ASSESSMENT OF ECOLOGICAL FACTORS LIMITING TROPICAL RAIN FOREST REGENERATION: CASE STUDY OF KAKAMEGA FOREST, WESTERN KENYA

BY

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT FOR THE DEGREE OF MASTERS OF SCIENCE UNIVERSITY OF NAIROBI

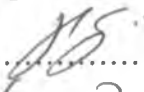## FEBRUARY 2010

Declaration

This thesis is my original work and has not been presented for award of a degree in any other university.

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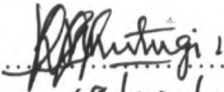
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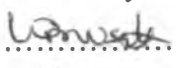
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Dedication

This thesis is dedicated to my dear parents Jairus Mukhongo and Joan Mukhongo for laying a good foundation for my education and inspiring me to attain the highest level in academics. I dedicate it also to my brothers and sisters who have been a source of encouragement and support through out my study.

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List of abbreviations and acronyms

BIOTA   Biodiversity Monitoring Transect Analysis

ANOVA   Analysis of variance

N.M.K.   National Museums of Kenya

ISTA   International Seed Testing Association

KEFRI   Kenya Forestry Research Institute

ICRAF   International Centre for Research and Agro forestry

%   Percentage

Ha.   Hectare

N   Nitrogen

K   Potassium

Ca   Calcium

C   Carbon

P   Phosphorus

Mg   Magnesium

N   North

E   East

EC   Electrical conductivity

SE   Standard error

M   Meters

Cm   Centimeters

mm   millimeters

cm^3	cubic centimeters.
gm^{-3}	grams per meter cube
ml	milliliters
μm	Micro-meter
g	Gram
kg	kilogram

Acknowledgement

Abstract

Slow rate of regeneration poses a major challenge to our depleted tropical rain forests, however soil seed bank has been deemed as the main source of forest regeneration. This study was designed to assess various biotic and abiotic factors in the southern part of Kakamega forest to verify their contribution to regeneration. Sampling was done in six habitats using three transects of 100m and 5×5 m quadrants. Aspects looked into were soil physical-chemical parameters, micro-climate, soil seed bank, seed viability and anthropogenic impacts.

The soil seed banks for all the habitats were mainly dominated by the herbaceous species. A vertical distribution of seeds in the seed bank revealed a high density in the upper soil layers for the secondary grassland, shrubland, natural glade and plantation. However, the burnt glade and the natural forest, had small variations in seed density with soil depth. The seed viability for the six habitats was low and ranged between 1.3-33.8%. Soil fertility for all the habitats was found to be generally low and highly depleted of nutrients. The pH was generally medium (it ranged between 5.3 to 6.09), making the soils weakly acidic in nature. The soils comprised of a high sand percentage, and were well drained. Anthropogenic impacts appeared to affect the regeneration of the forest. There were significant differences in the micro-climates of the habitats. The soil seed bank was found to be inadequately reliable for the regeneration of the forest because of its low viability and being dominated by other herbaceous species. Soil nutrients were found to be low for the support of the growth and establishment of seedlings. It was found that forest regeneration does not entirely rely on the soil seed bank but is affected much by other biotic and abiotic factors. The understanding of impacts of these factors gives a clear methodology on regeneration in the various habitats.

Key words: habitat, seed bank, micro-climate, soil fertility, viability, herbaceous species.

CHAPTER ONE

1.0 INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Forest regeneration is the act of renewing a forest or trees cover, which can be through coppicing, seed germination, root suckers and seedling planting (Zimmerman *et al.*, 2000; Obiri *et al.*, 2005). Slow seedling regeneration is the main threat that most tropical forests are currently faced with because of increased exploitation. Tropical forests harbour the richest biodiversity in the world yet they are becoming the chief centres of human - forest conflicts (Kirika, 2005). This is because they provide many valuable goods and services to mankind, which include construction timber, food, medicinal values, fibers, recreation and water catchment services. Man has been abusing tropical forests by over exploiting their resources (Bennun & Njoroge, 1999; Ludeki *et al.*, 2006). The estimated net global loss of forest is 7.3 million hectares per year, with tropical rain forests suffering the greatest net loss (FAO, 2006).

