to June growing period, in 2001.

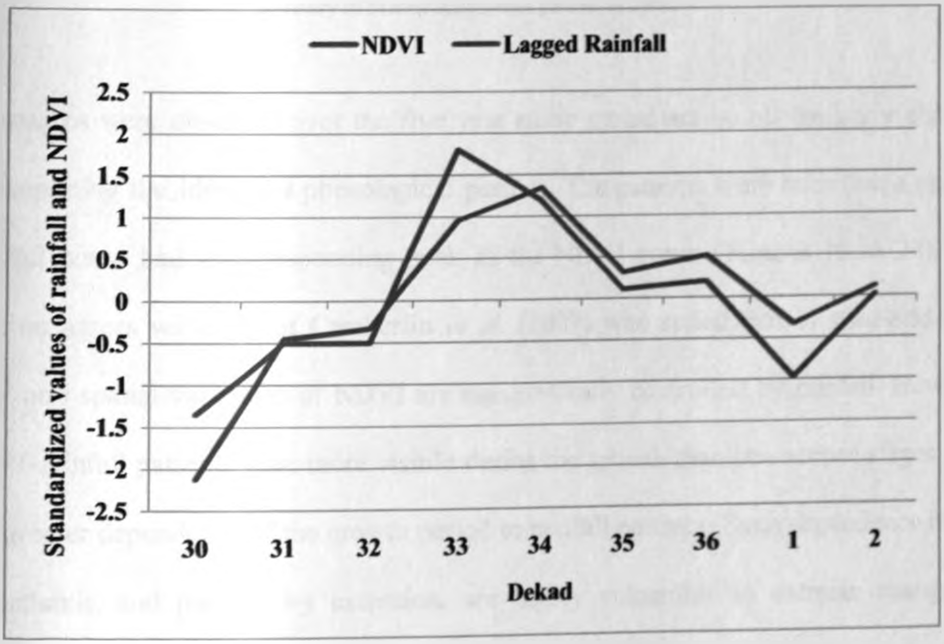

Figure 23: Curves of standardized values of NDVI and rainfall (lag3) in Baringo district (point B3), during the October to January growing period, in 2001.

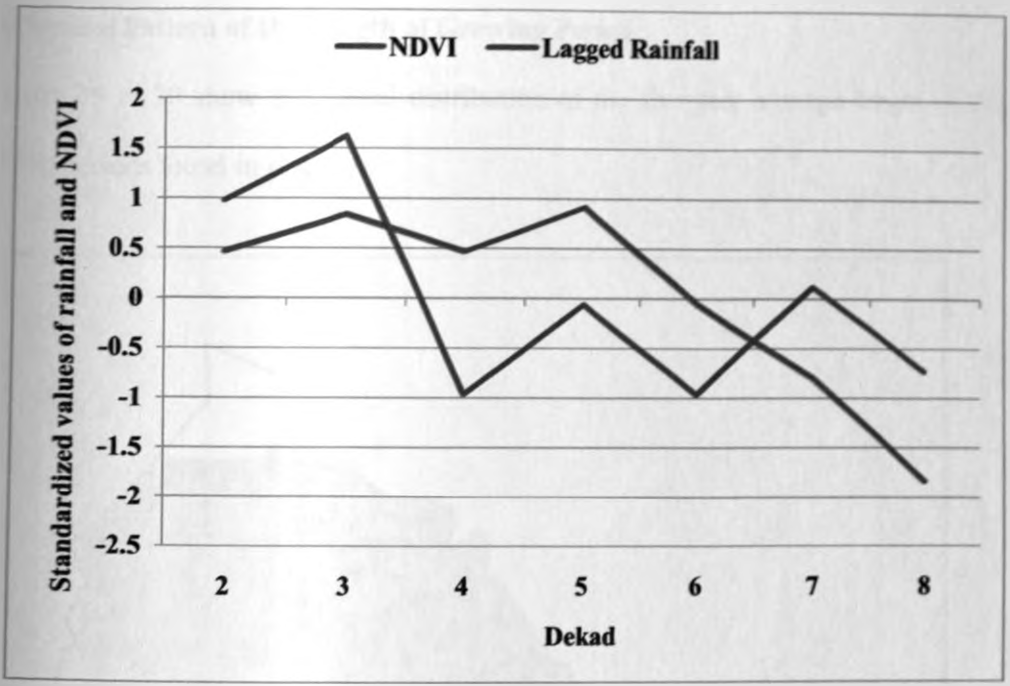

Figure 24: Curves of standardized values of NDVI and rainfall (lag5) in Baringo district (point B3), during the January to March senescence period, in 2001.

These patterns were observed over the five year study period across all the study districts, hence supporting the identified phenological periods. The patterns were such that a peak in the rainfall curve had a corresponding peak in the NDVI curve (Figures 16 to 24). This observation agrees with that of Camberlin *et al.* (2007) who stated that in semi-arid areas temporal and spatial variations of NDVI are unequivocally controlled by rainfall. However, the NDVI-rainfall patterns were more visible during the growth than senescence stages. This implies greater dependence of the growth period to rainfall patterns. Such dependence means that grasslands, and pasture, by extension, are highly vulnerable to extreme changes in rainfall. In addition, this observation supports the idea of the memory and recovery effect (Martiny *et al.*, 2005), which indicates that vegetation continues to benefit from a wet spell (memory effect) while it has difficulty in overcoming a dry spell (recovery effect).

4.5. Spatial Pattern of the Length of Growing Period

Figures 25 to 30 show the spatial distribution of the five-year average length of the two growth periods found in a year.

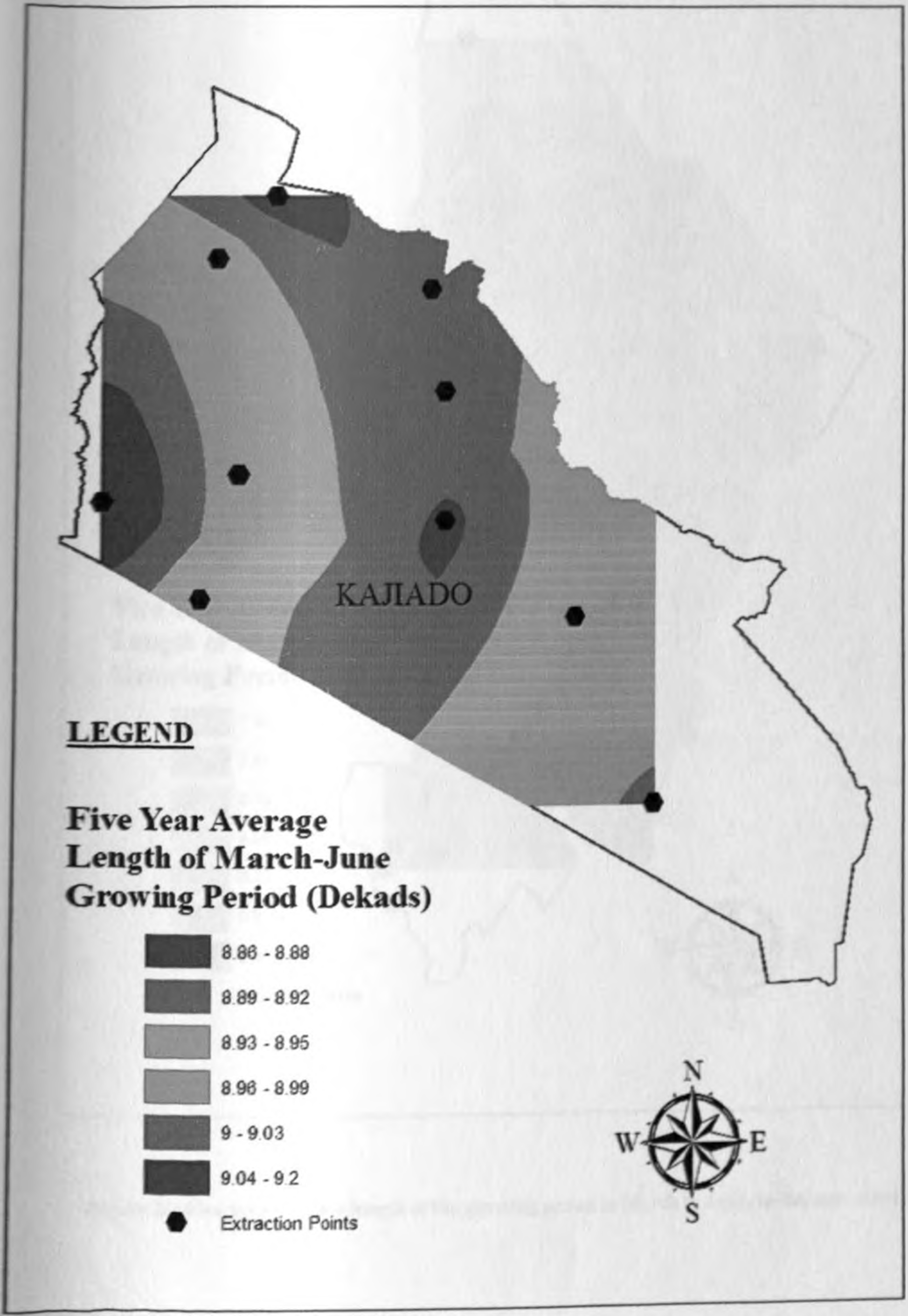

Figure 25: Five-year average length of the growing period in March to June, in Kajiado district.

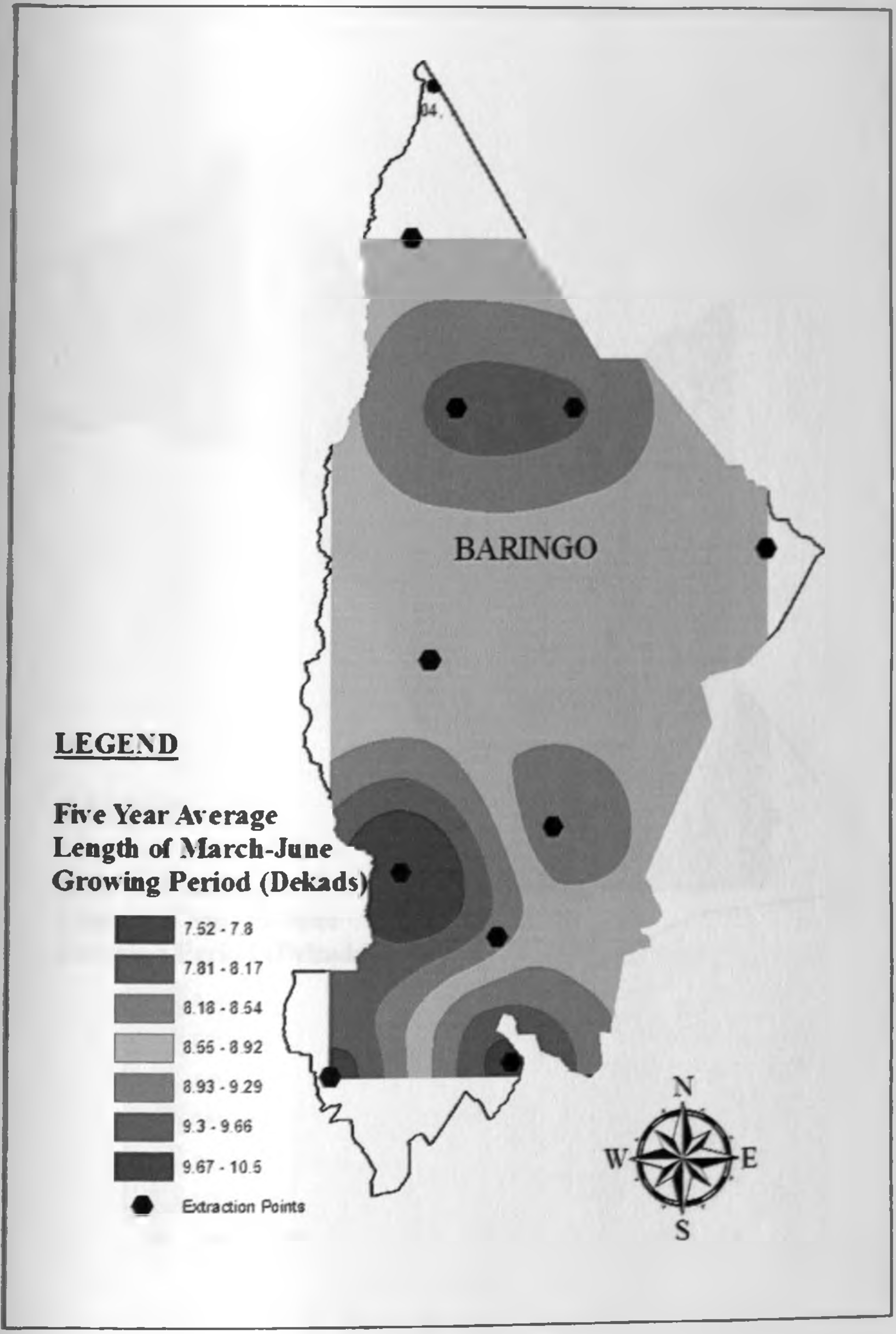

Figure 26: Five-year average length of the growing period in March to June, in Baringo district.

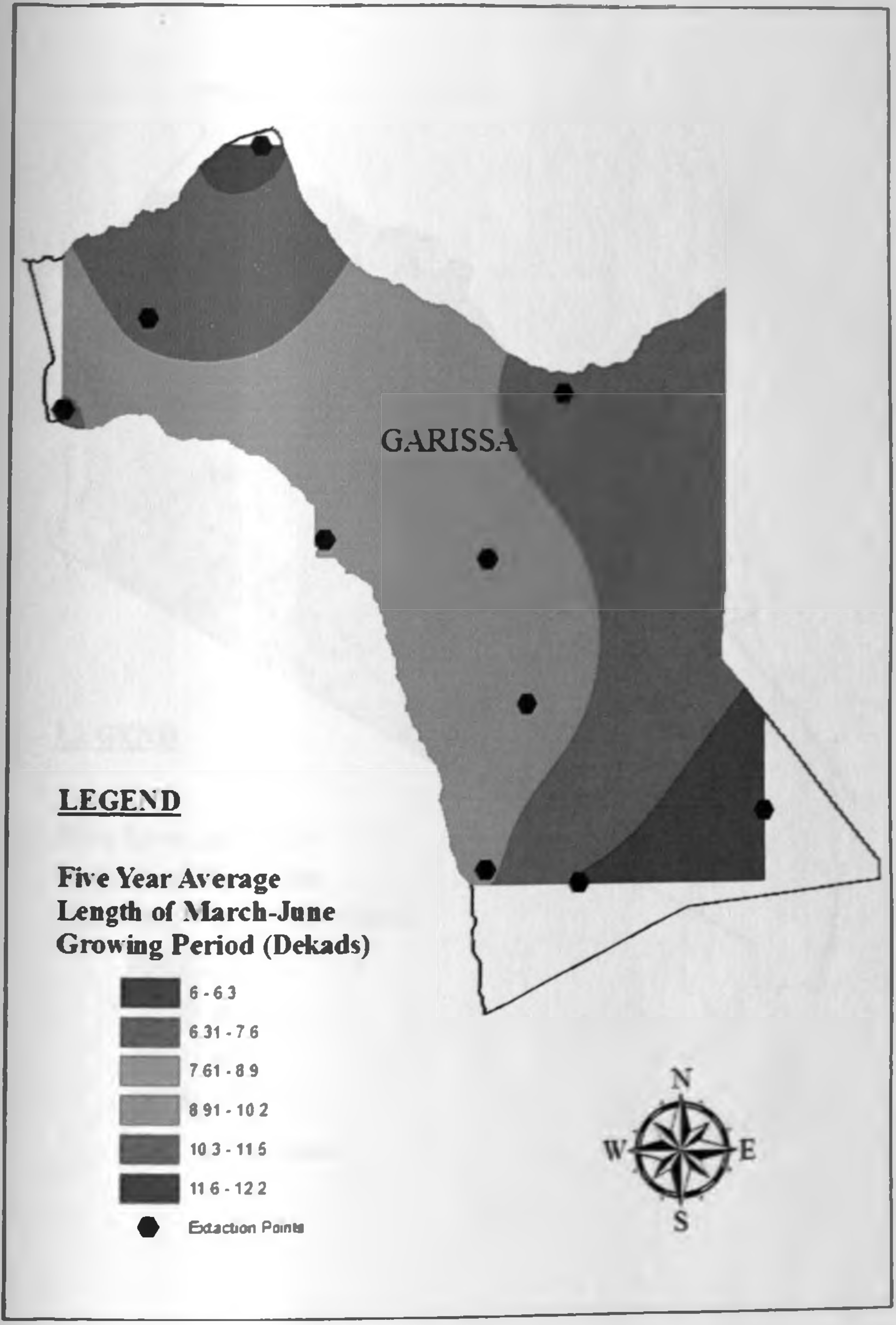

Figure 27: Five-year average length of the growing period in March to June, in Garissa district.

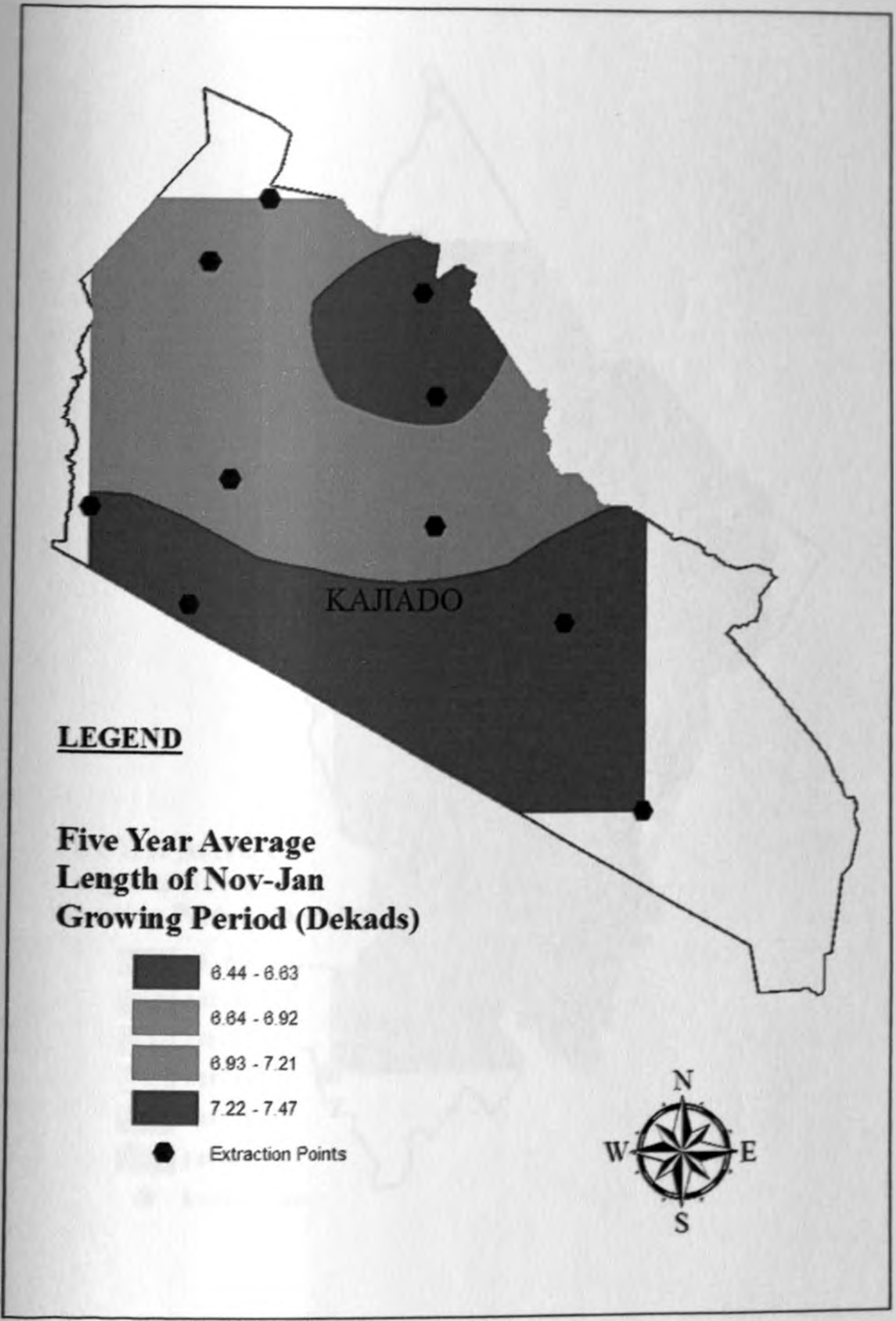

Figure 28: Five-year average length of the growing period in November to January, in Kajiado district.