Recent decades have seen a serious biodiversity decline due to habitat loss and alteration especially of tropical forests leading to a profound species-extinction crisis (Heywood, 1995; Pimm *et al.*, 1995; Whitmore, 1997). Africa suffered a net loss of about 4.0 million hectares per year between 2000 and 2005 (FAO, 2006). Degraded natural forest habitats are most of the time invaded by non-wood plants such as ferns, vines, grasses and shrubs at the expense of woody species, which may take decades to recruit (Verheyen *et al.*, 2003). Much of tropical forest biodiversity is unlikely to survive without effective protection (Pimm *et al.*, 1995; Myers *et al.*, 2000) following extensive anthropogenic impact on the forests.

The decolonization process entails major shifts in life-form composition, relative abundance and species richness (Capers *et al.*, 2005). There is need to counteract the negative anthropogenic

impacts, conserve biodiversity and protect areas facing increasing levels of environmental degradation due to poaching, encroachment and logging (Gathua, 2000).

Kakamega forest and its associated fragments have been under severe anthropogenic pressure over years (Tsingalia, 1988; Mitchell, 2004). The indigenous forest has had its closed canopy cover decline progressively (KEFRI, 2006). The main agents of degradation of the forest being selective logging for very large trees since 1940s (Cords, 1987; Tsingalia, 1988). The forest also suffers from some illegal exploitation through trees felling for poles, liana cutting during removal of dead firewood, honey harvesting and medicinal use (Kokwaro, 1988; Fashing *et al.*, 2004; Mitchell, 2004). These activities pose a threat to this ecosystem because of its slow natural regeneration (Tsingalia, 1988; Mitchell, 2004). The original size of Kakamega forest which was once a vast natural forestland is constantly declining at an alarming rate (Kirika, 2005).

Interactions among abiotic environments, micro site variation and seed genotypes determine which soil seeds successfully germinate and establish into surface plant populations (Robert *et al.*, 2000). Therefore slow regeneration in Kakamega forest could be attributed to factors such as lack of viable seeds in the soil seed bank, depletion of the soil seed bank, unconducive micro-climate, depletion of soil nutrients and anthropogenic factors (e.g. grazing, firewood collection and soil compaction). These factors could impinge on regeneration singly or in concert, this study was to verify the cause of slow regeneration in Kakamega forest.

1.2 Literature review

1.2.1 Forest regeneration

There is scanty information on relative influence of mature forest on forest regeneration at regional scale, of up to hundreds of square kilometers, where other landscape attributes such as climate and soils may become important (Turner *et al.*1995). Regeneration depends on germination of recently released seeds and the periodic renewal of immature individuals (Brokaw, 1985). Plants show a difference in their regeneration following variations in their flowering, fruiting, germination and seedling growth which may contribute to coexistence. Plant population size depends on germination and the availability of safe micro-sites for germination (Guariguata & Dupuy, 1997). Regeneration niche is not only key to understanding coexistence but also understanding distribution on a large spatial scale. There is a difference in plant germination season and broad germination season. Plants with a broad germination niche are able to recruit new individuals throughout the year (Guariguata & Dupuy, 1997). Several barriers to forest regeneration have been identified and include: low seed viability, soil infertility, low propagule availability, high levels of seed and seedling predation, root competition, low light levels underneath a thick layer of other herbaceous material, and annual fires (Aide & Cavelier, 1994).

Work done on regeneration generally shows that large trees regenerate poorly compared to other species (Zimmerman *et al.*, 2000). Work done on regeneration has revealed that, species regenerating abundantly differ from those dominating the stand (Barik *et al.*, 1996; Abdella *et al.*, 2007). Also seedlings of any one of the dominant species may be completely absent on the forest floor (Abdella *et al.*, 2007). Guariguata & Dupuy (1997) describing regeneration of dipterocarp forest of Adam Island, noticed a preponderance of mature and over mature trees but few younger age classes and a completely absence of seedlings and saplings. The only seedlings present were on roadsides, abandoned campsites and recently felled areas.

1.2.2 Seed dispersal

Seed dispersal greatly influences regeneration patterns of a forest. Dispersed seeds may be the main source of trees propagules in the grasslands, since regeneration via seedlings, trees sprouts, and the seed bank is often eliminated after several years of cultivation. This conclusion is supported by the fact that the majority of forest area expansion occurs within 100m of previously established forest. For example, Gutterman *et al.* (2007) found out that, forest regeneration decreased with increasing distance from established forest. Seed dispersal enables seeds to escape seed predation, competition and increases the chances of seeds landing in micro sites suitable for germination, growth and establishment. Seed dispersal distances vary depending on whether propagules are wind or animal-dispersed (Dalling *et al.*, 1997). For example, wind-dispersed trees seeds can travel more than 100 m from their source in undisturbed forest, but most seeds fall within 30m radius from the parent (Augspurger, 1983; Kitajima & Augspurger, 1989; Viana, 1990). Although poorly studied and understood, dispersal movements and fate of seed may critically affect the subsequent structure of many plant communities (Robert *et al.*, 2000). However it has been argued that wind dispersal is rare in tropical rain forests (Muriuki & Tsingalia, 1988).

Large plants with small seeds are adapted to dispersal because of great mobility of small seeds and the large number of offsprings that can be potentially dispersed (Kirika, 2005). This strategy is favourable when offspring mortality results from distance or distance-dependent factors (e.g. predation or competition). Seed predation may destroy a considerable proportion of seeds in a population prior to and after dispersal (Gutterman *et al.* 2007). In contrast relative small plants of large seeds can increase seedling establishment and can be favoured when mortality primarily results from limitation of resources (e.g. moisture, nutrients, or light). Undispersed seeds experience a high rate of decay and low germination; seed longevity is also prevented more by the predator (Forget *et al.*, 1998).

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1.2.3 Soil nutrients and seed regeneration

Soil serves a central role in terrestrial ecosystems, it serves as; a habitat for plants, micro-organisms and soil animals, and as a water and nutrient reserver for plants (Heanes, 1984). Tropical rain forests have been known to be of low fertility with only a few of them being fertile (Lars *et al.*, 2003). The main source of nutrients in the forest are mainly from the weathering rock and nitrogen fixation by the fixing symbioses (Lars *et al.*, 2003). Nitrogen supply limits plant growth on young soils, and plants with nitrogen fixing symbioses do well because of their ability to fix nitrogen. In many tropical forests, primary production and other ecosystem processes are constrained by low rates of nutrient supply. A change in availability of nutrients on a regional or local scale corresponds with shifts in abundance of species, composition and diversity of plant communities (Musila, 2007). Studies done in the humid regions indicate that growth changes from limited nitrogen availability in the early stages to limited phosphorus availability in later stages.

Many studies have indicated that forest conversion affects the distribution of soil nutrients and may in turn affect recovery of native ecosystems (Musila, 2007; Oesker, 2008). It has also been indicated that change of forest into pasture land has an impact on the general physical/chemical parameters of soil (Boyce & Dawnson, 2005). Seed germination in highly leached tropical soils may be limited by base cations (Burslem *et al.*, 1995; Gunatilleke *et al.*, 1997), yet few experiments have shown that large-seeded species tend to survive longer in the absence of soil nutrients and that their early growth may be less affected by the level of soil nutrients (Robert *et al.*, 2000; Thomas, 2000). Gunatilleke *et al.* (1997) has shown that it is only under extremely nutrient-impoverished situations that seedlings can have a problem in their establishment. It has also been demonstrated by Gunatilleke *et al.* (1997) that large seeds are at an advantage in nutrient-poor soils than smaller seeds.

Different vegetation types also influence soil properties differently; a forest can alter soil properties due to canopy interception of the atmospheric deposition. These include weathering of soil minerals,

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nutrient output via water seepage or biomass removal, quality of litter fall, mineralization, stem flow, throughfall and root activity (Lars *et al.*, 2003; Sandrine *et al.*, 2006). Low nutrients in the soil causes competition between the below ground and above ground growth (Olano *et al.*, 2002). The small scale distribution of nutrient input by nutrient leaching out of the leaves with throughfall is dependent on canopy structure and species diversity, and influences the competition at the forest floor (Dalitz *et al.*, 2004; Oesker, 2008).