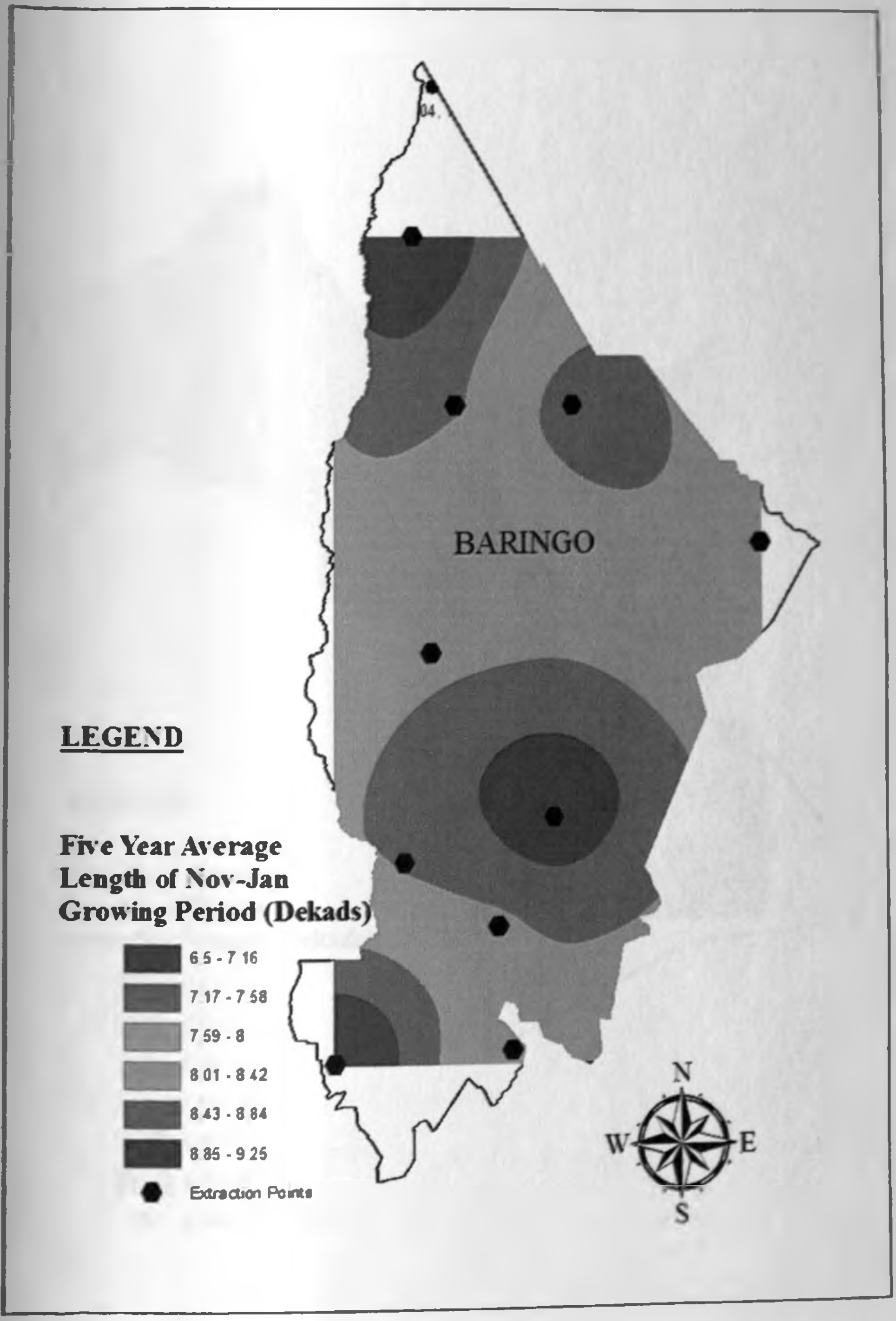

Figure 29: Five-year average length of the growing period in November to January, in Baringo district.

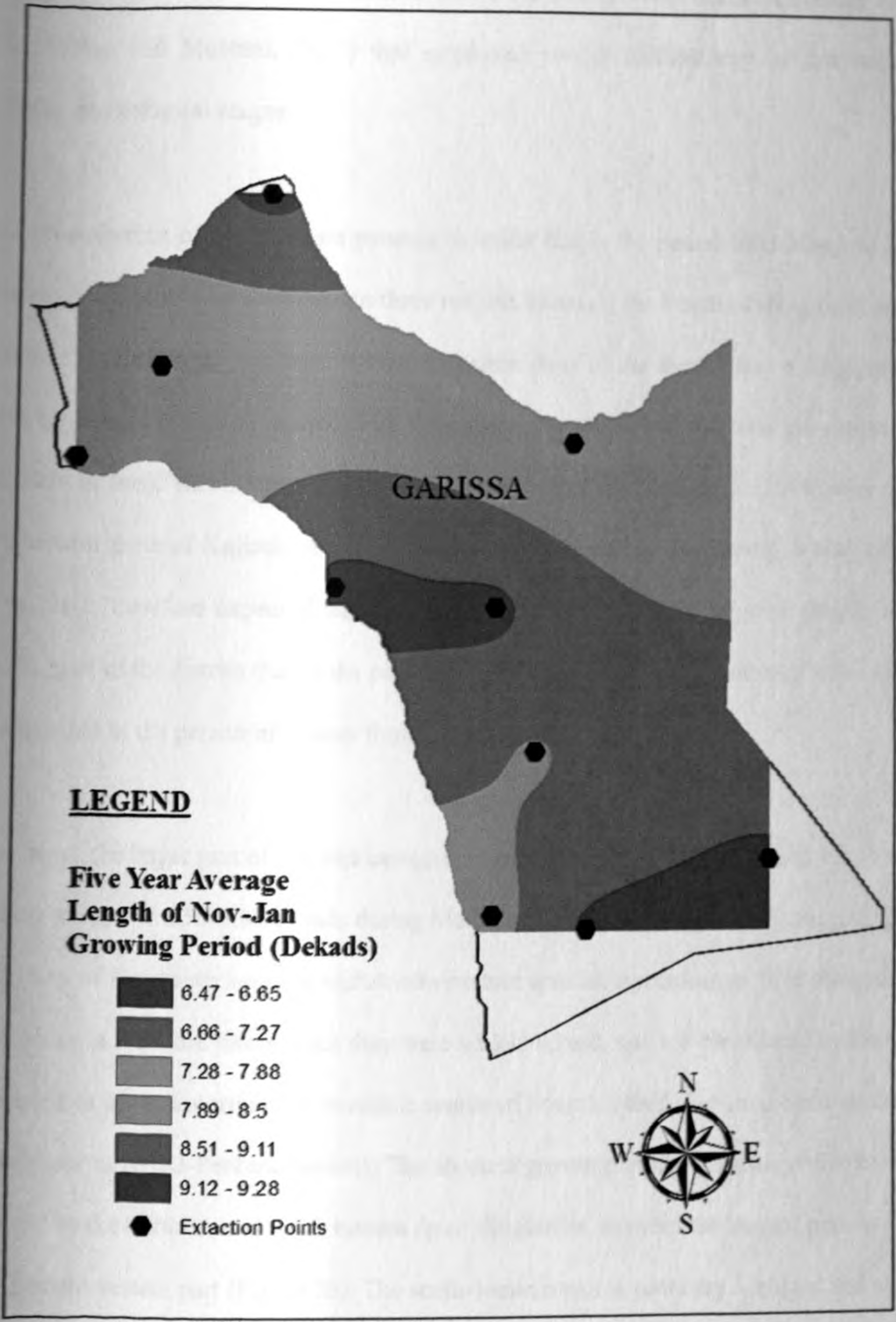

Figure 30: Five-year average length of the growing period in November to January, in Garissa district

From these figures, the lengths of both growing seasons (March to June and November to January) exhibited spatially coherent patterns, which seemed to gradually change from one part of a district to another. This observation agrees with previous researches (Zhang *et al.*, 2003; Fisher and Mustard, 2007) that employed similar methodology as this study in detecting phenological stages.

Close examination of the resultant patterns revealed that in the period from March to June, Kajiado district could be divided into three regions based on the length of the growth period (Figure 25) wherein the western and south-eastern parts of the district had a long growing season (9 dekads or more), separated by a central region which had a shorter growing season (8 dekads or less). This observation is in agreement with that of de Leeuw (1991), who noted that western parts of Kajiado receives much of its rains during the March to May rainfall season. It is therefore expected that this rainfall would translate in to good growth in the western part of the district during the period, supplying the necessary amount of water for the development of the perennial grasses found in the area.

In Baringo, the larger part of the area categorized as pastoral (Figure 2 in Section 1.4.1) had a growing period of 8.55-8.92 dekads during March to June season (Figure 26), suggesting the possibility of *Eragrostis superba* and *Acacia* pasture species. According to field observations made, *Acacia* are more likely since they were widely spread, and are considered by the local communities as an important and available source of livestock feed (Personal communication with officer at KARI-Perkera Station). The shortest growth periods in Baringo district were observed to the northern and south eastern tip of the district, whereas the longest periods were to the south-western part (Figure 26). The south-western part is generally highland and would receive relatively good rainfall hence accounting for the longer growth periods observed. This is further supported by the agro-pastoral and farming practises that are carried out in that area (Figure 2).

Garissa district had a length of growing period that increased from north-western (shortest) to north-eastern and southern (longest) part of the district during the March to June season (Figure 27). The areas with a longer growing season support the presence of perennial grasses and shrubs/trees that are found in the district (refer to Section 1.4.2).

The November to January period in Kajiado district showed that the shortest growth season occurred in the north-eastern part of the district, and it increased towards the north-western and southern parts of the district (Figure 28). Such a pattern divided the district into two regions rather than the three observed during March to June period. Contrary to the whole of eastern Kajiado district receiving good rains in OND (de Leeuw *et al.*, 1991), this growth pattern suggests that a favourable amount is experienced in only the southern part.

In Baringo district, north-eastern and south-western parts of the district had the shortest growing seasons whereas the longest periods were to the north-western and south-eastern parts (Figure 29). Most of the pastoral area had length of growth period between 8.01 and 8.84 dekads, again suggesting the presence of *Acacia*. Comparison of this pattern with that observed in the March to June season (Figure 26) revealed that the duration of pasture availability remained the same during the two seasons although the spatial coverage changed slightly. The seasonal differences in spatial availability of pasture imply that grazing patterns would be from north to central and southern parts of the district during the short rains. In the long rains, there would be a concentration of livestock in the northern and southern parts of the district.

For Garissa district, the spatial spread of the length of growing period between November and January (Figure 30) was very similar to the March to June season (Figure Figure 27). It can be inferred that livestock migration in Garissa district would be from North West to South East during March to June season and from north to south in the November to January season.

Comparison of these spatial patterns with those of rainfall would probably give an adequate explanation of the results. The identified patterns can be indicative of the possible direction of pastoral community migration following availability of pasture; for example north to south in Garissa district (as seen in Figures 27 and 30). The areas where there is likely to be a concentration of livestock due to pasture can also be deduced and a possible alert of possible conflicts over the access and use of the pasture resources.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.0 Summary and Conclusions

This study focused on determining phenological stages of pasture using satellite data. The use of a land cover map restricted NDVI extracted for the study to areas categorized as grasslands. Logistic functions were used to generate smoothed curves of the NDVI time series from which transitions between phenological stages were determined. The functions were able to demarcate phenological stages for the whole study period and over all the study districts. This was through the presentation of clear growth-senescence inter-annual patterns. Further, these growth-senescence patterns were related to and followed the same pattern as lagged rainfall. The function-determined lengths of growing periods were also found to be consistent with growth of various grasses and browse species within the study districts. On a spatial scale, the length of both growth periods was seen to exhibit coherent patterns.

Consistency of the identified phenological stages with vegetation in the study districts and with the temporal patterns of lagged rainfall, together with the spatially coherent patterns of the growth period led to the conclusion that logistic functions are able to model grassland phenological stages in the ASALs. Such patterns are useful indicators of the growth cycle and spatial distribution of pasture, and how the pasture cycles and distributions change over time.

This information can be used by policy makers to develop strategies for aiding pastoral communities to delineate and preserve pasture. This is especially true because setting aside pasture for dry periods is already recognized as an important coping strategy for pastoral communities (Mundy, 2004). Hence, strengthening the pastoralists' capability to reserve pasture areas would not only be readily acceptable to these communities, but would also enhance their resilience. Another desirable quality of the information generated would be in formulating a spatial plan for alleviating land degradation by allowing known areas to rest and regenerate. These results, when used together with climate information, can be easily incorporated into guidelines for sustainable pasture management in the ASALs of Kenya.

5.1. Recommendations for Future Work

This study yielded interesting information that could guide ASAL management and utilization of pastures to avoid land degradation and community conflicts over access and use of pasture. However, further detailed investigations are needed to fine-tune the advisories to the stakeholders in the ASALs as follows:

1. Find out how the March to June growing season is related to the November to December growing season, and specifically what the relationship means in terms of NDVI values.
2. Use a longer time series of NDVI data and more sampling points across the study districts to ascertain the spatial patterns of the lengths of growing periods.
3. Compare *in situ* data and model generated patterns in order to validate the model results.

5.2. Advisory for Pasture Utilization

Results of this study have revealed several practical implications which lead to the following advisories for pasture management in the fragile ASAL areas of Kenya for both policy makers and user communities.

1. Information generated on the timing of onset of greenness and senescence, together with the spatial patterns of the length of growing seasons could be used by the local community as well as the relevant government institutions in management of pasture.

This information would also inform proper demarcation of pasture areas and control when they are used.

2. The ministry of livestock could use the generated spatial patterns of the length of pasture growing seasons to track the migration of livestock, with a view to controlling the spread of livestock diseases due to movement in search of pasture.
3. The Kenya Meteorological Department and other institutions engaged in seasonal prediction of rainfall should use the lagged response of grassland phenological stages to rainfall to advise ASAL communities on the availability of pasture. Preparedness following this information would likely lead to improved income from livestock production and improved community livelihood.

Acknowledgment

Foremost, I thank the Almighty God for taking me this far and being my source of strength, life and health. Gratitude goes to the University of Nairobi for awarding me a scholarship to pursue my M.Sc. degree studies. I wish to express my appreciation to the following people. My supervisors: Dr. Ouma for his encouragement, support and advice right from the initial idea to the final product; Mr. Lukorito for your valuable help in designing and conducting the field work part of this project as well as his advice and support in developing the write up. Many thanks to the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) for the support they extended to me to enable me carry out the field work component of this study.

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Assessment of differentiation of vegetation composition and structure of dry and moist intermediate zones in Imenti forest, Mt. Kenya ecosystem

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July, 2011

Declaration

I, Cornelius M. Matingi, hereby declare that this is my original work and has not been presented for a degree in any other university to the best of my knowledge.

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Dedication

This thesis is dedicated to my dear wife, Benedettah Ndinda; and my children, Annet Mbeke and Adrian Matingi. Your inspiration, encouragement and moral support drove me during the whole period of my study.

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Abstract

Forests in East Africa occur in lowland and upland areas with some recognized as worlds' biodiversity hotspots. The moist and dry intermediate forest types occur on the eastern side of Mt. Kenya forest. Mt. Kenya forest ecosystems represent nearly 20% of the natural forests remaining in Kenya and consist of Ngare Ndare and Imenti forests. The World Agroforestry Centre has produced an improved and revised version of vegetation map for Mt. Kenya forest ecosystem. The revised map was mainly based on the earlier version by Trapnell and colleagues. However, the accuracy of revised map had not been tested. The aim of the study was to determine vegetation floristics and physiognomy of dry and moist intermediate vegetation types. Four field surveys were made from October 2009 to January 2010.The mapped vegetation boundary of the moist and dry forests was marked using Map source software and then loaded into Garmin map60CSX GPS. Quadrats of 40 x 40 m were established at intervals of 500 m in the five sampling sites identified in each vegetation type. Species composition was documented by recording all individual trees with DBH $\geq$ 5cm and height $\geq$5 m in the quadrats. A 10 x10 m sub-quadrat was randomly selected from the 40 x 40 m quadrat to record saplings with height in between 1m and <5 m. A 4 x 100 m belt transect was used to record species composition in each forest for the development of profile diagrams. Ordination analysis was used to compare similarity in species composition. One-way ANOVA was used to test for difference in the mean values among the sites. Two sample t and z tests were used to compare mean differences of the tree densities, DBH and heights. Shannon-Wiener diversity index was used to compare species diversity of the two forests. Vegetation structure of the forests was compared by use of histograms computed from various DBH (stem) and height size classes. A total of 104 species were recorded in both forests. Similarity in species composition for moist and dry forests was found to be low as it was clearly separated. Shannon-Wiener diversity index and tree density were not significantly different ($p>0.05$) between the moist and dry forests. A sub-set of 20 characteristic species was recorded based on Trapnell checklist. Species abundance patterns of the two forests assumed an inverse J-shaped distribution as majority of the species occurred in smaller DBH class sizes. The important value indices showed that *Cordia africana* and *Olea europaea* were dominant species in moist and dry forest respectively. The accuracy of the revised vegetation map for Imenti section of Mt. Kenya ecosystem was found to be correct. A study on the lower plants is important for future monitoring of the forests while re-forestation efforts should be enhanced to restore the forests. Surveillance needs to be improved to curb illegal logging and charcoal burning.

Key words: Forest structure, species diversity, moist and dry forests and Mt. Kenya ecosystem

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
DBH	Diameter at Breast Height
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GPS	Global Positioning System
ICRAF	World Agroforestry Centre
ITCZ	Inter-tropical Convergence Zone
IUCN	International Union for Conservation of Nature
IVI	Importance Value Index
KFS	Kenya Forest Service
KWS	Kenya Wildlife Service
NMK	National Museums of Kenya
UNESCO	United Nations Educational, Scientific and Cultural Organization
VECEA	Vegetation and Climate Change in Eastern Africa

CHAPTER ONE

1.0 INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

The main forest types in East Africa are the lowland and upland (montane) types with their arbitrary boundary occurring at 1350m asl (above sea level) (Lind and Morrison, 1974). The Montane forest ecoregion occur in high altitude patches along a chain of isolated mountain ranges (Coe, 1967). The mountains stretch from their northern extent in southern Sudan, through Mt. Elgon in Kenya/Uganda, Aberdares Range to Mt. Kenya in Kenya, Mt. Kilimanjaro, Usambara and Meru in Tanzania (Chege and Bytebier, 2005; Bussmann, 2001).

There are, however many small outliers and isolated low mountains within the region such as Kulal, Nyiru, Bukkol, Hanang and Mbulu among others (Bagine, 1998). Forest ecosystems of East African have high species diversity with some listed as worlds' biodiversity hotspots (Myers *et al.,* 2000). The high diversity is mainly attributed to stable environmental conditions in the region and their long evolutionary period (Chege and Bytebier, 2005).

The Mt. Kenya forest ecosystem represents nearly 20% of the natural forests remaining in Kenya (Bussmann and Sigrun, 1999). However, this forest like other forest ecosystems in the country has been severely disturbed due to anthropogenic activities. According to Gathara (1999), some of the major threats to the Mt. Kenya forest ecosystem include; charcoal production, fire occurrences, illegal grazing of livestock, encroachment and logging of indigenous trees. The most targeted indigenous species for logging are *Ocotea usambarensis*, *Juniperus procera*, *Olea europeae*, *Hagenia abyssinica* and *Premna maxima* (Gathara, 1999). The continued destruction of forests has caused reduced water supplies, loss of biodiversity and resource conflicts in many regions (Gete and Hans, 2001).

Kenya's forest cover is currently below 2% of the total land surface of the country, far much below the recommended United Nations Environment Programe cover of 10% (Hitimana *et al.*, 2004). According to Kindt *et al.* (2007) and Trapnell (1997), most of the original indigenous forests in Kenya have been lost. There are only few remnants and secondary rather than primary vegetation is the most common. Moreover, impacts associated with climate change remain the major threat to the tropical forest ecosystems and their biodiversity (Colwell *et al.*, 2008; Bernard *et al.*, 2005; Kruss and Stefan, 1987).

This study was part of a larger project being carried out by Forest and Landscape Denmark and the World Agroforestry Centre (ICRAF) and entitled "Vegetation and Climate Change in Eastern Africa (VECEA)". The main aim of the project was to revise old vegetation maps and produce new digital ones in order to monitor variation of natural vegetation due to changes in land use systems and climate in several eastern African countries. These countries, include Ethiopia, Kenya, Uganda, Tanzania, Rwanda, Malawi and Zambia.

The project has produced a potential natural vegetation map for the seven target countries. In Kenya, the map builds on vegetation maps produced White (1983) and (Trapnell and Brunt, 1987). The maps and the species database are intended to be developed into a decision support tool that will assist in selecting suitable trees species for specific areas based on tree function.

However, the accuracy of the new maps has not been field tested by establishing the characteristic trees species and composition of the various zones of the mapped vegetation. It is on this basis the current study on vegetation composition and structure of moist and dry intermediate forest types of Imenti forest was conducted. Imenti forest contains the only remnants on the eastern side of Mt. Kenya of the moist and dry intermediate forest types that have been occasioned by forest excision (Sjöberg and Swenson, 1990).

According to Kindt *et al.* (2007) and Gathara (1999) most of the natural forests on the eastern parts of Mt. Kenya have been cleared for agricultural activities. In some sections encroachment almost reaches the bamboo zone. Therefore, based on characteristic species of the two forest types, as mentioned in Trapnell field notes of 1957-1964, it would give an opportunity to re-examine the current vegetation status of the two forest types. Imenti forest which is part of larger Mt. Kenya forest ecosystem is managed by Kenya Forest Service (KFS).

1.2 Literature review

1.2.1 Forest structure

According to FAO (2001) a forest is a stand of trees with canopy cover of more than 10% and has a height of 5 m or more. Natural forests have both vertical and horizontal structures. The vertical stratification depends on life form of the plant species, sizes and branching patterns (Wang *et al.*, 2003). Vertical stratification of most tropical forests consists of distinct strata that vary from one to several strata or canopies owing to presence of different species (Hitimana *et al.*, 2004; Takyu *et al.*, 2002). The strata are formed when species continue to grow laterally after attaining their mature heights. However, the diversity of life is influenced by the leaf density which is dependent on availability of vertical gradient of light (Wang *et al.,* 2003). Vegetation survey in Imenti forest by Sjöberg and Swenson (1990) observed between two to three strata in the moist and dry forest respectively.

Horizontal structure of vegetation across landscapes and ecosystems is as a result of species patchiness (Takyu *et al.,* 2002) owing to differences in plant reproduction patterns and timing (Vandik and Birks, 2002). Species dispersed by wind and animals tend to have a continuous distribution along the landscapes. However, vegetative reproducing plants tend to occur in distinctive clumps of homogenous environment (Lind and Morrison, 1974). Therefore, horizontal structure of vegetation can be used to establish change in species composition over landscapes (Llyod *et al*., 2002).

1.2.2 Forests species diversity and composition

Species diversity is an important concept of biodiversity as it has been used to measure species numbers in different habitats (Primack, 2006). The key components of diversity are species richness, evenness and abundances Myers *et al.* (*2000*). Communities with more species are considered to be more diverse and tend to occur within the tropical regions. Diversity indices provide information that is important in understanding community structure and composition (Lulekal *et al*., 2008). According to (Myers *et al.,* 2000) distinct geographic patterns of plant species diversity are important in prioritizing and initiating conservation measures in various ecosystems.

In montane forest ranges, numerous gradually blended habitats are common where animal species from different communities interact regularly (Camarero *et al*., 2006; Grab *et al.,* 2004).

For instance, tropical forest communities have a diverse vertical stratification that support high numbers of forest specialist bird species (Bennun and Njoroge, 1999). According to Wassie *et al.* (2009) forest patches are also significant habits for mammal species. They have a narrow spatial extent with steep ecological gradient thus retaining high species richness (Lloyd *et al.*, 2000).

1.2.3 Vegetation succession and environmental factors

According to the Clementian vegetation succession theory, when climax plant communities are disturbed, they would follow a sequential pattern to retain their original status (Bussmann and Sigrun, 1999). The community would therefore be made of distinct populations regarding to temporal dynamics. On the other hand, Gleason viewed vegetation spatial heterogeneous patterns as component of individual species responding to spatial gradients in the environment (Turner, 1989).

Ordination analyses are essential for investigating species composition and floristic distance (Okasan and Minchin, 1997; Ogutu, 1996). Abrupt discontinuities in vegetation patterns are normally associated with changes in the physical environment and disturbances (Wassie *et al.*, 2009). Structural equation models of factors determining plant species density in a gradient landscape also show that vegetation distribution is directly correlated to environmental changes (Skinner *et al.*, 2001; Gough and James, 1999).

Nevertheless, the greatest challenge is to understand how environmental factors influence plant community structure well enough to predict the response of communities to the changing environmental conditions (Vandik and Birk, 2002; Gough *et al.*, 1994). This is because there is little agreement as to what environmental variables are necessary to categorize species diversity models across different communities and ecosystems (Colwell *et al.,* 2008; Lulekal *et al*., 2008).

Forest ecosystem dynamics involves interactions of both biotic and abiotic factors which maintain their biodiversity (Lulekal *et al*., 2008; Diez and Pulliam, 2007). Soils provide anchorage, water and nutrients to plant communities for primary production enhancing ecosystem productivity and stability (Elmendorf and Kara, 2007; Bush 2003). However, the soil physical condition is more important in influencing the distribution of forest types, their structures and floristic composition than chemical characteristics (Diamantopoulos *et al.,* 1994). For instance, Musila *et al.* (2009) observed that soil pH, texture, phosphorus and carbon are strongly related to altitudinal vegetation distribution in Sirimon and Chogoria areas of Mt. Kenya forest. Therefore, spatial patterns of climax vegetation reflect localized intersections of species responding to complex environmental gradients (Fuhrer, 2000).

1.2.4 Human and natural impact on forest ecosystems

Disturbance is an important component of many tropical forest ecosystems (Hitimana *et al*., 2004; Gete and Hans, 2001). Variations in disturbance regime affect forest community structure, composition and functioning (Tracy *et al*., 2007), thus maintaining species diversity or encouraging invasions (Hooper, 1998; Hobbs, 1996). According to Petraitis *et al.* (1989) "disturbance is the process that alters the birth and death rates of individuals present in a patch by affecting resource levels and natural enemies in a way that alters survival and fecundity".

Ecosystem disturbances are caused by natural and anthropogenic factors such as fires, herbivory, floods, droughts, diseases and nutrients inputs among others (Tracy *et al*., 2007; Hoft and

Martina, 1995). Disturbances associated with climate change such as increases in wild fires, floods and severe droughts threaten forest ecosystems (Tracy *et al.*, 2007). They destabilize the existing equilibrium making the communities not to return to their original status (Hobbs, 1992) and cause recolonization (Martin *et al.,* 2007). On Mt. Kenya, wild forest fires are responsible for removing thick litter layer altering micro-climate and soil nutrient content which favours regeneration of species like *Juniperus procera* (Bussmann and Sigrun, 1999).

Impacts of climate change are on the increase and will intensify desertification (Colwell *et al.*, 2008), reduce precipitation and increase evapotranspiration (Bachelet *et al.,* 2001). Ecological changes in response to climate change will occur at global level (Bernard *et al.,* 2005), with the signals being detected remarkably in tropical forest fragments (Martin *et al.,* 2007). According to Lamb *et al.* (2003), the genera *Ocotea* and *Podocarpus* on Mt. Kenya forest have shown cyclic patterns of increase and decrease due to change in rainfall over the years.

More importantly, overexploitation of forest resources remains a major challenge in tropical forest ecosystems. Unsustainable utilization will further increase habitat and biodiversity losses (Busing and Fujimori, 2002; Ney-Nifle and Marc, 2000; Raven, 1998). In this case, forest ecosystems remain important units for monitoring effects of climate change, anthropogenic stresses and subsequent plant adaptation (Colwell *et al.,* 2008; Clark, 2007).

Ecosystems have been noted to maintain highest species diversity at moderate perturbations than at low or high perturbations (Hobbs, 1992) as species gradually and continually adapt (Petraitis *et al.,* 1989). For instance, herbivores act as seed dispersal agents, cause nutrients recycling and open up tropical forests (Hobbs, 1996; Hoft and Martina, 1995). These result into distribution and regeneration of various species associated with disturbances within different ecosystems.

The response of any given community to disturbance is determined by the adaptive attributes of the component species (Martin *et al.,* 2007). However, disturbance frequencies, intensities, scale and timing are major factors that determine the rate of ecosystem degradation (Hobbs, 1992). This is because disturbances act primarily by affecting the availability of suitable microsites and invasive organisms (Tobias and Gertrud, 2006; Vandik and Birks, 2002).

1.2.5 Vegetation classification of Mt. Kenya ecosystem

The Mt. Kenya forest ecosystem is the most studied mountain ecosystem in the East Africa region compared to others such as Mt. Kilimanjaro, Elgon and Ruwenzori Bussmann and Beck (1995). Vegetation classification has been based on altitudinal changes, physiognomy and floristics characteristics (Bussmann, 2001; Speck, 1982). The ecosystem has three distinct belts of major vegetation types that include montane forest, ericaceous and alpine zones.

However, using the species composition, four major ecological zones were recognized, namely moist montane, moist intermediate, dry montane and dry intermediate (Trapnell and Griffiths, 1960). The moist and dry intermediate zones occur between the lowland forests and at altitude below 2000m above sea level. This classification is preferred as most structure and species composition of upland forests are mainly associated with rainfall and relief (Hayashi *et al.*, 2006)

The floristic method groups vegetation communities into classes, order, alliances and associations with emphasis on each individual species (Bussmann and Beck, 1999; Schmitt, 1991). However, a finer classification may be based on species composition with a detailed study of the communities covering frequency, dominance and density (Musila *et al.*, 2009; Agnew, 1985).

The physiognomic method is based on vertical stratification, growth form of vegetation and physical appearance to subdivide vegetation types into component communities (Smith and Thomas, 2001). The method is useful for naming and delineating communities over large areas (Grubb *et al.*, 1963). For instance, dominant species have been used to describe forest on Mt. Kenya such as *Croton Sylvaticus-Calodendrum-Juniperus* community zone (Gathara, 1999).

Vegetation description work by Bussmann and Beck (1999) identified over twenty two vegetation units on Mt. Kenya based on syntaxonomical ranking. However, species check list notes by Trapnell (from 1957 - 1964) have been used to identify characteristic species for each vegetation zone. For instance, *Lovoa swynnertonii*, *Trichilia emetica, Cordia africana* are among characteristic species of moist intermediate while *Uvariodendron anisatum, Calodendrum capense, Teclea simplicifolia* are for dry intermediate Trapnell (1997). However, due to wildlife and human disturbances species composition within various ecological zones could have changed over time thus affecting characteristic species (Ojany, 1993).

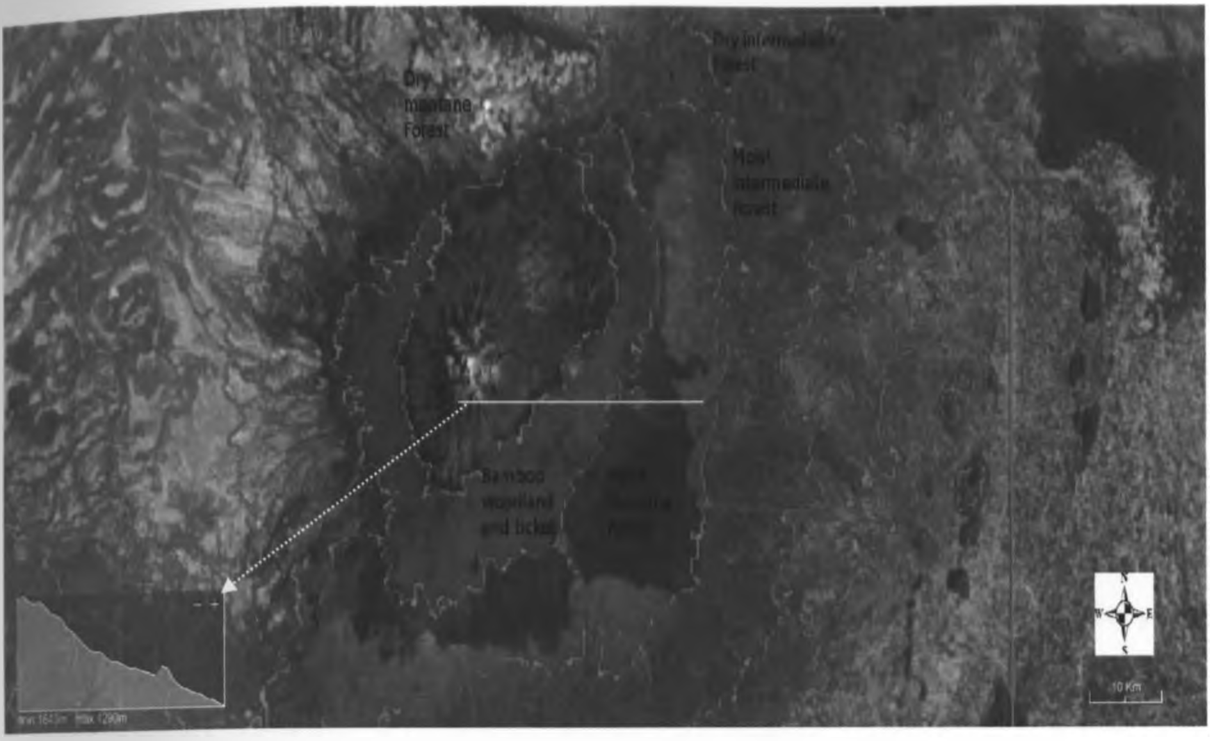

Figure 1: Map showing the generalized potential natural vegetation types on Mt.Kenya (http://ti.arc.nasa.gov/projects/worldwind/).

1.2.6 Importance of forest ecosystems

Forest ecosystems are providers of goods and services at local and global levels with the benefits being direct or indirect. Direct benefits of forests are mainly associated with monetary benefits acquired from forest resources such as timber products, medicinal materials, rubber and fuel wood among others. Indirect benefits are mainly the ecosystems services offered such as climate modifiers, carbon sinks, habitats for wildlife and aesthetic values (Watson, 2008). Both the direct and indirect forest benefits are important for promoting sustainable development of economies of many countries.

The Mt. Kenya forest is an important water tower in Kenya and a source of Tana River that supports a number of hydropower stations and irrigation schemes (Akotsi *et al.*, 2006; Gichuki, 1999). Apart from the cultural values attributed to the forest ecosystem by local communities, it also provides them with firewood, timber, grazing grounds and domestic water among others (Ojany, 1993).

The Mt. Kenya forest has diverse wildlife habitats due to the broad range in altitude and rainfall pattern thus supporting a rich biological diversity (Bussmann, 1994). The ecosystem is gazetted as a UNESCO heritage site due to its diverse habitats illustrating numerous ecological processes (Akotsi *et al.*, 2006; Bussmann, 1999). The aesthetic landscape associated with Mt. Kenya is a valuable asset for sustaining the tourism industry and scientific research.

In the recent past, forests have started to be regarded as important resources for counter balancing the effects of climate change. Forest ecosystems tend to serve as sinks for absorbing atmospheric carbon dioxide and condensing suspended particles thereby checking global warming and environmental pollution (Bachelet *et al.*, 2001; FAO, 2001). Forest ecosystems are also important in moderating climatic patterns of many landscapes where they occur (Watson, 2008).

1.2.7 Problem statement and significance of the study

There is very little climax forest available in Kenya due to human encroachment and unsustainable utilization (Bussmann and Beck, 1995). Therefore, most of the original dominants have been replaced by degraded forests types contributing to loss of biodiversity. According to Trapnell (1997), the emergence of dense secondary undergrowth has also slowed the successful regenerations of most of the disturbed indigenous forest. Therefore, the historical vegetation maps of (White, 1983; Trapnell, 1966) might not show the current vegetation distribution patterns of the Mt. Kenya forest ecosystem given decades have elapsed since they were constructed.

In order to capture the present scenario, the VECEA project has revised these vegetation maps and species database for the Mt. Kenya ecosystem, which are intended to be developed into a decision support tool. The database would assist in selecting suitable trees species for specific areas and particular tree function. Moreover, show variation in natural vegetation and compare to variation in climate and current land use (Kindt *et al.*, 2007). However, the accuracy of the revised maps had not been tested by establishing the presence of characteristic species within the different remnants of mapped vegetation zones.

Data generated from the study would be useful for testing the accuracy and nature of mapped vegetation types in the area under study by the VECEA project. The baseline information generated would assist policy makers, conservationists and forest managers in decision making towards initiating conservation measures by prioritizing the threatened and right species. If the revised vegetations maps and species databases are found to be correct, it would increase confidence in their usage by the local and global communities.

1.3 Objectives

1.3.1 Main objective

The overall aim of the study was to determine differences in vegetation floristics and physiognomy between dry and moist intermediate forest sections of Imenti forest in the Mt. Kenya ecosystem.

1.3.2 Specific objectives

The specific objectives included the following

1. To check the accuracy of the potential natural vegetation map developed by the VECEA project for the area covered by Imenti forest
2. To document vegetation composition of moist and dry forests of Imenti forest
3. To establish vegetation structure of dry and moist forests of Imenti forest

1.3.3 General hypothesis

There was no difference in species composition of moist and dry intermediate vegetation types.

CHAPTER TWO

2.0 MATERIALS AND METHODS

2.1 Study area

2.1.1 Location

The Mt. Kenya forest ecosystem is located on 0° 10' S, 37° 20' E and is about 180km north of Nairobi on the eastern side of the Great Rift Valley (Figure 2). Mt. Kenya is of volcanic origin where majority of the eruptions occurred in the lower and middle Pleistocene (Speck, 1982). The bulk of the area is covered with forests reaching up to approximately 3400m in the South and 3000m in the North. Due to the wide range of altitude that spans the indigenous forest (from 1200 to 3400m) and major climatic differences between the slopes, the forest vegetation of Mt. Kenya is characterized by high diversity of forest types (Coe, 1967). The Mt. Kenya forest ecosystem consists of Imenti and Ngare Ndare forests fragments.

The Imenti forest is divided into two sections; lower and upper Imenti. According to Mr. Anabiu (Meru District Forest Officer, personal comm.) the two sections comprise approximately 1,800 and 6,000 hectares respectively. The Upper Imenti forest contains a small portion of moist and dry intermediate zone with larger portion occupied by moist montane, bamboo, moorland zones and Mt. Kenya National Park. It is in the lower Imenti forest where the largest part of the moist and dry intermediate forests occurs. According to Sjöberg and Swenson (1990), the sudden change in vegetation in the Imenti forest could be attributed to decrease in rainfall and variation in soil structure.

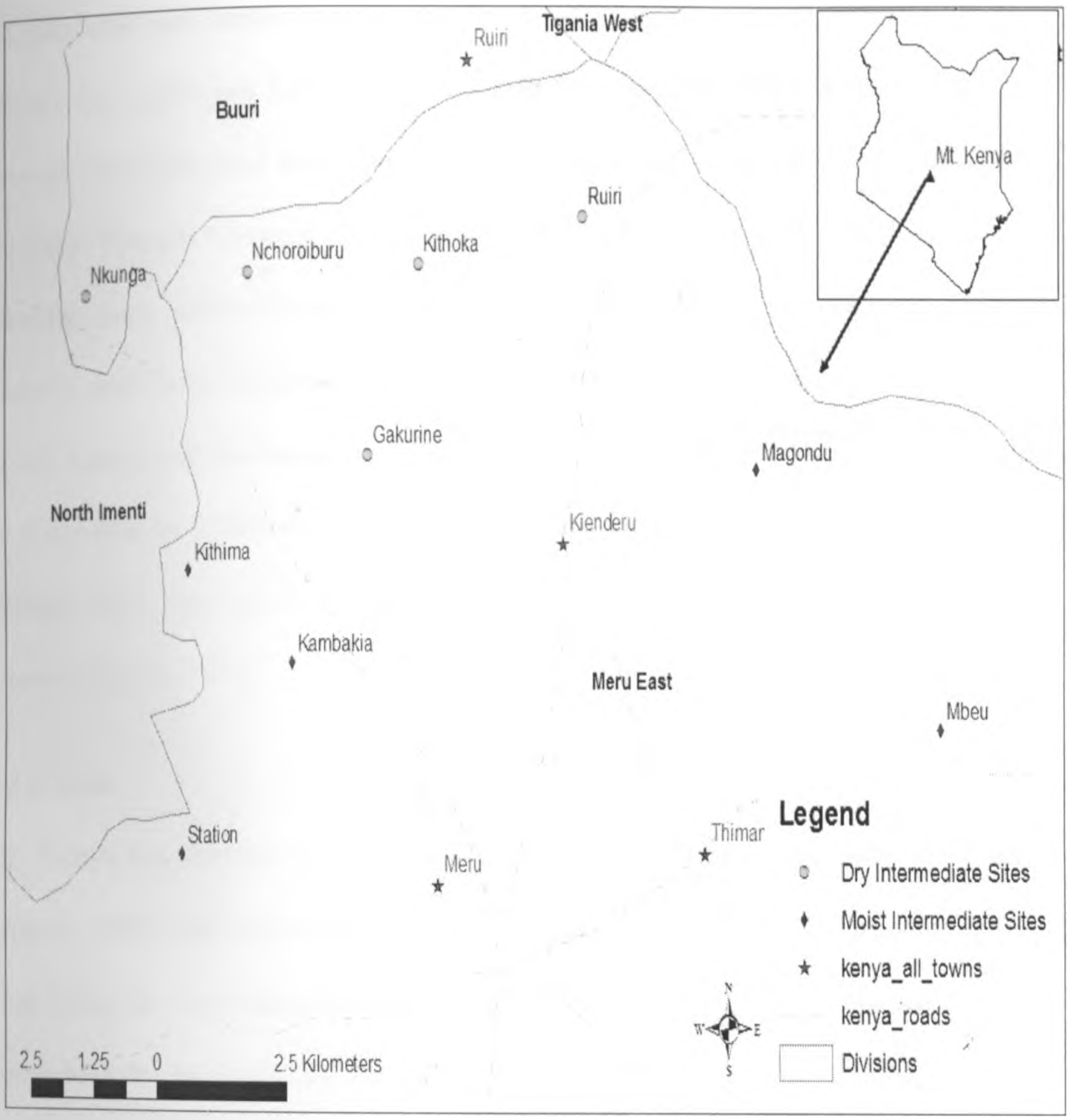

Figure 2: Map of the study area showing the sampling sites of moist and dry forests. Inset is the map of Kenya showing the location of Mt. Kenya and Imenti Forest.