Nye & Greenland (1964) found that burning of secondary forest of about 30 years has only a little effect on carbon and nitrogen levels in the soil. Few reliable data have shown changes in forest soils following shifting cultivation, although Grecen and Sands (1980), found a small loss of potassium, calcium and Magnesium between 1-11 years after clearing a forest. After 3 years of exposure a tropical forest soil lost about 30% of its total nitrogen (Nye & Greenland,1964)). However, it has been found that forest colonization of anthropogenic grasslands is not restricted by low soil nutrient availability, but rather by the other barriers like seed predation (Forget *et al.*, 1998). Studies done on Kakamega forest soils by Musila (2007), have indicated that the soils are heavily impoverished. It also revealed that the disturbance in the forest altered soil nutrient composition.

1.2.4 Anthropogenic effect on forest regeneration

The increasing growth rate in human population has resulted in a lot of pressure on natural resources (Emerton, 1994), especially encroachment on tropical rain forests. Information on how tropical forests respond to past disturbances may provide insight on ways to facilitate forest recovery (Tsingalia, 1988). Human activities such as shifting cultivation, firewood collection and pasture grazing have altered the forest vegetation. A study by Bleher *et al.* (2004) showed that heavy logging contributed to loss of biomass and soil nutrients from the soil. Timber harvesting also contributed to nutrient export and this affects the vegetation community depending on extraction intensity (Cannon *et al.*, 1998).

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Some studies have shown that forest disturbance resulted in removal of larger seeds (Forget *et al.*, 1998) with a mass of 5g and more, with a reduction in the recruitment of undispersed seeds in logged parts compared with unlogged forests (Webb, 1998). Consequences of logging do not only include loss of habitat, but also changes in the micro-climatic environment, which has an impact on the regeneration (Bleher *et al.*, 2004). Seed germination in logged areas increase because of light penetration, but this again is limited by soil compaction, high temperatures and poor nutrient substrate. Disturbance of the soil through grazing increases soil compaction hence interfering with seed germination (Robert *et al.*, 1980).

Kakamega forest has great impact from the local community who rely heavily on the forest for their livelihoods. There are diversity of activities going on in the forest which include: firewood collection, herding, collection of other herbal medicine, grass cutting for thatching and illegal logging (Bleher *et al.*, 2004; Lung, 2004; Mitchell, 2004; Kirika, 2005). A study by Kirika (2005), in Kakamega forest, has demonstrated that disturbance has an effect on frugivores, which in turn affects seed dispersal which is critical for forest regeneration. He also demonstrated that disturbance contributed to more seedling density in fragmented areas than in continuous forest. Higher seedling establishment does not lead to higher trees densities and diversity, which means that seedling maturity is curtailed in forest fragments. On the contrary, other studies have tried to show the positive effect in forest regeneration following disturbance.

1.2.5 History of forest exploitation in Kenya

Commercial exploitation of forests in Kenya began as soon as the railway was established. Initial exploitation was intended to provide fuel for the railway steam engines (Tsingalia, 1988). The railway facilitated transportation enabling the beginning of saw milling. During initial stages, saw milling was to supply timber to meet the needs of the colony. Beginning 1905, commercial exploitation of timber had proceeded at a rapid rate. One of the concerns at this time was whether indigenous trees would be able to regenerate following felling (Tsingalia, 1988).

To enhance natural production, felling was therefore in principle supposed to be carried out on regular basis. Regulated felling was to be effected in small portions with some cultivation below the seedling trees to enhance seed germination (Tsingalia, 1988). Even with all this, the suspicion was that the forest regeneration will be too low to meet the forestry needs of the colony. Attempts to plant indigenous species to meet the regeneration demand were abandoned by 1923, while selective logging was effected very shortly and again abandoned. Knowledge on natural regeneration remains scanty, making exploitation on sustainable basis of Kakamega forest a hard option (Tsingalia, 1988; Blackett, 1994).