2.2 Climate and geology

2.2.1 Rainfall and temperature

Mt. Kenya region has bimodal rainfall patterns with short rains occurring from about October through November and long rains from about March through June. The rainfall is influenced by the Inter-Tropical Convergence Zone (ITCZ) which is associated with the southeast trade winds blowing from Indian Ocean (Speck, 1982) and occasional convectional currents from Lake Victoria and Congo airstream (Ojany, 1993). However, a striking sharp rainshadow occur north of Mt. Kenya and northwest of the Nyambene hills which records about 750mm annual rainfall as compared to 2300mm on the south eastern slopes. The average temperatures depend on altitude with very small minimal variations where lowest temperatures coincide with rainy seasons (Speck, 1982).

2.2.2 Soils

Mt. Kenya has four recognized pedo-ecological belts which vary with topography and altitude (Speck, 1982). The upper region has shallow and stony soils rich in organic matter with volcanic plug being the dominant physiographic feature. The upper slopes between 2500 and 4000m are dominated by andosols and peat soils (Ojany, 1993). The lower slopes are characterized by highly weathered, deep soils with argillic horizons while on the plains to the west and northwest have fine textured soils with dark top soils (Coe, 1967). The soils have been developed from volcanic ash and pyroclastic rocks. There is great variation in soil moisture in the region which is mainly dependent on climatic patterns and soil characteristics (Bussmann, 1999).

2.3 Flora

Vegetation zonation of Mt. Kenya has been categorized into three belts by (Hedberg 1951 cited in Bussmann, 1994) and boundaries are related to altitude, disturbances and soil type regimes. The montane forest belt is characterized by broad-leaved and coniferous trees differentiated into several montane rainforest, bamboo and *Hagenia - Hypernicum* vegetation zones with an altitude range of 2000 to 3400m. The ericaceous belt (3400 to 3600m) is characterized by the moorland zone and protea while tussock grassland, *Senecio* and *Alchemilletum* are the main communities of alpine belt (Speck, 1982).

However, a general zonation system was suggested by (Boughley 1955 cited in Bussmann 1994) in contrast to Hedberg's 1951 classification. The Boughley zonation identified five belts as lowland zone 0 to 800m, foothills zone 800 to 1500m, highland zone 2300 to 3000m, temperate zone 4000 to 4500m and alpine desert zone above 4500m. The Hedberg classification system seems to define the various vegetation types although at broader sense hence it suits Imenti forest.

On the basis of the Hedberg classification system, various zones of Mt. Kenya forests tend to be associated with certain plant communities. For instance, the *Newtonia* forest occurs near rivers and forest edges on the eastern slopes at lower altitudes (1200 to 1800m), while *Croton-Brachylaena-Calodendrum* community is dominant in an area around Meru Town. This is a rare type of forest in Africa covering approximately 6,000 hectares of which 50% is only found on Mt. Kenya (Bussmann and Beck, 1999). According to Bussmann and Beck (1999), there is one unique site in upper Imenti at altitude of 1500 to 1800m made up of *Croton sylvaticus* forest. The

Juniperus - Olea forest type occurs in the western and northern slopes of Mt. Kenya (Gathara, 1999).

There are over 882 plant species, subspecies and varieties belonging to 479 genera which have been recorded in the Mt. Kenya forest ecosystem (Bussmann, 1994). The region has endemic or near endemic plant species which include *Senecio keniodendron, S. keniensis keniensis, Lobelia deckenii keniensis, L. bambuseti, Alchemilla argyriphylla, Iora scheffleri keniensis, Pavetta hymenephulla, Maytenus keniensis* and *Embelia keniensis* (Musila *et al.*, 2009; Bussmann, 1994). These species mainly occur in the indigenous forests both in the forest reserve and Mt. Kenya National Park. Both the forest reserve and park cover over 271,000 hectares (Bennun and Njoroge, 1999).

2.4 Fauna

There is no comprehensive description of the Mt. Kenya forest ecosystem fauna that has been published yet despite it having a great variety of wildlife (Bussmann, 1994). However, the ecosystem has a rich montane bird fauna with Fifty three out of Kenya's Sixty seven African high lands biome species, Thirty five forest specialist species and 6 of the 8 species that make up the Kenyan mountains endemic bird area (Bennun and Njoroge, 1999). The bird species consists of 3 groups, namely globally threatened species, restricted range species and regionally threatened species (Bennun and Njoroge, 1999; Bussmann, 1994). Globally threatened species include the Lesser kestrel, Jackson's widowbird, Sharpe's longclaw and Abbott's starling while range restricted are the Jackson's francolin, Hunter's cisticola and Kenrick's starling. The regionally threatened species are the African green ibis, Lammergeier, Cape eagle owl, Ayres's hawk eagle among others (Musila *et al.*, 2009; Bennun and Njoroge, 1999).

There are over Fifty two species of mammals recorded in the ecosystem where IUCN red listed species include; the Leopard *Panthera pardus*, Bongo *Tragelaphus euryceros*, Giant Forest Hog *Hylochoerus meinertzhageni*, Black Rhino *Diceros bicornis*, African Elephant *Loxondata africana*. Among the endemic species are Mole Shrew *Surdisorex polulus*, Mole Rat *Tachyoryctes rex*, Thicket Rat *Grammomys gigas*, Highland Musk Shrew *Crocidura allex alpina* and the Rock Hyrax *Procavia johnstoni mackinderi* Bennun and Njoroge (1999).

The region also has endemic reptiles and amphibians such as the bush viper *Atheris desaixi*, montane viper *Vipera hindii*, soft horn chameleon *Chameleo schubotzi*, while butterfly species is *Capys meruensis*. Some of the fish species recorded in the various water bodies in Mt. Kenya ecosystem include *Oncorhynchus mykiss, Oreochromis spirulus* and *Barbus* spp. among others (Musila *et al.*, 2009).

2.5 Rehabilitation of Imenti forest

Imenti forest is important migratory corridor for elephants connecting Isiolo area and Meru National Park. In this case, some sections have been fenced off. Some of the study sites which had electric fence were Kithoka, Nchoroiburu, Nkunga, Station, Ruiri and Kithima. Fencing was implemented to reduce human wildlife conflicts mainly caused by elephants and deter human encroachment. However, fencing work at Mbeu and Magondu is incomplete. Due to lack of fence in these areas, human encroachments are common with farms extending right into the forest. This has resulted into proliferation of *Lantana* spp. and *Trema orientalis*, which are among the pioneer species of disturbed ecosystems (Beentje, 1994).

The re-afforestation programme is managed by Kenya Forest Service (KFS) where seedlings are sown by the Nyayo Tea Zone, Forest Department and local community. The prioritized areas for rehabilitation were those initially cleared for the Shamba system (Gathara, 1999). The major trees species re-planted are; *Vitex keniensis, Cordia africana, Grevillea robusta, Croton megalocarpus, Prunus africana, Eucalyptus saligna, Podocarpus falcatus, Cupressus lusitanica* and *Premna maxima* among others.

2.6 Study sites

Study sites were delineated by a network of tracks for vegetation sampling. Exploratory track mapping survey in the eastern part of Mt. Kenya forest ecosystem was done from Chuka to Meru and was carried out from 26th September to 3rd of October 2009 using a Garmin Global Positioning System (GPS) model map60CSX. Based on KFS forest management units containing natural forests, a total of 5 sampling sites in each forest type were identified (Table 1 and Figure 2). Four field sessions were made from 7th to18th October 2009, 9th to 16th November, 24th November to 19th December 2009 and 12th January 17th 2010.

Table 1: Sampling sites, coordinates and altitude

Sampling sites	GPS Co-ordinates	Altitude (m asl)
Mbeu (Moist forest, Lower Imenti)	N 0 03.795 E 37 45.154	1189
Magondu (Moist forest , Lower Imenti)	N 0 06.559 E 37 42.570	1348
Kambakia (Moist forest , Upper Imenti)	N 0 04.663 E 37 37.436	1543
Kithima (Moist forest , Upper Imenti)	N 0 05.462 E 37 36.934	1623
Station (Moist forest ,Upper Imenti	N 0 03.342 E37 37.170	1698
Nchoroiburu (Dry forest, Upper Imenti)	N 0 07.563 E 37 37.965	1574
Ruiri (Dry forest, Upper Imenti)	N 0 08.461 E 37 40.135	1514
Kithoka (Dry forest, Upper Imenti)	N 0 06.354 E 37 38.955	1530
Gakurieni (Dry forest, Upper Imenti)	N 0 07.247 E 37 38.996	1563
Nkunga (Dry forest, Upper Imenti)	N 0 07.462 E 37 35.381	1806

Plate 1: A section of Kithima site characterized by tall trees

2.6.1 Establishment of the moist and dry vegetation boundary

The GPS coordinates and or the routes and points recorded during the initial exploratory survey were downloaded using Garmin Map source software version. The coordinates of the routes and points were subsequently overlaid on the vegetation map using Quantum GIS (Quantum GIS Development Team, 2010) and the expected vegetation type was identified for each of the mapped locations. To aid in the selection of sampling sites and sample points in the field, the vegetation boundary of the moist and dry intermediate forest was uploaded to the Garmin GPS map60CSX used during the fieldwork. This information was used in the field to ensure sampling was done within the two selected vegetation types.

2.6.2 Vegetation sampling techniques

Quadrats measuring 40 x 40 m were established in each vegetation type at intervals of 500 m. The first quadrat was set on the vegetation boundary while subsequent quadrats moved towards the forest edges or other vegetation types. In order to ensure a right angle was maintained, two perpendicular straight lines were determined from the geo-referenced first corner of each quadrat. Two 40 m polythene twines were then placed following the set direction of the two perpendicular lines. A set of another two polythene twines of the same distance were then placed on the second and third corners following the determined direction of the first corner. All the 4 corners of each quadrat were then geo-referenced. Quadrats were located 100 m away from the pathways to cater for edge effects. All woody species with the required circumferences of $\geq$ 15.7 cm (DBH = 5cm) and heights of $\geq$ 5 m were recorded in each quadrat. In total, sixty (60) quadrats were established in both forest types with each forest having thirty (30).

2.6.3 Sampling for saplings

Saplings were counted by use of a 10 x 10 m quadrat that was randomly selected from each of the 40 x 40 m quadrat after it was divided into 16 sub-quadrats. All the saplings with height of ≥ 1 m but < 5 m were documented. However, their diameters at breast height were not taken.

2.6.4 Diameter at breast height (DBH)

Tree circumferences were approximately measured at 1.35 m above the ground level (for calculation of diameter at breast height) within each 40 x 40 m quadrat using a tape measure (Musila *et al.*, 2009; Wilder *et al.*, 1998). DBH for trees with an enlarged stem base or buttressed tree was taken at 30 cm above or below the enlargement while for vertically growing tree on a slopes measurement were taken on the upper side of the slope. DBH for leaning tree was measured along the undersides of the trunk. In case of trees forked near breast height, measurements were taken at the narrowest part of the main stem below the fork (Abed and Stephens, 2003). The circumference measurements were later converted to diameter values using the following formula.

$$D = C/\pi \quad \text{.. (Equation 1)}$$

Where;

C = circumference (cm)

D = diameter (cm)

$\pi = 3.14$

2.6.5 Tree height

Tree heights ≥ 5 m were estimated using a Suunto clinometer after Abed and Stephens (2003) and Korning and Karsten (1994). A convenient horizontal baseline distance was chosen and determined from the tree to be measured. The tip of the tree was sighted and angle of inclination on the scale was recorded. The bottom of the tree was also sighted and the scale read again. The height of the tree was calculated using the two angles of inclination and the baseline distance (Figure 3).

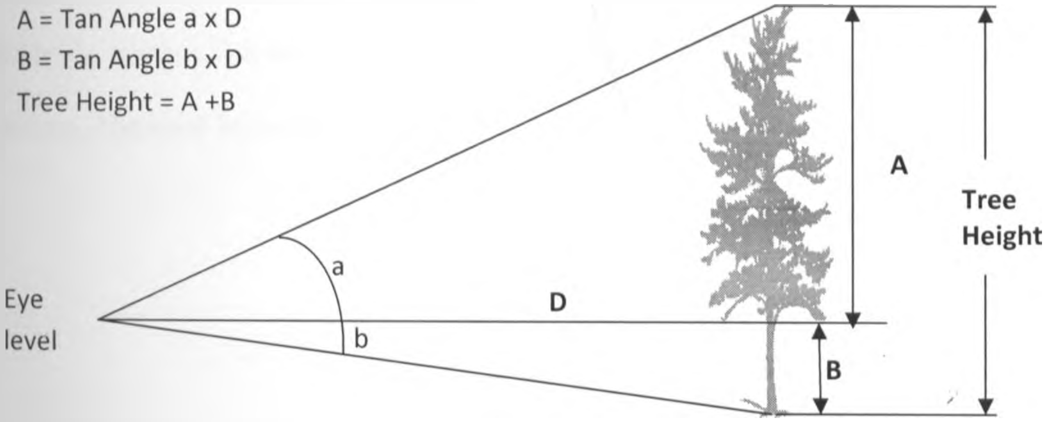

Figure 3: Illustration of trigonometric principles for measuring tree height

2.6.6 Vegetation profile

A 4 x 100 m belt transect was set in each vegetation type to document vertical and horizontal structure of woody species within it after Althof (2005) and Busing and Fujimori (2002). Tree parameters namely individuals' distance from the start point, crown diameter, total height and trunk height were recorded. Profile diagrams were drawn from starting point to the end of the transect using these parameters at a scale of 1cm: 5 m. The trees were differentiated by giving each species a numerical value.

2.6.7 Specimen collection, pressing and identification

Tree specimens were indentified in the field using local names and confirmed later by use of reference materials (Beentje, 1994; Maundu and Tengnas, 2005). Herbarium vouchers were collected for species that could not be identified in the field and were identified at the East Africa Herbarium, National Museums of Kenya.

2.7 Data analysis

The tree species data were entered into Excel spreadsheets. Data analysis was done using BiodiversityR version 2.10.0 (http://www.worldagroforestry.org/resources/databases/tree-diversity-analysis), PAST version 1.36 (http://folk.uio.no/ohammer/past) and SPSS version 12.0. Two sample t and z tests were used to test for mean differences between the moist and dry forests. To test for differences among the five sites in each forest, a one –way ANOVA was applied. Ordination analysis was performed to compare similarities in species composition for moist and dry forest. Descriptive models of bar charts were used to represent the counts of tree that occurred in the various DBH and height classes and while Chi-square was performed to test for their differences. Species data were transformed accordingly to approximate normal distribution before analysis (Fowler *et al.*, 1998; Zar, 1984). All statistical analysis were evaluated at the $p<0.05$ level of significance.

2.7.1 Species diversity

Species richness and diversity indices were computed (see sub-sections 2.7. 2 and 2.7. 3 below) for trees species recorded in moist and dry forests. Comparisons were illustrated by the two ecological indices.

2.7.2 Tree species richness (S)

The simplest measure of species richness is the total number of species (S) present in a sample of individuals in an area and at a specific time (Kindt and Coe, 2005). However, since sample size frequently varies, S can only be used as a crude measure of community species richness. The total number of species recorded in each vegetation types were used as a measure of its species richness.

2.7.3 Shannon-Wiener's diversity index (H′)

This index is dependent upon species richness (number of species), and evenness (number of individuals in each (species in the sample). Shannon-Weiner's diversity index is sensitive to either rare or common species (Sutherland, 1996).

$$H' = -\sum (Pi)\ (\ln Pi) \quad \text{……………………………………………… (Equation 2)}$$

Where;

H' is the index of species diversity

Pi is the proportion of the i^{th} species in the sample

2.7.4 Structural parameters

The following structural parameters for each species were computed following Lulekal (*et al.*, 2008), Kent and Coker (1992) and Cox (1990).

2.7.4.1 Tree density

Quadrat sampling technique was adopted to determine tree densities for the two vegetation types. Density refers to the number of individuals per unit area (Cox, 1990). The number of individual trees that met the required DBH and height were recorded in the 40 x 40 m quadrats. Total area per sampling site was done by multiplying the number of plots with their respective area (Equation 3).

$$D = \frac{N}{A} \quad \text{……………………………………………………… (Equation 3)}$$

Where;

D = density

N = number of individuals

A = area sampled (m^2)

2.7.4.2 Relative tree density

Relative density indicates the percentage density contribution of a single species against the total density of all other species sampled and was calculated following the formula (Equation 4).

$$RD = \frac{D}{TD} \text{ x } 100\ \% \text{...(Equation 4)}$$

Where;

RD = relative density

D = density of a species

TD = total density of all species

2.7.4.3 Dominance

Dominance refers to per unit area (basal area or crown cover) that a species occupies in relation to the total area sampled. The basal area for each species was determined by use of the following formula (Equation 5).

$$B = \left(\frac{DBH}{200}\right)^2 x\ \pi \text{ .... (Equation 5)}$$

Where;

B = basal area (m^2)

DBH =Diameter at breast height (cm)

$\pi = 3.14$

Dominance was then computed by dividing the total basal of each forest type by the area sampled.

2.7.4.4 Relative dominance

This represents the percentage dominance of a species in relation to the total dominance of all other species. This follows the formula (Equation 6)

$$RD = \frac{D}{TD} x100\ \% \quad \text{.. ...... (Equation 6)}$$

Where;

RD = relative dominance

D = dominance of a species

TD = total dominance of all species

2.7.4.5 Frequency

Species frequency was computed as the proportion of samples within which a species was found. The presence of a species in quadrats was indicated by value of 1 and absence by 0. Species presence was summed up and frequency determined as follows (Equation 7).

$$F = \frac{Ns}{Nt} \quad \text{.. (Equation 7)}$$

Where;

F = frequency

Ns = number of plots in which a species occurs

Nt = total number of plots sampled

2.7.4.6 Relative frequency

Relative frequency of a species indicates its percentage occurrence in relation to total frequency of all other species and was determined as follows (Equation 8).

$$RF = \frac{F}{Ft} x 100 \% \quad \text{.. (Equation 8)}$$

Where;

RF = relative frequency

F = frequency value for a species

Ft = total frequency values for all species

2.7.4.7 Importance Value Index (IVI)

The Importance value index of a species is a measure of importance of a species in the community. Importance value index for species was computed from values of relative frequency, relative density and relative dominance as follows (Equation 9).

$$IV = RF + RD_e + RD_o \quad \text{... (Equation 9)}$$

Where;

IV = Importance value

RF = Relative frequency

RD_e = Relative density

RD_o =Relative dominance

2.7.4.8 Vegetation structure

Vegetation structure was expressed in terms of DBH (stem) and height distribution size classes. The units for DBH were (cm) while height was expressed in terms of (m). There were 8 and 7 DBH and height classes respectively.

CHAPTER THREE

3.0 RESULTS

3.1 Accuracy of the potential natural vegetation map

3.1.1 Characteristic species of moist and dry forests

Characteristic species associated with both moist and dry forests were identified as indicated by Trapnell (1997) (Appendix 1). The presence of such species was an indication that the sampled sites occurred within the respective vegetation type and verification that digital map was accurate. A subset of only twenty one characteristic (indicator) species was recorded in both forests. In moist forest, 11 species were recorded compared to 10 species in dry forest. Shannon-Wiener diversity index for moist forest was ($H'=3.014$) compared to that of dry forest ($H'=3.015$). There was no significant difference (Two sample t-test: $t = 0.253$, $df=29$, $p>0.05$) in the mean characteristic species diversity indices between the moist and dry forests.

3.1.2 Characteristic species density

The density of characteristic species was not significantly different (Two sample t-test: $t=1.478, df=29, p>0.05$) in the moist forest at 35.5 ± 5.6 trees/ha compared to dry forest at 50.8 ± 8.4 trees/ha (Figure 4).

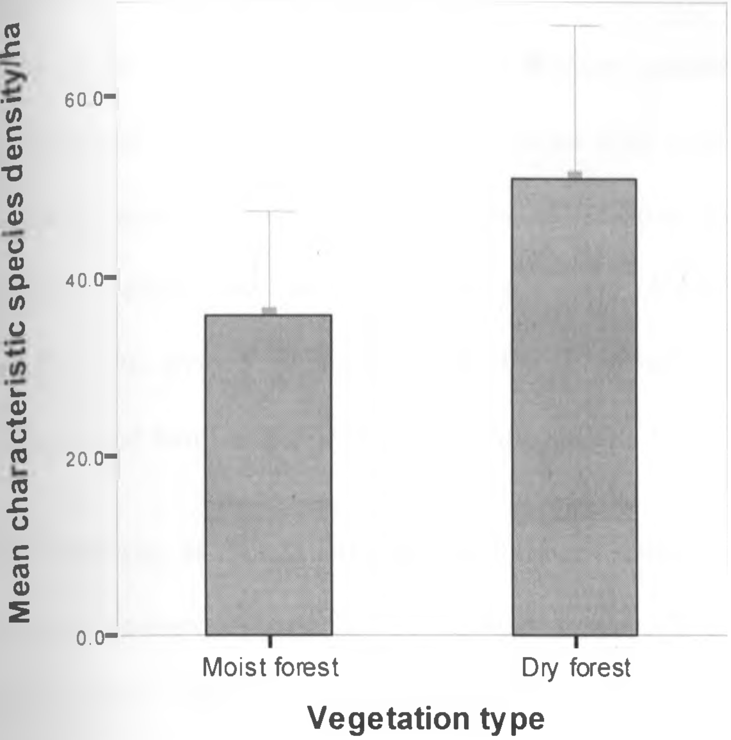

Figure 4: Mean (±SE) density (trees/hectare) of characteristic species in the moist and dry forests

3.2 Floristic composition

A total of 2,486 trees consisting of 108 species were recorded in moist and dry forests during the study period. In the moist forest, a total of 1,452 individual trees comprising of 38 families and 87 tree species were recorded. Dry forest had 26 families, 59 species and 1,034 individual trees. At family level, Euphorbiaceae and Rutaceae were the most dominant families in both moist and dry forests. Euphorbiaceae was represented by 9 species in moist and 6 species in dry forest while Rutaceae had 7 species in each forest type (Appendices 2 and 3). The proportions of families represented by 1 to 2 species were 66%, 3 to 4 species was 15%, 5 to 6 species was 15

, and more than 6 species was 4% in the moist forest. In the dry forest, the proportions of milies represented by 1 to 2 species was 74%, 3 to 4 species 18%, 5 to 6 species 4% and more an 6 species was 4%. Some of the most frequent species recorded in at least 10 quadrats and sted in order of abundance in the moist forest were *Cordia africana*, *Ehretia cymosa*, *Croton lvaticus*, *Neoboutonia macrocalyx*, *Clausena anisata*, *Teclea trichocarpa* and *Vangueria* spp. the dry forest they included; *Olea europaea*, *Calodendrum capense*, *Olea capensis*, *E. mosa*, *Celtis africana*, *Vangueria* spp. and *C. sylvaticus*. The abundance per species, numbers f species and families list are shown in Appendices 2 and 3.

.2.1 Similarity of species composition between moist and dry forests

he species composition of the two forests was well separated. Ordination results of redundancy nalysis (RDA) based on Bray-Curtis ecological distance showed that similarity in species omposition between moist and dry forest was low. Species composition of moist forest was ore separated by sites compared to that of dry forest which showed a high similarity (Figure 5).

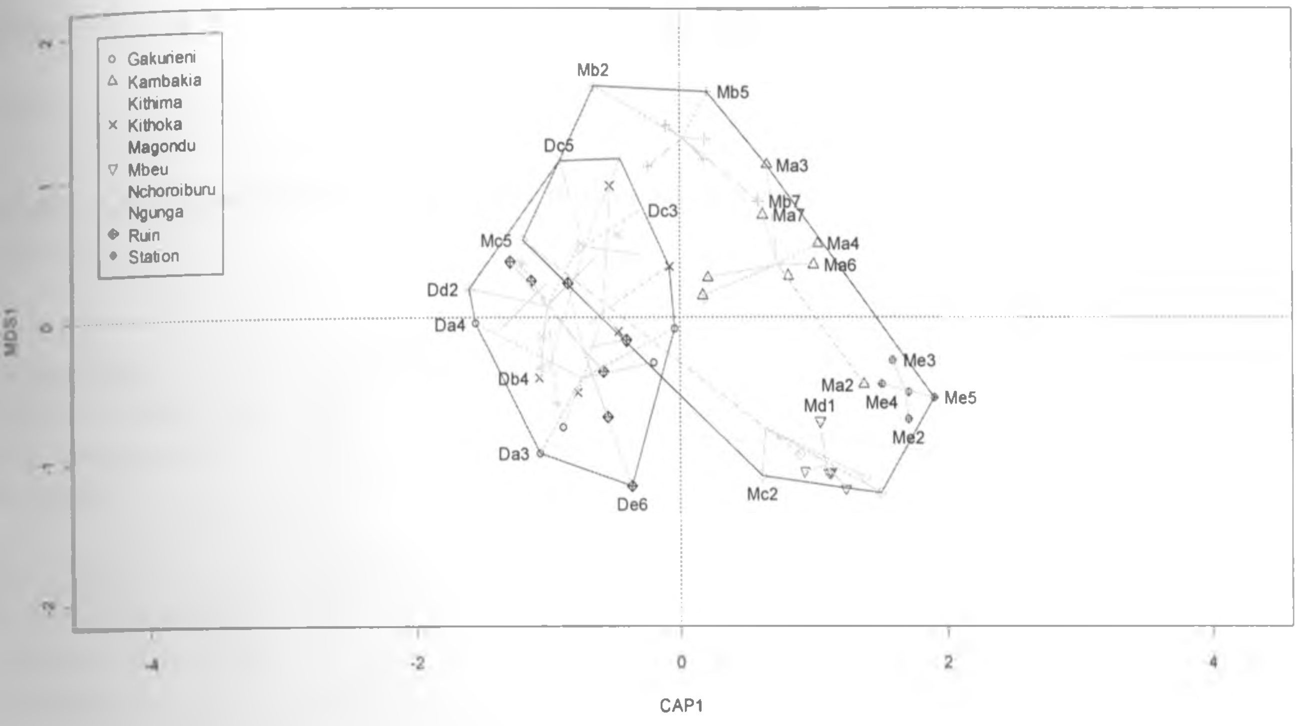

Figure 5: Db-RDA ordination graph for the species composition of the quadrats in moist and dry forests. Moist forest sites = Kambakia, Kithima, Magondu, Station and Mbeu
Dry forest sites = Kithoka, Gakurieni, Ruiri, Nchoroiburu and Nkunga

3.2.2 Species diversity among the sites of moist and dry forests

Species richness among sites in moist forest were varying with Kambakia recording the highest richness (S = 46) and Magondu the least (S = 25). Shannon-Wiener diversity index (H') ranged from H'= 3.376 in Kithima to H'= 2.442 in Station (Table 2). There was no significant difference (One way ANOVA: $F_{4,\ 170} = 1.449,\ p>0.05$) in the mean species diversity indices among the sites in moist forest. Species richness among the sites of dry forest was highest in Ngunga (S = 39) while Gakurieni had the least (S =20). Shannon-Wiener diversity index ranged from H' =

There was no significant difference (One way
ecies diversity indices among the sites in dry

s and evenness in the moist and dry

a	Mbeu	Station	Magondu
	31	29	25
	2.68	2.44	2.76
	0.47	0.4	0.63

iburu	Kithoka	Ruiri	Gakurieni
	24	23	20
	2.72	2.48	2.64
	0.63	0.52	0.7

rest

l species richness of 87 and 59 were recorded
respectively (Figure 6). The Shannon-Wiener
vhile dry forest had H'=3.24. There was no
535, $df = 144$, $p > 0.05$) in the mean species

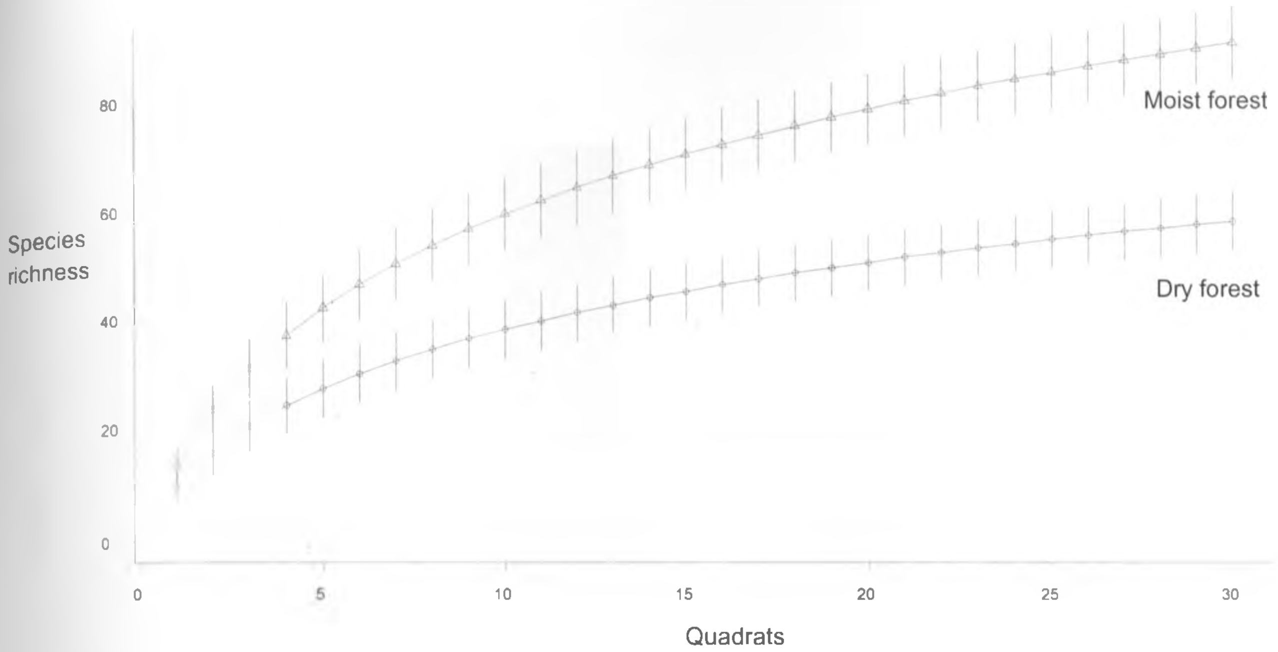

Figure 6: Species accumulation curves for moist and dry forests

3.2.4 Sapling density and diversity

A total of 282 saplings belonging to 34 species were recorded in moist and dry forests. In the moist forest, *Blighia unijugata* saplings were the most abundant while *Ritchiea albersii* was most abundant in the dry forest (Appendix 4). Moist forest had a mean sapling density of 24.9±1.87 sapling/ha compared to dry forest at 26.64±1.94 sapling/ha (Figure 7). The mean sapling density was not significantly different (Two sample t-test = 0.954, *df* = 29, *p*>0.05) in the two forests. Moist forest had sapling richness of S = 29 compared to S = 14 in dry forest. Shannon-Wiener diversity index for moist forest was H'= 3.099) compared to H'= 2.315*)* in dry forest. There was a significant difference (Two sample t-test*: t = 2.55, df = 41, p<0.05*) in mean sapling species diversity indices between the moist and dry forest. This means that saplings species diversity was higher in the moist forest compared to the dry forest hence good reproduction and recruitment.

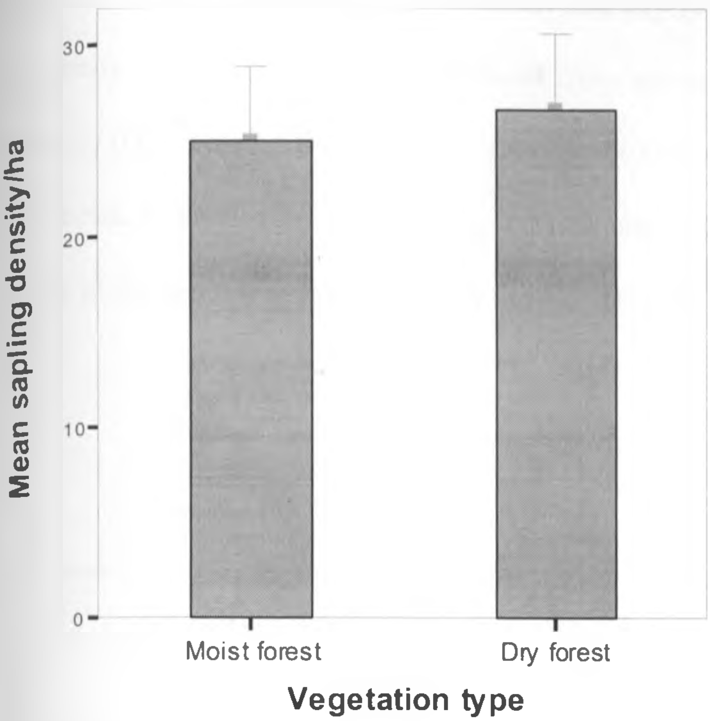

Figure 7: Mean (±SE) sapling density/ha in the moist and dry forests

3.3 Vegetation structural parameters

3.3.0 Tree density among the sites of moist and dry forests

The density of trees in moist forest differed from site to site (Figure 8). There was a significant difference (One way ANOVA: $F_{4,25} = 32.9, p<0.05$) in the mean tree density within the sites of moist forest. In the dry forest, there was a significant difference (One way ANOVA: $F_{4,25} = 6.3, p<0.05$) in the mean tree density among the sites (Figure 9).

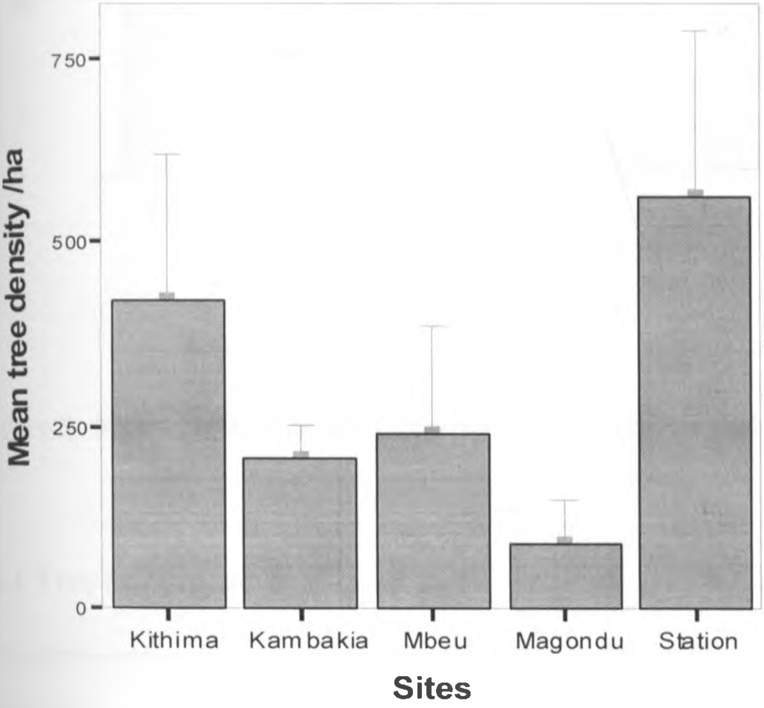

Figure 8: Mean (±SE) density (trees/hectare) of trees within the sites of moist forest

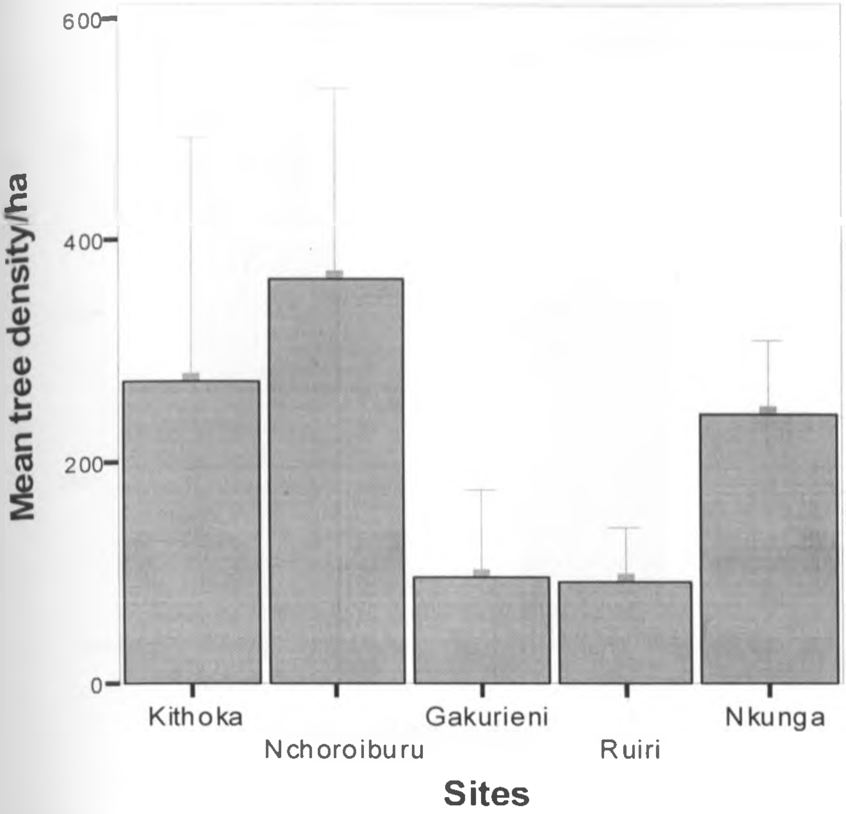

Figure 9: Mean (±SE) density (trees/hectare) of trees within the sites of dry forest

3.3.1 Tree density between moist and dry forests

The mean tree density was not significantly different (Two sample t-test: *$t = 0.284$, $df = 29$, $p > 0.05$)* in the moist forest at 303.54 ± 37.69 trees/ha compared to dry forest at 208.87 ± 27.31 trees/ha (Figure 10).

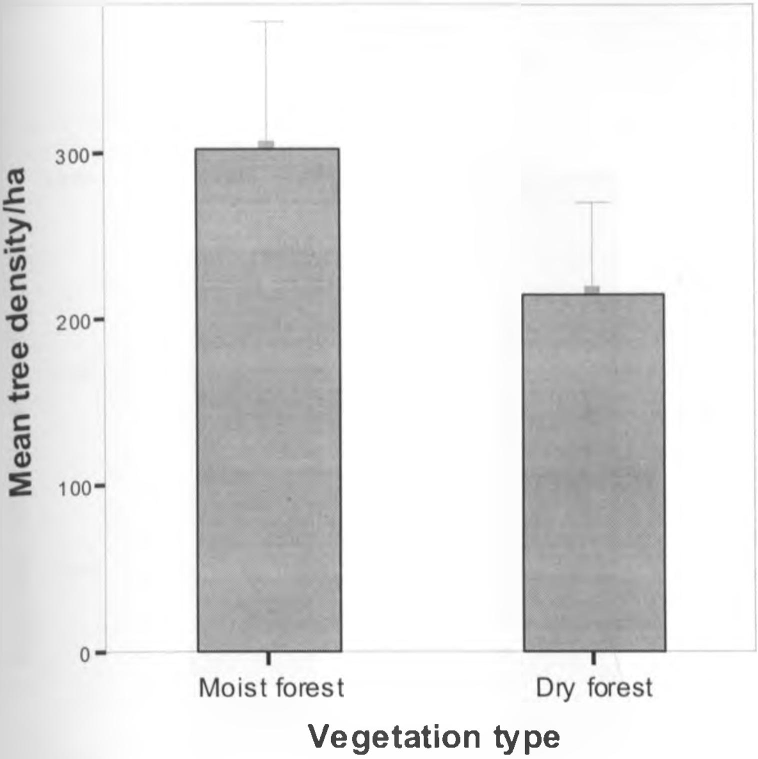

Figure 10: Mean (±SE) density (trees/hectare) of trees sampled in the moist and dry forests

3.3.2 Species relative density in the moist and dry forests

The contribution of 10 species with highest relative density in the moist forest was 52.6 %. These species were *X. monospora* (8.9%), *R. albersii* (7.2%), *Cordia africana* (6.9%), *E. cymosa* (5.7%), *Diospyros abyssinica* (5.3%), *C. sylvaticus* (4.8%), *Tabernaemontana stapfiana* (4.8%), *V. keniensis* (3.8%), *Trema orientalis* (3.4%) and *N. macrocalyx* (2.9%) (Appendix 5). In contrast, the 10 species with highest relative density in dry forest contributed 66.1% of the total relative density. The species were *O. europaea* (12.3%), *P. viridiflorum* (9.1%), *O. capensis* (7.9%), *C. capense* (6.8%), *E. cymosa* (6.3%), *Celtis africana* (5.9%), *R. albersii* (5.5%), *Rawsonia lucida* (4.5%), *C. sylvaticus* (3.7%) and *Vangueria* spp. (3.6%) (Appendix 6). There was no significant difference (Two sample t-test: *t = 1.783, df = 9, p>0.05)* in the mean relative density of the 20 species in both moist and dry forests (Figure 11).