1.2.6 Anthropogenic history of Kakamega forest

According to Kokwaro (1988) ancient land use has an effect on the present land composition. In the pre-colonial era, farming was limited to slash and burn farming practices, combined with hunting and gathering. A surge in human population brought about changes from hunter gathering to shifting cultivation, and later to small scale subsistence farming. While people were allowed to farm in the forest, small scale farming in the village was combined with shifting cultivation inside the forest till 1986, when it was banned. The first official farming in the forest began with the setting up of the Forest Department together with a group of forest workers, where each worker was allocated 2 ha. of

land to farm on. In the initial stages this was not seen as a threat to the forest until the workers population started soaring up, and more forest land was converted to farmlands. The Forest Department had lost control on land allocation in the forest. In the early stages, shifting cultivation was to be limited to the forest edge, but in 1978 some glades had been turned into sugar plantations (Tsingalia, 1988).

1.2.7 Logging in Kakamega forest

Kakamega forest has been subject to lumbering activities on large scale since the 1930's (Gathua, 2000). It is therefore likely that the physiognomic changes visible to day in the forest have their origin in the early 20th centuary lumbering activities. The first lumbering company sawmill was set up at Shisalinain in 1931 in Kakamega forest (Tsingalia, 1988). Gold was struck in the forest and this called for more timber to be used in ladder construction. Mining was done in Lirhanda hill while alluvial gold was extracted from along large rivers in the forest. To facilitate the exploitation of the gold deposits, the forest was divided into two major blocks; the north Eastern and Southwestern blocks. The Southwestern Block called Alosi forest block had a sawmill called Rondo sawmill (Tsingalia, 1988). Exploitation was mainly done on forest edges because of transportation problem, but with advancement in transport technology, exploitation intensified and this accelerated the destruction of the forest.

Bunyala and Malava forests are struggling forests dominated by timber colonizing species, of which *Trema guineensis* is the commonest (Gathua, 2000). To date, most of these forests are constantly subject to bursts of uncontrolled grazing pressure. Logging of the forest died off early 1950's through mid 1960's, picking up again in late 1960's through the 1970's, until it was banned completely in late 1982 by a presidential decree (Tsingalia, 1988).

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1.2.8 Influence of micro-climate on seed regeneration

The abiotic environment largely determines the extent to which the soil seed bank in turn affects the distribution of emerging surface plants, favourable conditions trigger germination of seeds whereas unfavourable conditions facilitate seed dormance (Roberts *et al.*, 2000). Turner *et al.*(1995) has demonstrated how micro-climate changes contribute to forest fragmentation. Plant communities are also affected by the relative period of dormancy of the seeds (Roberts *et al.*, 1980), as a result of such abiotic factors as humidity and temperature. More so, during dormancy, most seeds remain edible to granivores until the establishment process starts.

By staying longer in a dormant state, the seed jeopardizes its chance of survival because of the risk of predation (Brown *et al.*, 1979). It has been shown that germination is markedly influenced by temperature, moisture, light and pH (Gutterman *et al.*, 2007; Robert *et al.*, 2000). Soil moisture poses no problem to seedlings in regions of year round precipitation such as Kakamega forest ecosystem (Thomas, 2000). Increased seed germination can be obtained by altering temperatures, as shown by Crocker & Barton (1957) rather than constant temperature. For a seed to germinate effectively it needs a combination of the environmental gradients of light, temperature, and moisture (Thomas, 2000).

1.2.9 Soil seed bank and seed regeneration

Tropical trees produce seeds showing a wide range of sizes, shape, structure, chemical composition, water content and dispersal mechanisms (Poiani & Dixon, 1995). Forest regeneration is mainly supported by the soil seed bank and sproutings from old stems. A seed bank is a viable seed reservoir present in the soil (Robert *et al.*, 2000) which is able to facilitate regeneration of a forest. According to Barker (1989) this is a reservoir of seeds that have not germinated but have the potential of germinating under conducive environmental conditions. All the viable seeds present in the soil and in

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litter are referred to as the seed bank (Robert *et al.*, 2000). Seed bank studies started way back in 1859 by Darwin who observed seed emergence from soil samples collected from the bottom of a lake. The study on seed banks is very crucial in conservation because seeds stand for legacy; a seed can be dormant for a shorter or longer period of time but on germinating form part of current or future generation (Van der Valk *et al.*, 1989). There are two main types of seeds found in a soil seed bank: temporary seeds, which persist for less than one year in the soil (Thomas, 2000) and persistent seeds, which remain in the soil for more than one year. Seed banks may critically affect the structure of a plant community in a forest where seeds are the most viable form of many plant species (Robert *et al.*, 2000; Thomas, 2000).