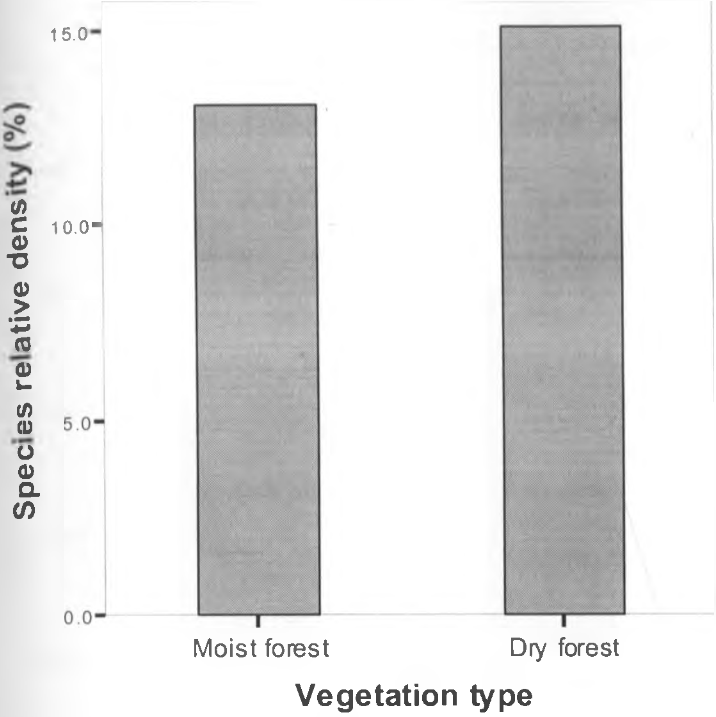

Figure 11: Mean relative density of the 20 species in the moist and dry forests

3.3.3 Species basal area and dominance for moist and dry forests

The total basal area for moist forest was 87.83m^2/ha compared to that of dry at 88.26m^2/ha. The mean basal area for moist was 1.01±0.19 m^2/ha compared to that of dry forest at 1.49±0.36 m^2/ha (Figure 12a). However, there was no significant difference (Two sample t-test: *t = 1.129, df =144, p>0.05)* in the mean basal area between the moist and dry forests. The mean dominance of moist 2.92±0.34m^2 compared to dry forest at 2.94±0.30m^2 (Figure12b). There was no significant difference (Two sample t-test: *t = 0.061, df =29, p>0.05)* in the mean species dominance between the moist and dry forests.

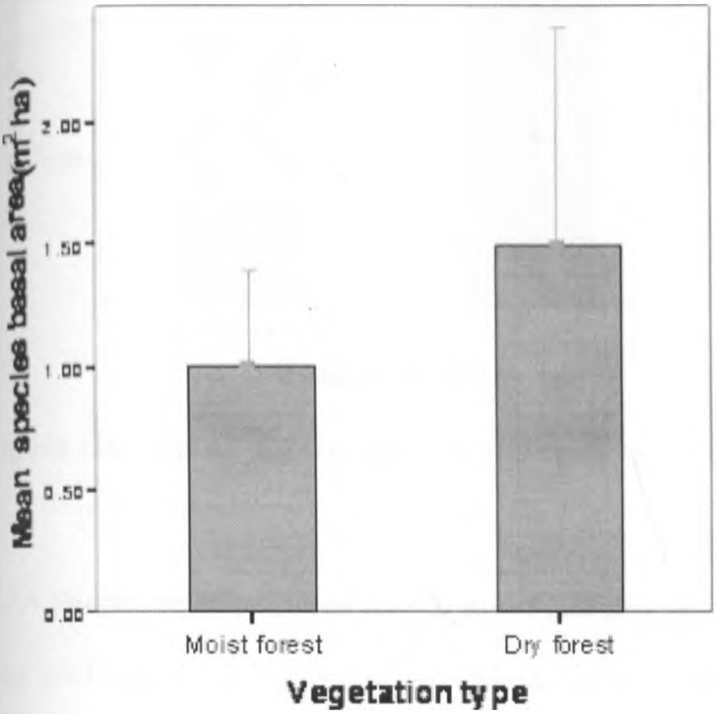

Figure 12a: Mean (±SE) basal area of species counted in the moist and dry forests

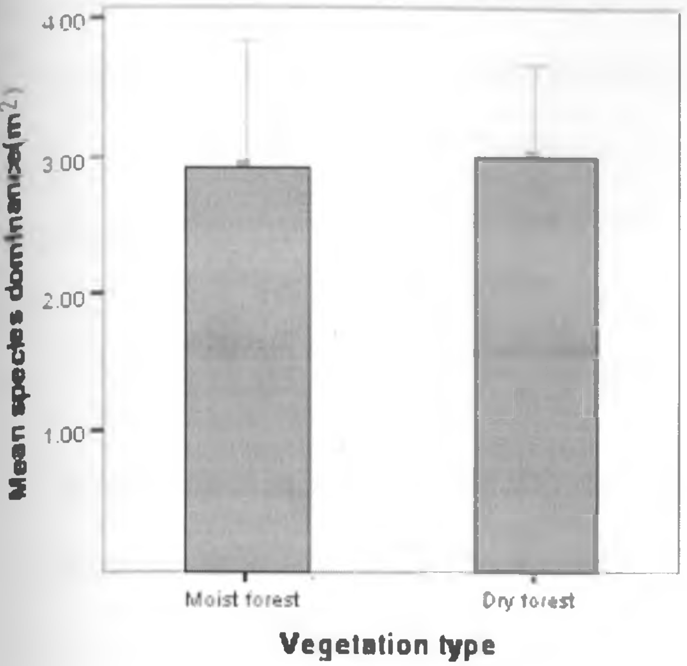

Figure 12b: Mean (±SE) dominance of tree species counted in the moist and dry forests

3.3.4 Species relative dominance in moist and dry forests

The total relative dominance of both forest types was mostly contributed by 10 species. In the moist forest, they contributed 57% of the total relative dominance. These species included *F. thonningnii* (11%), *Cordia africana* (10%), *V. keniensis* (6%), *M. lutea* (5%), *Celtis africana* (5%), *E. cymosa* (5%), *P. africana* (4%), *Diospyros abyssinica* (4%), *P. viridiflorum* (4%), *B. unijugata* (4%) and *C. battiscombei* (4%) (Appendix 5). In the dry forest, 10 species contributed 83% of the total relative dominance and included *O. europaea* (21%), *P. viridiflorum* (14%), *M. lutea* (12%), *Celtis africana* (8%), *C. capense* (8%), *Ficus* spp. (7%), *O. capensis* (5%), *Margaritaria discoidea* (4%), *E. cymosa* (3%) and *F. thonningnii* (2%) (Appendix 6). There was no significant difference (Two sample t-test: $t = 0.910$, $df = 9$, $p>0.05$) in the mean relative dominance of the 10 species between the moist and dry forests.

3.3.5 Species relative frequency in moist and dry forests

The mean species relative frequency was significantly different (Two sample t-test: *t =2.022, df = 144, p<0.05*) for moist 1.15 ± 0.11 compared to that of dry forest at 1.69 ± 0.23. In moist forest species, among species that had highest relative frequency were *Cordia africana* (5%), *E. cymosa* (5%) and *C. sylvaticus* (4%) (Appendix 5). In the dry forest they included *O. europaea* (7%), *C. capense* (7%) and *E. cymosa* (6%) (Appendix 6).

3.3.6 Species Importance Value index (IVI) for moist and dry forests

Parameters of relative frequency, relative density and relative dominance were used to compute Important Value index for moist and dry forests. Different species had different IVI in both moist and dry forests (Appendices 5 and 6). In the moist forest, 9 species contributed an IVI of 40% and included; *Cordia africana* (7%), *E. cymosa* (5%), *X. monospora* (5%), *F. thonningnii* (5%), *Diospyros abyssinica* (5%), *C. sylvaticus* (4%), *Celtis africana* (4%), *V. keniensis* (4%) and *M. lutea* (3%). In dry forest, *O. europaea* (14%), *P. viridiflorum* (8%), *C. capense* (7%), *Celtis africana* (7%), *O. capensis* (6%), *E. cymosa* (5%), *M. lutea* (5%), *Vangueria* spp. (9%) and *M. discoidea* (3%) had an IVI of 58%. There was no significant difference (Two sample t-test: *t =1.884, df =144, p>0.05)* in the mean species importance value index between the moist and dry forests.

3.4 Diameter at breast height (DBH) between moist and dry forests

The mean tree DBH was significantly higher in dry forest at 25.62±0.64 cm compared to moist forest at 20.83±0.49 cm (*z = 4, p<0.05*). This means that trees in dry forest had a higher DBH compared to moist forest (Figure 13).

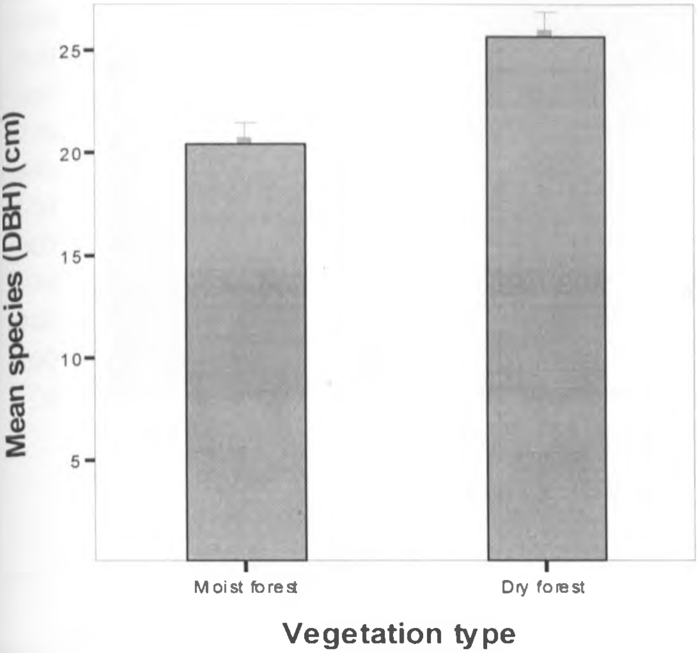

Figure 13: Mean (+SE) DBH of trees in the moist and dry forests

3.4.1 Stem structure (DBH classes) between moist and dry forests

The trees were grouped into 7 stem size classes (DBH) which indicated that more trees were recorded in the smaller classes and gradually decreased in the larger classes (Figure 14). In moist forest, among the dominant large sized trees with DBH greater than 100 cm were *F. thonningii, V. keniensis, B. unijugata, P. africana, C. battiscombei, Cordia africana* and *S. ellipticum.* In the dry forest, species with DBH greater than 100 cm were *Dovyalis abyssinica, M. lutea, O. europaea, P. viridiflorum, F. thonningii* and *Ficus* spp. There was a significant difference (χ^2 =75.5, *df* = 7, *p<0.05)* in the number of tree counts among the various DBH classes in the two forests.

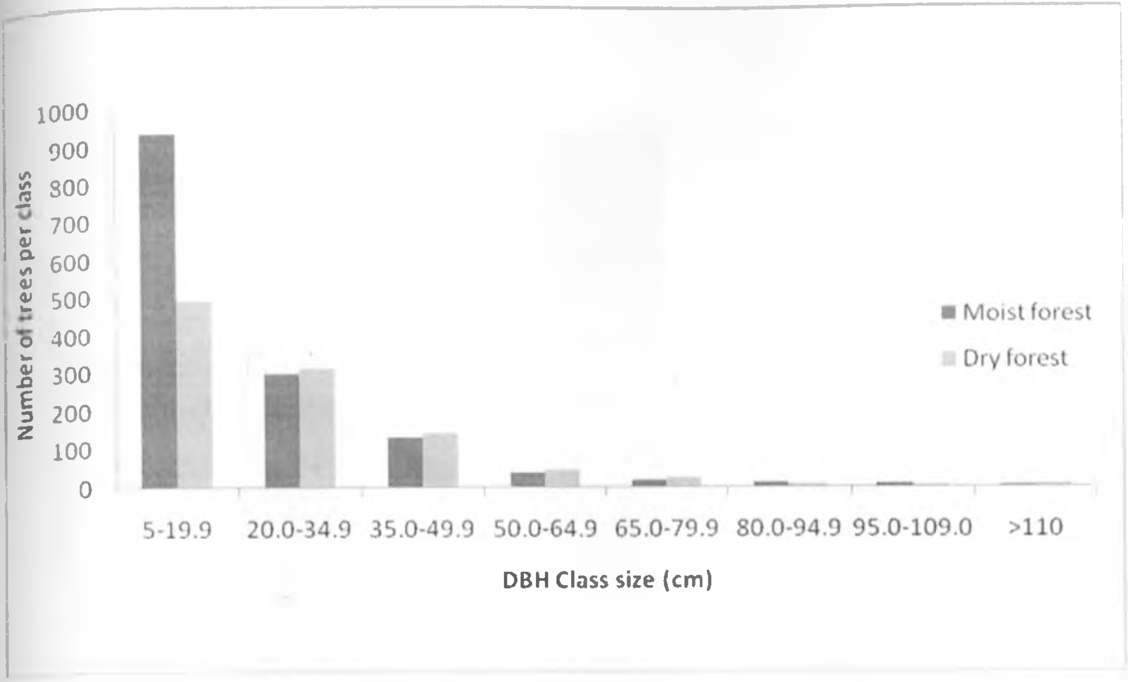

Figure 14: Number of tree counts (DBH ≥ 5 cm) in moist and dry forests

3.5 Tree heights between moist and dry forests

When tree heights were considered, the mean tree height did not differ significantly between the moist forest (13.28±0.17 m) and dry forest (13.34±0.18 m) ($z = 0.24$, $p>0.05$) (Figure 15).

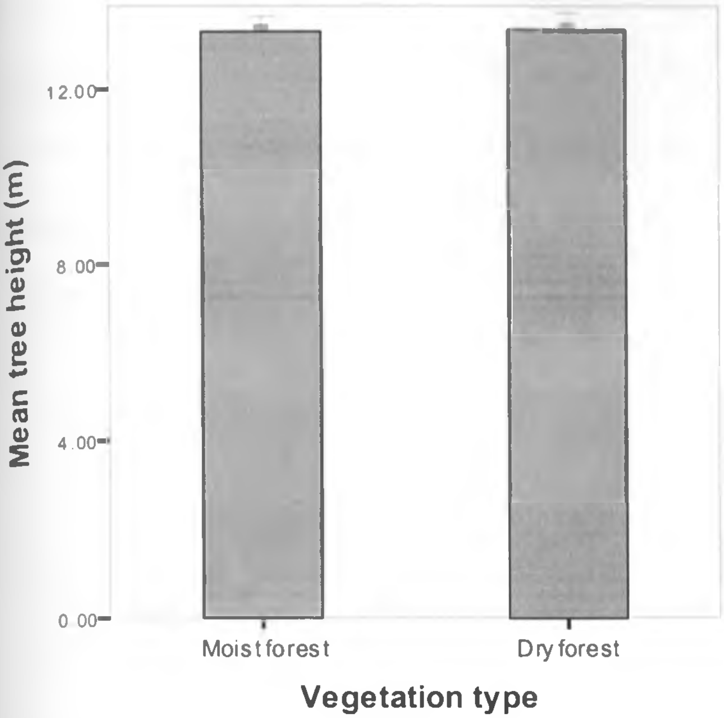

Figure 15: Mean (±SE) height of trees in the moist and dry forests

3.5.1 Height structure in moist and dry forests

The structure of trees with height ≥ 5 m in the two forests indicated that height class 5.0 - 9.9 m which represented the under storey trees had the highest tree counts in both forests, a gradual decline occurred in the middle (10.0 - 19.9 m) and upper classes >20 m (Figure 16). There was a significant difference ($\chi^2 = 37.79$, $df = 6$, $p<0.05$) in the number of tree counts among the various height classes in both forests.

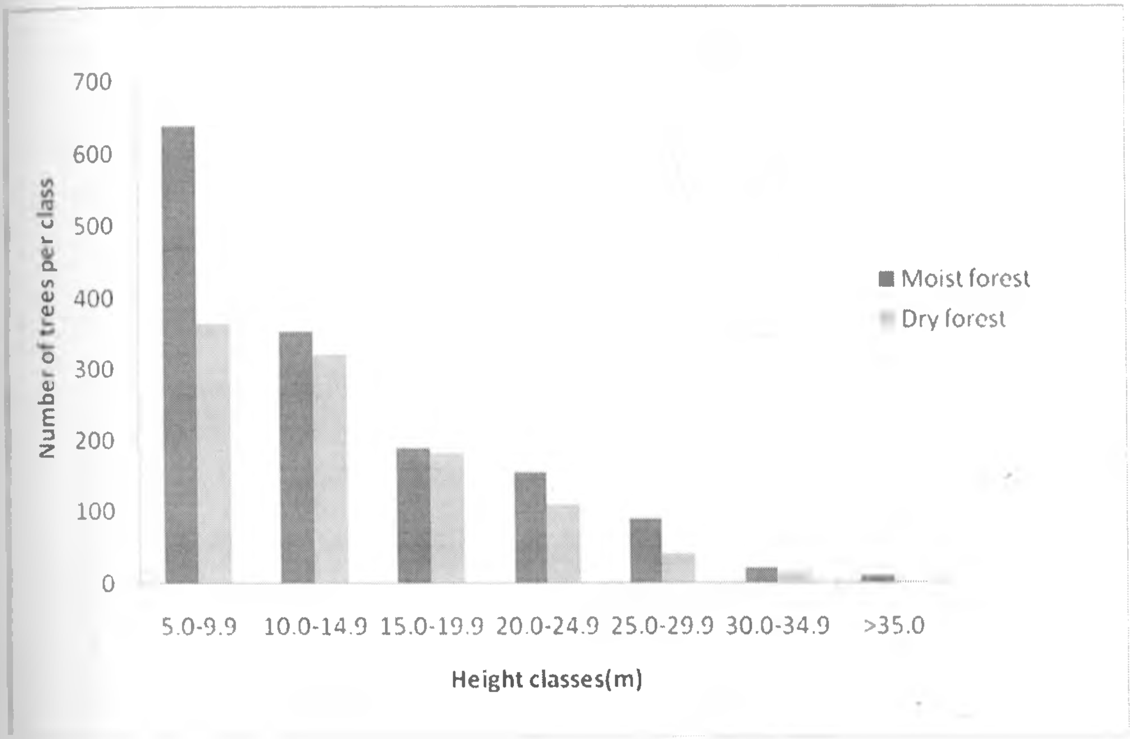

Figure 16: Distribution of tree counts in the various height classes

3.6 Vegetation profile diagrams

3.6.1 Vegetation profile diagram of moist forest

The vertical structure indicated that the upper tree stratum was about 30 m high and consisted of species like *Cordia africana* and *Celtis africana.* The middle stratum 10-20 m was made of species such as *R. urcelliformis, X. monospora* and third stratum (understory trees) below10 m comprised of species like *E. bongensis, T. simplicifolia* among others (Figure 17).

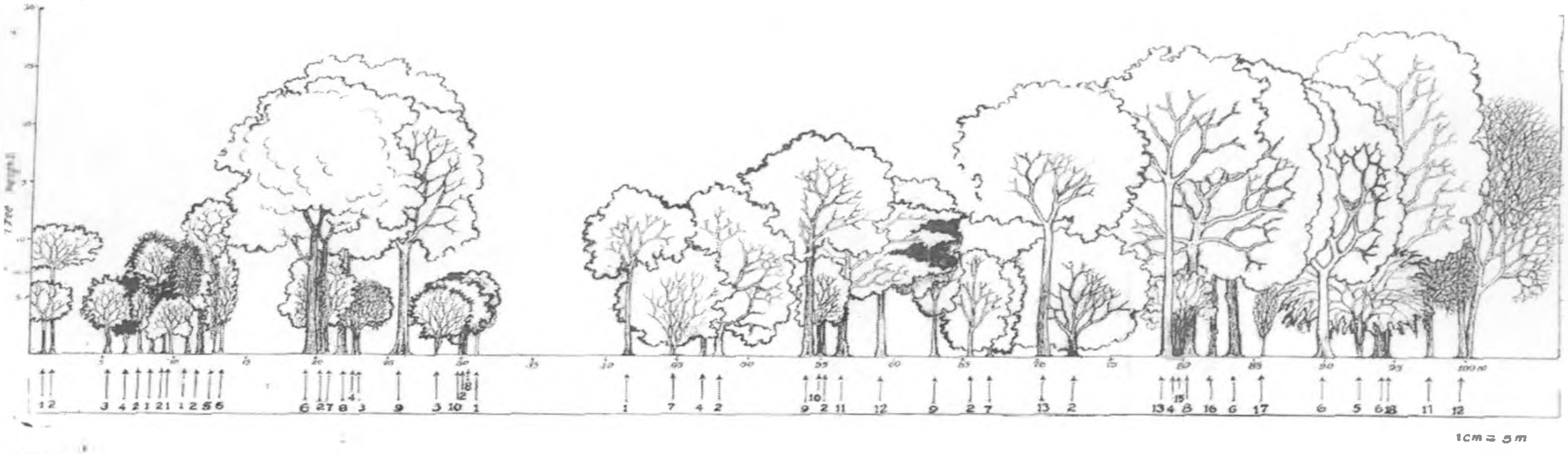

Figure 17: A profile diagram of moist forest at Kambakia area; GPS co-ordinates- N 0° 04.498' E 37° 37.671', Altitude 1612 m asl

Species key

1. Rothmannia urcelliformis, 2. Xymalos monospora, 3. Erythrococca bongensis, 4.Trilepisium madagascariense, 5. Ehretia cymosa, 6. Cordia africana, 7. Flacourtica indica, 8. Celtis africana, 9. Croton sylvaticus, 10. Diospyros abyssinica, 11. Pittosporum viridiflorum, 12. Celtis gomphophylla, 13. Casaeria battiscombei, 14. Ritchia albersii, 15. Berma abyssinica, 16. Olea capense, 17. Teclea simplicifolia, 18. Premna maxima.

3.6.2 Vegetation profile diagram of dry forest

The upper tree stratum was about 25 m in height consisting of few trees such as *Celtis africana,* and *Ficus* spp. while *P. viridiflorum* and *C. capense* occurred in the middle stratum between 10-20 m. The third stratum (understory trees) was poorly developed with *O. europaea* and *S. henningsii* as the main species (Figure 18). Trees were more spaced compared to moist forest.

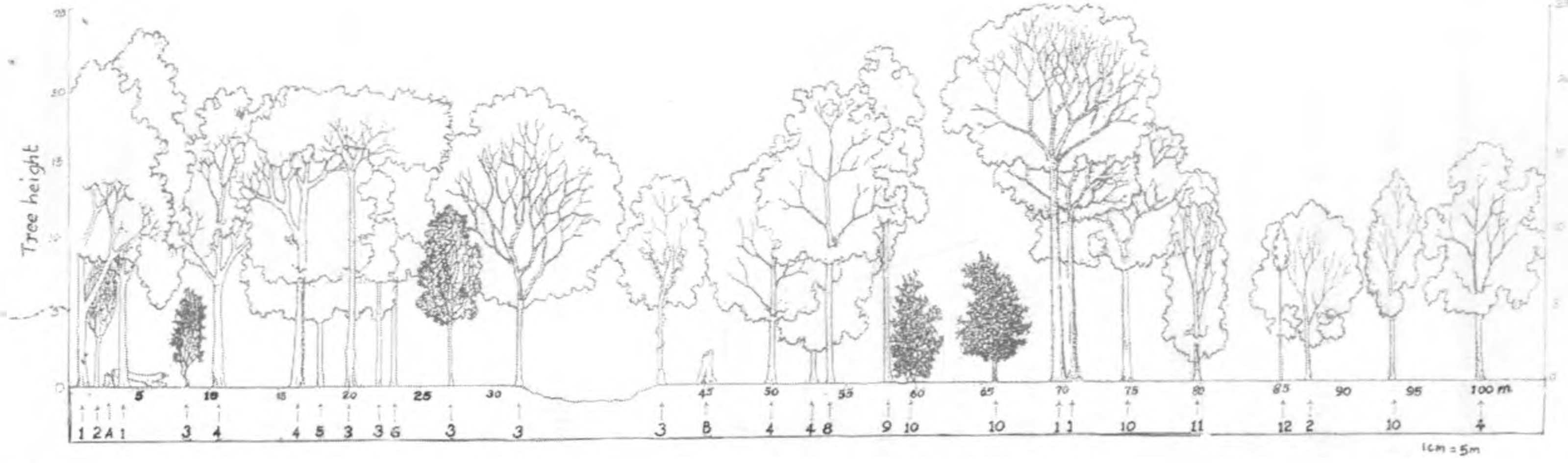

Figure 18: A profile diagram of the dry forest at Kithoka area; GPS coordinates - N 0° 08.065' E 37° 39.564', Altitude 1514 m asl

Species key

1. Celtis africana, 2. Uvariodendron anisatum, 3. Pittosporum viridiflorum, 4. Calodendrum capense, 5. Ritchea albersii, 6. Teclea trichocarpa, 7. Teclea simplicifolia, 8. Croton megalocarpus, 9. Ficus sp., *10. Olea europaea, 11. Ehretia cymosa, 12. Strychnos henningsii, A. P.viridiflorum log, B. O. europaea stump.*

CHAPTER FOUR

4.0 DISCUSSION, CONCLUSION AND RECOMMENDATIONS

4.1 Discussion

4.1.1 Characteristic species and the accuracy of vegetation map

Forest ecosystems are made up of different species which can be considered individually or as communities depending on their ecological adaptations (Hitimana *et al.*, 2004). Suitable indicator species allow for a rapid assessment of forest structure and quality (Althof, 2005). Hayashi *et al.* (2006) noted that floristic composition is important as some species could be used as indicator of variations in environmental conditions in a forest due to their unique ecological requirements. Following Trapnell (1997) checklist, only a sub set of twenty one species were indentified from both forests (Appendix 1). There was an overlap, where characteristic species associated with moist forest occurred in dry forest and vice versa. For instance, most of the characteristic species of dry forest occurred in the moist forest except for *Schrebera alata* and *S. henningsii.* In the moist forest, the *P. maxima* was the only characteristic species that occurred in the dry forest.

Moreover, other characteristic species for moist and dry montane vegetation types were also recorded. Characteristic species for moist montane forest that were recorded included *X. monospora, Macaranga kilimandscharica, V. keniensis, Ocotea kenyensis* and *Tabernaemontana stapfiana* while *Dovyalis abyssinica, Juniperus procera, Mystroxylon aethiopicum, P. viridiflorum, Ochna holstii* and *R. albersii* were for dry montane zone. The overlap of these characteristic species could be related to their wider ecological adaptation. Kindt *et al.* (2007) reported similar overlaps and attributed such species composition patterns to ecotone characteristics. Fewer characteristic species recorded could be attributed to the fact that most of the initial moist and dry intermediate forest zones have been cleared for human settlement (Gathara, 1999). Therefore, low density of the characteristic species that was not significantly different ($p>0.05$) was recorded. The presence of Trapnells' characteristic species in Imenti forest is an indication that the revised vegetation map is accurate.

4.1.2 Species composition and diversity

Species composition results showed that the most abundant species in the moist forest included *X. monospora, R. albersii*, *Cordia africana* and *E. cymosa* while in the dry forest they consists of *O. europaea, P. viridiflorum, C. capense* and *O. capensis.* However, other species were abundant in both vegetation types such *E. cymosa, R. albersii, P. viridiflorum, Diospyros abyssinica* and *C. sylvaticus.* In terms of distribution, the results showed that most frequent species in both moist and dry forest were different. In the moist forest, *Cordia africana, E. cymosa* and *C. sylvaticus* were the most frequent compared to *O. europaea, C. capense* and *E. cymosa* in the dry forest. The most frequent species indicated that they could probably have a wider ecological tolerance compared to the other species in each respective forest type.

Ordination results indicated that the species composition of moist and dry forest was different as they were clearly separated. However, in the dry forest, similarity was high since there was no clear separation in species composition. Sites in moist forest were more separated than was in the dry forest indicating a higher dissimilarity in species composition. This could be attributed to higher altitudinal variations of the moist forest sites as compared to dry forest. Similar work by Musila *et al.* (2009) in Chogoria and Sirimon also found a high dissimilarity in species composition between and within the zones. Moreover, there seemed to be an overlap as some quadrats in moist forest were categorized in dry forest especially in Magondu and Kithima zone.

This was attributed to their closeness to the vegetation boundary of the two forests hence a gradual change in species composition.

Species diversity is among the most important parameters for ecological assessments that have been used in various studies in tropical forests (Mligo *et al.*, 2009). Species diversity results show that there was no difference in diversity within the sites of the moist and dry forest and also between the moist and dry forests ($p>0.05$). Species accumulation curves showed that moist forest recorded more species than the dry forest concurring with findings by Sjöberg and Swenson, (1990). This could be attributed to variation in ecological factors including rainfall, soil quality, spatial and temporal heterogeneity within the study area. Rainfall is an important environmental factor which influences ecological ranges of plant species by affecting the micro-habitats resulting to variation in vegetation composition (Hayashi *et al.*, 2006). A Similar study by Musila *et al.* (2009) recorded higher species richness in Chogoria area on the windward side than Sirimon on the leeward side of Mt. Kenya. A section of Imenti forest especially Nkunga and Nchoroiburu area occur on the rain shadow zone between north of Mt. Kenya and northwest of the Nyambeni Hills according to Bernard (1972), as cited by Sjöberg and Swenson, 1990). Vegetation composition and structure in these areas seemed to reflect a dry ecosystem as indicated by the characteristic species.

Regeneration of forest can be measured by the recruitment and successful establishment of various tree species (Wassie *et al.*, 2009). The presence of saplings is an indication of good reproduction of certain species in both forests. The recruitment of saplings in a forest ecosystem show growing populations and thus ecological stability (Lulekal *et al.*, 2008). The saplings recorded during the study indicated that moist forest had a higher diversity ($p<0.05$) compared to the dry forest. Some saplings were more established than others such as *B. unijugata, P.*

viridiflorum and *Euclea schimperi* in moist forest with *R. albersii, P. viridiflorum* and *Uvariodendron anisatum* in dry forest. Successful seedling development is mainly hampered by several factors such as variations in environmental gradient, light penetration, forest litter thickness and seed quality (Wassie *et al.*, 2009). Therefore, poor regeneration of some species within the two forests could be attributed to such factors.

Most forest ecosystem contains rare, endemic or threatened plant species (Beentje, 1994). From the species composition results, some of plant species that are of conservation concern are *P. maxima, J. procera, O. europaea, U. anisatum* and *P. africana*. The *Fagaropsis angolensis* which has medicinal values among the local communities was recorded during the study period although Sjöberg and Swenson (1990) had suggested that it had been cleared.

4.1.3 Vegetation structure

Density is an important ecological component which reflects how individuals are distributed in an ecosystem. Tree density results indicated that there were variations ($p < 0.05$) in mean densities among the sites of moist and dry forest but the overall mean tree density between the moist and dry forests was not significant ($p>0.05$). The mean tree density in each forest type was higher compared to that of Kakamega forest as found out by Althof, (2005). According to Grubb *et al.* (1963), differences in tree density in forest ecosystems could be attributed to variations in micro-habitats such as slope, soil, altitude and disturbance regimes. Tree density is also related to patterning of various species in a forest ecosystem (Althof, 2005). In the dry forest, clumps of some species such *O. europaea* and *C. capense* were conspicuous. Sjöberg and Swenson, (1990) noted that the clumped *Olea - Rhamnus* vegetation in the dry forest form dense foliage layers affecting the development of other species.

Structurally, important value index (IVI) is a good indicator of species dominance and their significant role they play in influencing the biodiversity of forest ecosystems (Coroi *et al*., 2004). In the moist forest, species such as the *Cordia africana*, *E. cymosa, F. thonningnii* and *X. monospora* had the highest important value index. Similarly, the *O. europaea, P. viridiflorum, C. capense* and *Celtis africana* showed highest IVI in the dry forest. Nevertheless, some species such as *C. africana, E. cymosa, M. lutea* and *C. sylvaticus* showed a high IVI in both forests (Appendix 5 and 6).

Lulekal *et al*. (2008) observed that species with large basal area have a higher relative dominance making such species to be dominant among forest communities. The results indicated that most of the species that had the highest importance value index in the two forests types had high basal area. The basal area of moist and dry forests in Imenti was higher compared to Mt. Elgon as noted by Hitimana *et al.* (2004). However, it is lower than that of Mana Angetu forest in Ethiopia according to Lulekal *et al*. (2008).

However, not all the species that had high values of IVI recorded large values of relative density and relative frequency. In the moist forest, species of *X. monospora, R. albersii* and *Cordia africana* recorded the highest values of relative densities compared to *O. europaea, P. viridiflorum* and *O. capensis* in the dry forest. Survey work by Sjöberg and Swenson (1990) noted high densities of similar species. In terms of relative frequency, species of *Cordia africana*, *E. cymosa* and *C. sylvaticus* had higher values in moist forest similar to *O. europaea, C. capense* and *E. cymosa* in the dry forest.

Vegetation regeneration patterns are normally identified by the structural analyses of stem and age of individuals within populations (Chege and Bytebjer, 2005). Therefore, such patterns may enhance the understanding of the relationship between forest structure, diversity and composition aspects. In this study, both vegetation types had highest numbers of tree individuals' occurring in the lower DBH size classes. However, the numbers of trees in the intermediate DBH size classes declined gradually with few individuals occurring above DBH >100 cm. Some of the species that occurred in this DBH classes were *M. lutea, Ficus sp., P. africana, B. unijugata* and *Celtis africana.*

DBH graph (Figure 14) indicated that the vegetation structure of the moist and dry forest had an inverse J-shape. A study by Althof (2005) in Kakamega forest found a similar vegetation pattern and structure. Forests with an inverse-J shape indicate that regeneration is taking place hence moving towards ecological stability (Mligo *et al.*, 2009). Moreover, this could be an indication that the forest had been previously subjected to exploitation pressure with the resultant DBH size classes being skewed to the lower size classes.

According to Sjöberg and Swenson (1990), Imenti forest has undergone a lot of human disturbance where there has been selective logging of certain tree species. Lehmann and Kioko (2005) noted that selective logging of trees reduces the basal area and stem density of forest communities allowing trees with small DBH to thrive. Trapnell (1997) observed that Mt. Kenya forest has a lot of secondary vegetation with only a few trees with large DBH. Such individuals could be used as indicators of the previous primary forests due to human and natural disturbances (Althof, 2005).

In terms of tree heights (Figure16), results indicated that high numbers were recorded in the lower height classes of 5 - 9.9 m and gradually declined in the other classes. Therefore, most of the species formed the third (under storey) stratum. Few trees reached height of over 25 m in both forests. Some of the species that had attained such heights included *Cordia africana, P. africana, Celtis africana, T. emetica* and *P. viridiflorum.* There is a strong relation between DBH size (age) and tree height. In tropical forests, size is often used as an indication of age where large tree are assumed to be older than smaller one in some species (Hitimana *et al,*. 2004).

The profile diagrams (Figures 16 and17) indicated that moist forest had a more closed canopy compared to dry forest. Three distinct strata occurred in the moist forest. The upper stratum consisted of tree species with height above 20 m such as *Cordia africana, Celtis africana, C. sylvaticus* and *C. battiscombei.* The middle stratum with height between 12-18 m was made up of trees such as *X. monospora, R. urcelliformis* and *E. cymosa.* The under-storey consisted of trees about 5-10 m where *Erythrococca bongensis, Flacourtica indica* and *T. simplisifolia.*

In the dry forest, only two strata could be distinguished. The upper stratum consisted of tree species like the *Celtis africana, C. capense* and *Ficus sp.* among others. The second stratum was made up of *O. europaea, T. simplisifolia* and *R. albersii.* The lack of under-storey trees (stratum) in the dry forest could be attributed to poor recruitment and establishment of saplings. Similarly, Sjöberg and Swenson (1990) observed a poor strata development and decreased tree height in the drier parts of the forest.

4.2 Conclusions

From this study, it has been observed that:

1. Species composition of the two forests was different as moist and dry forests were clearly separated by ordination analysis.
2. Species diversity of moist and dry forests was not different while tree density differed within the sites of two forests.
3. Most individuals occurred in smaller DBH class sizes indicating that the two forests are re-generating and moving towards stability. The few trees with heights of more than 20 m could be used as remnant indicators of climax vegetation of Imenti forest.
4. Depending on the characteristic tree species of moist and dry forests, the accuracy of the revised vegetation map of Mt. Kenya forest was confirmed to be true.

4.3 Recommendations

1. Future research work should focus on documentation of all other life forms of vegetation in the moist and dry forest since this work concentrated on woody species. This would help to establish a detailed vegetation inventory giving baseline information which is important for achieving the long-term objective of the project in monitoring variation in natural vegetation due current land use systems and climate change over time.

2. Kenya Forest Service (KFS) should enhance security patrols and surveillance in order to stop illegal logging of mature trees and charcoal burning. The stalled electric fence project at lower Imenti forest should be completed to reduce human encroachment.

3. Instead of allowing natural regeneration to occur which takes long periods, re-forestation programme should be enhanced in order to restore those areas which have been degraded. Indigenous species should be encouraged and especially those species which are of conservation concern within Mt. Kenya ecosystem such *P. maxima, J. procera, P. africana* and *O. capensis* among others. The local community should be integrated in the re-afforestation programes.

4. There is a need to develop those sites with eco-tourism potential such as the Lake Nkunga and 'King Muuru' (oldest and largest *V. keniensis* tree) in the area. This can be a collaborative initiative of KFS, KWS and other partners for the benefits of the local community.

5. There is a need to control cattle grazing especially in the reforested zones to allow for successful establishment of planted trees. Goats and camels should be restricted from the forest.

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APPENDICES

Appendix 1: The occurrence of characteristic tree species in moist and dry forests. The species were sorted from the Trapnell indicator species checklist (1987).