Most of the tropical rain forest seeds are recalcitrant; therefore, sensitive to desiccation and low temperatures, which are conditions necessary for their storage (Roberts, 1973; Chin & Roberts, 1980; Farrant *et al.*, 1988). If a fall in moisture occurs below some critical value the seed bank becomes unviable for germination (Farrant *et al.*, 1988). Variation in seed sizes versus number can reflect a compromise between seed dispersal and seedling establishment (e.g. seed germination and seedling emergence, growth and survival) (Robert *et al.* 2000). There are many plant populations that rely entirely on seeds for their regeneration and maintenance (Thomas, 2000) and the success of a seed bank is determined by the density of seeds ready to germinate to replace the depleted or dead plants when conditions are conducive. The depth at which the seed is buried also determines the effectiveness of a seed bank, as the location of seeds within the soil profile will affect seed germination (Guttterrman *et al.*, 2007). The author has also showed that the depth of seeds can impair germination due to altered moisture, light, air and temperature bringing the seeds into a state of dormancy. Hans (1994) demonstrated that large seeded species had higher survival when buried in the soil than on the surface. However, a study by Lewis (1961) revealed that the most rapid depletion of a seed bank occurred during the first year of seed burial in the soil. Soil stored seeds evolve barriers to germination making the seed dormant. The dormancy can be broken by fire, inducing

germination for the seed (Zimmerman *et al.* 2000). Seeds that remain dormant in the soil due to unconducive environment become very important because they guarantee a species survival even when the population of a plant is completely eliminated (Olano *et al.*, 2002; Thomas, 2000). However, seeds buried too deep in the soil may fail to grow to the soil surface and get autotrophically established (Thomas, 2000). Nevertheless it has been established that seed distribution in the soil generally decreases with soil depth (Johnson & Anderson, 1986; Warr *et al.*, 1994).

Studies done in various ecosystems to establish the relationship between the seed bank and the aboveground vegetation have shown poor correlation between the seed bank and aboveground vegetation (Thomas, 2000; Valbuena *et al.*, 2001). However, exceptions have been found mainly in annual-dominated communities in which life forms survive harsh conditions in form of seeds. They often contain early succession species but not representative of late or dominant succession species (Robert *et al.*, 2000). The difference is due to dispersal, which can be in form of mechanical ejection, passive form, fire, wind, water, animals, seed burial and predation (Bakker *et al.*, 1996). Other studies indicate that other herbaceous species dominate the soil seed banks while only a few woody species are capable of accumulating long-lived seeds in the soil (Gutterman *et al.*, 2007). This implies that other herbaceous species have better chances of recovery than woody species from the soil seed banks in the event of disturbance (Jose & Fernsandez, 1999). This is hardly surprising considering that seed bank density and dominance by weeds increases with continuous farming (Abdella *et al.*, 2007).

1.2.10 Seed viability

Seed viability is the ability of a seed to germinate when the right environmental conditions are available. However, there are a number of factors that determine the viability of a seed, which can be both internal and external factors. Seed viability is determined right from pollination stage, where incomplete fertilization may lead to seeds which are not viable. This may be as a result of a seed being without or with an incomplete embryo, hence is unable to germinate despite favourable conditions (http://tomclothier.hort.net/index.html 04.21.2008). Seed storage also affects the viability of a seed, with most seeds species doing well when stored under a relative humidity of 30% and a temperature of 39°C (http://www.Storing Seed Grain - Maintaining seed viability and vigor.htm 04.21.2008).

Studies have shown that most of the seeds are rapidly lost through predation and disease hence only a small fraction is viable (Robert *et al.*, 2000). Seed predation may be very high when other food resources are scarce but it reduces when other resources such as macro-fauna are abundant (Poiani & Dixon, 1995). Seed predation differs also according to species; hence in areas in which seed predation is high, species with low predation may have a major competitive advantage over species that suffer high predation. The elucidation of general patterns of seed predation may be particularly important for improving efforts to encourage forest regeneration in tropical areas disturbed by human activities (Forget *et al.* 1998).