Moist intermediate	**Dry intermediate**
Allophylus ferrugineus	*Acokanthera schimperi**
*Blighia unijugata**	*Albizia schimperiana*
*Celtis gomphophylla**	*Brachylaena huillensis*
Celtis mildbraedii	*Calodendrum capense**
*Chaetacme aristata**	*Cassipourea rotundifolia*
*Cordia africana**	*Chrysophyllum viridifolium*
Ficus exasperata	*Craibia brownii*
*Lecaniodiscus fraxinifolius**	*Elaeodendron buchananii**
*Lovoa swynnertonii**	*Euphorbia cussonoides*
Manilkara butugi	*Heywoodia lucens*
*Milicia excelsa**	*Manilkara discolor*
*Myrianthus holstii**	*Margaritaria discoidea**
Newtonia buchananii	*Psydrax schimperiana*
Polyscias fulva	*Rawsonia lucida**
*Premna maxima**	*Schrebera alata**
Rauvolfia caffra	*Strychnos henningsii**
Spathodea campanulata	*Strychnos mitis*
Tabernaemontana ventricosa	*Teclea simplicifolia**
Trichilia dregeana	*Teclea trichocarpa**
*Trichilia emetica**	*Uvariodendron anisatum**
*Trilepisium madagascariense**	

Note. Species with asterics (*) were confirmed in their respective vegetation type

Appendix 2: The abundance of tree species in moist forest

Family	Species	Abundance
Monimiaceae	*Xymalos monospora* (Harv.) Baill.	129
Capparaceae	*Ritchiea albersii* Gilg	104
Boraginaceae	*Cordia africana* Lam.	91
Boraginaceae	*Ehretia cymosa* Thonn.	82
Ebenaceae	*Diospyros abyssinica* (Hiern) F.White	77
Euphorbiaceae	*Croton sylvaticus* Hochst.	69
Apocynaceae	*Tabernaemontana stapfiana* Britten	65
Verbenaceae	*Vitex keniensis* Turrill	55
Ulmaceae	*Trema orientalis* (L.) Blume	49
Euphorbiaceae	*Neoboutonia macrocalyx* Pax	42
Rutaceae	*Clausena anisata* (Willd.)Hook.f.ex Benth.	41
Rutaceae	*Teclea trichocarpa* (Engl.) Engl.	40
Rubiaceae	*Vangueria* spp.	39
Ulmaceae	*Celtis africana* Burm.f.	37
Rutaceae	*Fagaropsis angolensis* (Engl.) Dale	34
Pittosporaceae	*Pittosporum viridiflorum* Sims	30
Melianthaceae	*Bersama abyssinica* Fres.	28
Bignoniaceae	*Markhamia lutea* (Benth.) K.Schum.	27
Sapindaceae	*Blighia unijugata* Baker	24
Rutaceae	*Calodendrum capense* (L.f.) Thunb.	23
Euphorbiaceae	*Erythococca bongensis* Pax	22
Verbenaceae	*Premna maxima* T.C.E.Fr.	20
Flacourtiaceae	*Casaeria battiscombei* R. E. Fr.	19
Annonaceae	*Uvariodendron anisatum* Verdc.	18
Rubiaceae	*Rothmannia urcelliformis* (Hiern) Robyns	17
Rubiaceae	*Rytigynia uhligii* (K. Schum. & K. Krause) Verdc.	16
Meliaceae	*Turraea abyssinica* Hochst.ex A.Rich.	15
Meliaceae	*Trichilia emetica* Vahl.	14
Rutaceae	*Teclea simplicifolia* (Engl.) I.Verd.	12
Euphorbiaceae	*Croton macrostachyus* Hochst.ex Delile	11
Oleaceae	*Olea capensis* L.	11
Ebenaceae	*Euclea schimperi* (A. DC.) Dandy	10
Euphorbiaceae	*Sapium ellipticum* (Hochst.) Pax	10
Oleaceae	*Olea europaea* L.	10
Flacourtiaceae	*Rawsonia lucida* Harv. & Sond.	9
Moraceae	*Ficus thonningii* Blume	9
Rosaceae	*Prunus africana* (Hook. f.) Kalkman	9
Celastraceae	*Elaeodendron buchananii* (Loes.) Loes.	7
Flacourtiaceae	*Oncoba spinosa* Forssk.	7
Moraceae	*Trilepisium madagascariense* DC.	6

Araliaceae	*Cussonia holstii* Harms ex Engl.	5
Euphorbiaceae	*Croton megalocarpus* Hutch.	5
Euphorbiaceae	*Macaranga kilimandscharica* Pax	5
Flacourtiaceae	*Dovyalis abyssinica* (A. Rich.) Warb.	5
Moraceae	*Myrianthus holstii* Engl.	5
Rhizophoraceae	*Cassipourea malosana* (Baker) Alston	5
Rubiaceae	*Tarenna graveolens* (S.Moore) Bremek.	5
Rutaceae	*Zanthoxylum chalybeum* Engl.	5
Sapindaceae	*Lecaniodiscus fraxinifolius* Baker	5
Bignoniaceae	*Kigelia moosa* Sprague	4
Papilionaceae	*Millettia dura* Dunn	4
Papilionaceae	*Lonchocarpus bussei* Harms	4
Anacardiaceae	*Sclerocarya birrea* (A.Rich.)Hochst.	3
Capparaceae	*Maerua* sp.	3
Euphorbiaceae	*Margaritaria discoidea* (Baill.) G.L. Webster	3
Flacourtiaceae	*Flacourtia indica* (Burm. f.) Merr.	3
Mimosaceae	*Albizia gummifera* (J.F. Gmel.) C. A. Sm.	3
Apocynaceae	*Acokanthera schimperi* (A.DC.) Schweinf.	2
Bignoniaceae	*Jacaranda mimosifolia* D.Don	2
Caesalpiniaceae	*Bauhinia tomentosa* L.	2
Lauraceae	*Ocotea kenyensis* (Chiov.) Robyns & R.Wilczek	2
Mimosaceae	*Albizia schimperiana* Oliv.	2
Meliaceae	*Lovoa swynnertonii* Baker f.	2
Moraceae	*Ficus* spp.	2
Moraceae	*Milicia excelsa* (Welw.) C.C. Berg	2
Rutaceae	*Teclea nobilis* Delile	2
Sapindaceae	*Deinbollia kilimandscharica* Taub.	2
Apocynaceae	*Landolphia buchananii* (Hallier f.) Stapf	1
Caesalpiniaceae	*Senna didymobotrya* (Fresen.) H.S.Irwin & Barneby	1
Capparaceae	*Capparis* sp.	1
Combretaceae	*Combretum molle* R.Br. ex G. Don	1
Compositae	*Vernonia auriculifera* Hiern	1
Cupressaceae	*Juniperus procera* Hochst .ex Endlicher.	1
Euphorbiaceae	*Euphorbia glochidiata* Pax	1
Papilionacea	*Dalbergia* sp.	1
Maliaceae	*Ekebergia capensis* Sparrm.	1
Meliaceae	*Melia azedarach* L.	1
Mimosaceae	*Acacia sieberiana* DC.	1
Mimosaceae	*Acacia* sp.	1
Moraceae	*Ficus vallis*-choudae Delile.	1
Ochnaceae	*Ochna holstii* Engl.	1
Rhamnaceae	*Rhamnus prinoides* L'Her.	1

Rubiaceae	*Psydrax parviflora* (Afzel.) Bridson	1
Rubiaceae	*Psychotria* sp.	1
Thymelaeaceae	*Peddiea fischeri* Engl.	1
Ulmaceae	*Celtis gomphophylla* Baker	1
Ulmaceae	*Chaetacme aristata* Planch.	1
	Total	**1452**

Appendix 3: The abundance of tree species in dry forest

Family	**Species**	**Abundance**
Oleaceae	*Olea europaea* L.	134
Pittosporaceae	*Pittosporum viridiflorum* Sims	94
Rutaceae	*Calodendrum capense* (L.f.) Thunb.	77
Oleaceae	*Olea capensis* L.	70
Boraginaceae	*Ehretia cymosa* Thonn.	65
Ulmaceae	*Celtis africana* Burm.f.	61
Capparaceae	*Ritchiea albersii* Gilg	57
Flacourtiaceae	*Rawsonia lucida* Harv. & Sond.	47
Euphorbiaceae	*Croton sylvaticus* Hochst.	38
Rubiaceae	*Vangueria* spp.	37
Rutaceae	*Teclea trichocarpa* (Engl.) Engl.	34
Ebenaceae	*Diospyros abyssinica* (Hiern) F.White	32
Annonaceae	*Uvariodendron anisatum* Verdc.	29
Loganiaceae	*Strychnos henningsii* Gilg	24
Rutaceae	*Clausena anisata* (Willd.) Hook.f.ex Benth.	22
Bignoniaceae	*Markhamia lutea* (Benth.) K.Schum.	20
Euphorbiaceae	*Erythococca bongensis* Pax	19
Apocynaceae	*Acokanthera schimperi* (A.DC.) Schweinf.	14
Euphorbiaceae	*Margaritaria discoidea* (Baill.) G.L.Webster	13
Rutaceae	*Teclea simplicifolia* (Engl.) Verdoorn	13
Ebenaceae	*Euclea schimperi* (A. DC.) Dandy	11
Cupressaceae	*Juniperus procera* Hochst .ex Endlicher.	10
	Turraea sp.	10
Oleaceae	*Schrebera alata* (Hochst.) Welw.	9
Papilionaceae	*Lonchocarpus bussei* Harms	9
Euphorbiaceae	*Croton megalocarpus* Hutch.	8
Rutaceae	*Zanthoxylum chalybeum* Engl.	7
Verbenaceae	*Premna maxima* T.C.E.Fr.	6
Anacardiaceae	*Rhus* sp.	5
Capparaceae	*Maerua* sp.	5

Melianthaceae	*Bersama abyssinica* Fresen.	4
Celastraceae	*Mystroxylon aethiopicum* (Thunb.)Loes.	3
Ebenaceae	*Euclea divinorum* Hiern	3
Moraceae	*Ficus* spp.	3
Moraceae	*Ficus thonningii* Blume	3
Rubiaceae	*Rothmannia* sp.	3
Rubiaceae	*Rytigynia uhligii* (K. Schum. & K. Krause) Verdc.	3
Rutaceae	*Teclea nobilis* Delile.	3
Anacardiaceae	*Rhus vulgaris* Meikle	2
Caesalpiniaceae	*Bauhinia tomentosa* L.	2
Celastraceae	*Maytenus heterophylla* (Eckl. & Zeyh.)Robson	2
Celastraceae	*Maytenus* sp.	2
Euphorbiaceae	*Croton macrostachyus* Hochst. ex Delile	2
Flacourtiaceae	*Dovyalis abyssinica* (A. Rich.) Warb.	2
Flacourtiaceae	*Scolopia zeyheri* (Nees) Harv.	2
Flacourtiaceae	*Trimeria grandifolia* (Hochst.)Warb.	2
Maliaceae	*Ekebergia capensis* Sparrm.	2
Meliaceae	*Turraea abyssinica* Hochst. ex A.Rich.	2
Rutaceae	*Fagaropsis angolensis* (Engl.) Dale	2
Bignoniaceae	*Kigelia moosa* Sprague	1
Caesalpiniaceae	*Senna didymobotrya* (Fresen.)H.S. Irwin & Barneby	1
Combretaceae	*Combretum molle* R.Br. ex G. Don	1
Euphorbiaceae	*Neoboutonia macrocalyx* Pax	1
Icacinaceae	*Apodytes dimidiata* E.Mey. ex Arn.	1
Malvaceae	*Triumfetta tomentosa* Bojer	1
Mimosaceae	*Acacia sieberiana* DC.	1
Oleaceae	*Chionanthus battiscombei* (Hutch.) Stearn	1
Rubiaceae	*Psydrax parviflora* (Afzel.) Bridson	1
Rubiaceae	*Psychotria* sp.	1
	Total	**1034**

Appendix 4: Sapling species abundance in moist and dry forests

Species (Moist forest)	**Abundance**
Blighia unijugata Baker	18
Pittosporum viridiflorum Sims	16
Bersama abyssinica Fres.	13
Ehretia cymosa Thonn.	13
Euclea schimperi (A. DC.) Dandy	13
Fagaropsis angolensis (Engl.) Dale	13
Trema orientalis (L.) Blume	12
Markhamia lutea (Benth.) K.Schum.	9
Maytenus sp.	9
Teclea simplicifolia (Engl.) Verd.	8
Diospyros abyssinica (Hiern) F.White	7
Rawsonia lucida Harv. & Sond.	7
Rytigynia uhligii (K. Schum. & K. Krause) Verdc.	7
Cordia africana Lam.	6
Teclea nobilis Delile	6
Neoboutonia macrocalyx Pax	5
Rothmannia urcelliformis (Hiern) Robyns	5
Casaeria battiscombei R. E. Fr.	3
Celtis africana Burm.f.	3
Croton sylvaticus Hochst.	3
Kigelia moosa Sprague	3
Dovyalis abyssinica (A. Rich.) Warb.	2
Milletia dura Dunn	2
Trichilia emetica Vahl.	2
Trilepsium madagascariense DC.	2
Xymalos monospora (Harv.)Baill.	2
Croton megalocarpus Hutch.	1
Deinbollia kilimandscharica Taub.	1
Uvariodendron anisatum Verdc.	1
Total	**192**
Dry forest	
Ritchiea albersii Gilg	21
Pittosporum viridiflorum Sims	14
Uvariodendron anisatum Verdc.	12
Celtis africana Burm.f.	7
Olea europeae L.	7
Rawsonia lucida Harv. & Sond.	6
Ehretia cymosa Thonn.	5

Croton megalocarpus Hutch.	4
Teclea nobilis Delile	4
Calodendrum capense (L.f.) Thunb.	4
Rytigynia uhligii (K. Schum. & K. Krause) Verdc.	3
Albizia gummifera (JF Gmel.) C. A. Sm.	1
Euclea schimperi (A. DC.) Dandy	1
Premna maxima T.C.E.Fr.	1
Total	**90**

Appendix 5: Species Importance Value Index (IVI) in the moist forest

Species	**Relative density**	**Relative frequency**	**Relative dominance**	**(IVI)**
Cordia africana	6.28	5.23	9.96	21.47
Ehretia cymosa	5.66	4.51	4.54	14.72
Xymalos monospora	8.91	1.63	3.34	13.89
Ficus thonningnii	0.62	1.90	11.20	13.72
Diospyros abyssinica	5.32	2.85	4.08	12.25
Croton sylvaticus	4.77	4.28	1.92	10.96
Celtis africana	2.42	3.09	5.08	10.59
Vitex keniensis	3.80	1.19	5.52	10.51
Markhamia lutea	1.86	3.09	5.48	10.44
Neoboutonia macrocalyx	2.90	3.33	3.11	9.34
Teclea trichocarpa	2.76	2.85	3.19	8.81
Ritchiea albersii	7.18	0.24	0.96	8.38
Pittosporum viridiflorum	2.07	2.14	3.66	7.87
Clausena anisata	2.83	3.56	0.67	7.07
Tabernaemontana stapfiana	4.49	0.71	1.52	6.72
Blighia unijugata	1.66	1.43	3.51	6.60
Vangueria spp.	2.69	2.85	1.01	6.56
Prunus africana	0.62	1.43	4.43	6.48
Casaeria bathiscombei	1.31	1.66	3.48	6.45
Trema orientalis	3.38	0.71	1.80	5.90
Fagaropsis angolensis	2.35	2.38	0.89	5.62
Bersama abyssinica	1.93	2.61	0.39	4.93
Calodendrum capense	1.59	1.43	1.52	4.53
Premna maxima	1.38	2.14	0.81	4.33
Teclea simplicifolia	0.83	2.61	0.77	4.21
Trichilia emetica	0.97	1.19	2.04	4.10
Erythrococca bongensis	1.52	2.38	0.25	4.15
Sapium ellipticum	0.69	0.71	2.43	3.83

Rytigynia uhligii	1.10	1.90	0.07	3.08
Elaedendron buchananii	0.48	0.71	1.53	2.72
Turraea abyssinica	1.04	1.19	0.44	2.66
Zanthoxylum chalybeum	0.35	1.90	0.35	2.60
Uvariodendron anisatum	1.24	1.19	0.15	2.58
Rawsonia lucida	0.62	1.66	0.15	2.43
Olea europaea	0.69	1.19	0.41	2.28
Croton macrostachyus	0.76	0.95	0.39	2.10
Tarenna graveolens	0.35	1.66	0.06	2.07
Margaritaria discoidea	0.21	0.71	1.08	2.00
Sclerocarya birrea	0.21	1.19	0.58	1.97
Rothmannia urcelliformis	1.17	0.48	0.27	1.92
Myrianthus holstii	0.35	0.95	0.49	1.79
Olea capensis	0.76	0.71	0.18	1.65
Lovoa swynnertonii	0.14	0.48	1.01	1.63
Ocotea kenyiensis	0.14	0.48	0.95	1.56
Euclea schimperi	0.69	0.48	0.24	1.41
Macaranga kilimandascharica	0.35	0.24	0.78	1.36
Dovyalis abyssinica	0.35	0.95	0.05	1.34
Oncoba spinosa	0.48	0.71	0.09	1.29
Ochna holstii	0.07	1.19	0.00	1.26
Trilepisium madagascariense	0.41	0.71	0.07	1.19
Maerua sp.	0.21	0.71	0.26	1.18
Croton megalorcarpus	0.35	0.48	0.26	1.08
Kigelia moosa	0.28	0.71	0.06	1.05
Lonchocarpus bussei	0.28	0.71	0.06	1.05
Psydrax parviflora	0.07	0.95	0.03	1.04
Peddiea fischeri	0.07	0.95	0.00	1.02
Milletia dura	0.28	0.71	0.03	1.02
Albizia schimperiana	0.14	0.24	0.59	0.97
Albizia gummifera	0.21	0.48	0.23	0.91
Cassipourea malosana	0.35	0.48	0.04	0.86
Ficus spp.	0.14	0.48	0.20	0.82
Ficus vallis	0.07	0.24	0.40	0.71
Cussonia holstii	0.35	0.24	0.09	0.68
Jacaranda mimosifolia	0.14	0.48	0.06	0.68
Acokanthera schimperi	0.14	0.48	0.04	0.65
Teclea nobilis	0.14	0.48	0.02	0.63
Lecaniodiscus fraxinifolius	0.35	0.24	0.01	0.60
Vernonia auriculifera	0.07	0.48	0.01	0.56
Psychotria sp.	0.07	0.48	0.01	0.55
Milicia excelsa	0.14	0.24	0.17	0.55
Flacourtia indica	0.21	0.24	0.08	0.52

Bauhinia tomentosa	0.14	0.24	0.02	0.39
Euphorbia glochidiata	0.07	0.24	0.09	0.39
Deinbollia kilimandscharica	0.14	0.24	0.01	0.38
Ekebergia capensis	0.07	0.24	0.05	0.36
Chaetacme aristata	0.07	0.24	0.05	0.35
Juniperus procera	0.07	0.24	0.04	0.35
Celtis gomphophylla	0.07	0.24	0.03	0.34
Combretum molle	0.07	0.24	0.03	0.34
Landolphia buchananii	0.07	0.24	0.02	0.33
Capparis sp.	0.07	0.24	0.02	0.33
Acacia sieberiana	0.07	0.24	0.02	0.32
Rhamnus prinoides	0.07	0.24	0.01	0.32
Acacia sp.	0.07	0.24	0.01	0.31
Dalbergia lactea	0.07	0.24	0.01	0.31
Senna didymobotrya	0.07	0.24	0.01	0.31
Melia azedarach	0.07	0.24	0.00	0.31
Totals	**100.00**	**100.00**	**100.00**	**300.00**

Appendix 6: Species Importance Value Index (IVI) in dry forest

Species	**R.density**	**R.frequency**	**R.dominance**	**IVI**
Olea europaea	12.93	7.32	21.41	41.66
Pittosporum viridiflorum	9.07	2.44	13.61	25.12
Calodendrum capense	6.76	6.97	7.74	21.46
Celtis africana	5.89	5.23	8.40	19.51
Olea capensis	7.92	5.92	4.76	18.60
Ehretia cymosa	6.27	6.62	2.65	15.54
Markhamia lutea	1.25	2.09	11.77	15.12
Vangueria sp.	3.57	4.88	0.41	8.86
Margaritaria discoidea	1.93	3.14	3.59	8.65
Croton sylvaticus	3.67	3.48	1.44	8.59
Ficus spp.	0.29	1.05	6.87	8.21
Diospyros abyssinica	3.09	2.44	1.42	6.95
Rothmannia sp.	5.50	0.70	0.19	6.39
Rawsonia lucida	4.54	0.35	1.02	5.91
Ritchiea albersii	0.29	3.48	1.82	5.59
Clausena anisata	2.12	3.14	0.14	5.40
Teclea simplicifolia	1.25	3.14	0.28	4.67
Euclea schimperi	1.25	3.14	0.24	4.63
Senna didymobotrya	2.32	1.39	0.02	3.73
Acokanthera schimperi	1.35	1.39	0.92	3.66

Ficus thonningnii	0.29	1.05	2.29	3.63
Uvariodendron anisatum	2.80	0.35	0.24	3.39
Teclea trichocarpa	2.41	0.35	0.54	3.30
Turraea sp.	0.97	1.74	0.36	3.07
Juniperus procera	0.97	1.05	0.99	3.00
Neoboutonia macrocalyx	0.10	2.79	0.02	2.90
Psydrax parviflora	0.10	2.79	0.01	2.89
Euclea divinorum	0.29	2.09	0.44	2.82
Teclea nobilis	0.29	2.44	0.03	2.76
Erythrococca bongensis	1.83	0.35	0.19	2.38
Schrebera alata	0.87	0.70	0.72	2.28
Zanthoxylum chalybeum	0.68	1.39	0.19	2.26
Premna maxima	0.58	0.35	1.12	2.05
Dovyalis abyssinica	0.19	0.70	0.99	1.88
Lonchocarpus bussei	0.87	0.70	0.14	1.71
Croton megalocarpus	0.77	0.70	0.24	1.71
Turraea abyssinica	0.19	1.39	0.05	1.63
Bersama abyssinica	0.39	1.05	0.03	1.46
Rytigynia uhligii	0.29	1.05	0.05	1.39
Maerua sp.	0.48	0.70	0.21	1.38
Rhus sp.	0.48	0.70	0.14	1.32
Maytenus sp.	0.19	0.70	0.12	1.01
Strychnos henningsii	0.10	0.35	0.56	1.01
Croton macrostachyus	0.19	0.70	0.09	0.98
Fagaropsis angolensis	0.19	0.35	0.43	0.98
Mystroxylon aethiopicum	0.39	0.35	0.22	0.96
Triumfetta tomentosa	0.19	0.70	0.06	0.95
Maytenus heterophylla	0.19	0.35	0.16	0.71
Ekebergia capensis	0.19	0.35	0.08	0.62
Acacia sieberiana	0.10	0.35	0.15	0.59
Apodytes dimidiata	0.10	0.35	0.14	0.58
Rhus vulgaris	0.19	0.35	0.04	0.58
Scolopia zeyheri	0.19	0.35	0.03	0.57
Bauhinia tomentosa	0.19	0.35	0.01	0.55
Psychotria sp.	0.10	0.35	0.08	0.53
Combretum molle	0.10	0.35	0.05	0.49
Chionanthus battiscombei	0.10	0.35	0.04	0.49
Trimeria grandifolia	0.10	0.35	0.03	0.48
Kigelia moosa	0.10	0.35	0.02	0.47
Totals	**100.00**	**100.00**	**100.00**	**300.00**