1.3 Justification

Escalating loss of tropical forests is the main challenge to forest managers and scientists in many parts of Africa. Forests play very key roles in nature as they act as carbon sinks, hydrological cycle by harnessing rain and offer a vast number of products (ecosystem goods and services). Advancement in technology and increase in human population have resulted in increased pressure on tropical rain forests hence posing a threat on the slow regenerating forests. Kakamega forest is one of the tropical rainforests faced with high rate of depletion from increasing human population and logging for raw materials. According to Barik *et al.* (1996), success in forest regeneration is determined by successive completion of several events in the life cycle of trees such as seed production, dispersal to safe sites, germination, seedling emergence, establishment and onward growth. Thomas (2000) argues that seed germination and establishment is limited by factors such as soil compaction, temperature and poor nutrient substrate. Adler *et al.* (2001) argued that impact of disturbance on vegetation results in spatial heterogeneity and loss of diversity. It is in this view that this study was carried out to ascertain the factors impinging on regeneration in Kakamega forest. This study investigated the role of soil nutrients, anthropogenic activities and soil seed bank effects on regeneration in Kakamega forest. The study was done in six different vegetation types identified as primary forest, secondary grassland, shrubland, burnt glade, natural glade and plantation. Information on forest regeneration is vital for the undertaking of forest restoration work (Duncan and Chapman, 2003) in degraded areas of a forest.

1.4 Objectives and hypothesis

The main objective of this study was to assess the factors contributing to the slow regeneration of Kakamega forest as well as those impinging factors on germination and establishment of seeds and seedlings in the forest.

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The specific objectives are as follows:

1. To determine the suitability of micro-climate (temperature and relative humidity) in sustaining forest regeneration.

2. To determine effects of some physical and chemical characteristics of soil (N, P, K, C, Ca, Mg, pH, texture, bulk density and electrical conductivity) that influence seed regeneration in Kakamega forest.

3. To assess the soil seed bank in Kakamega forest.

4. Assess anthropogenic impacts (browsing/grazing, trampling of seedlings and soil compaction) on seed regeneration in Kakamega forest.

The hypothesis of this study was:

Ho: Slow regeneration in Kakamega forest is due to poor soil fertility, unconducive micro-climate, anthropogenic impacts and depleted soil seed bank in the forest.

H$_1$: Slow regeneration in Kakamega forest is not due to poor soil fertility, unconducive micro-climate, anthropogenic impacts and depleted soil seed bank in the forest.

CHAPTER TWO

2.0 STUDY AREA, MATERIALS AND METHODS

2.1 Study area

Kakamega forest lies between latitudes 0° 10' and 0° 21' N and longitudes 34° 47' and 34° 58' E (Figure1). It is located in western Kenya at an altitude of 1500 to 1700 m (Bleher, 2004). Kakamega forest is a mid-altitudinal tropical rainforest, considered as the remnant of the lowland Congo Basin rainforests of Central Africa (Kokwaro, 1988). Kakamega forest was gazetted in 1933 with a total of 18,300 ha, out of which only an estimated 10,000 ha of the overall gazetted area is still closed canopy indigenous forest. Some 3,200 ha are in the National Forest Reserve (Blackett, 1994). The remaining consists of grass-bushed glades and 1,700 ha of plantations of softwood and commercially valuable hardwood (Kirika, 2005).

2.1.1 Rainfall, temperature and drainage

Kakamega forest has an average annual rainfall of between 1,200 mm and 2,100 mm per year (Emerton, 1994). The rainfall is bimodal, with the two wet seasons falling in March to June and mid August to November (Figure 2). Mean monthly maximum temperature ranges from 18°C to 29°C. Diurnal temperatures range between a minimum of 10.6°C and a maximum of 27.7 °C (Kokwaro, 1988; Tsingalia, 1988). Kakamega forest is an important water catchment with the Isiukhu and Yala rivers flowing through the forest and draining into Lake Victoria making Kakamega forest an important catchment area in this basin (Kirika, 2005).
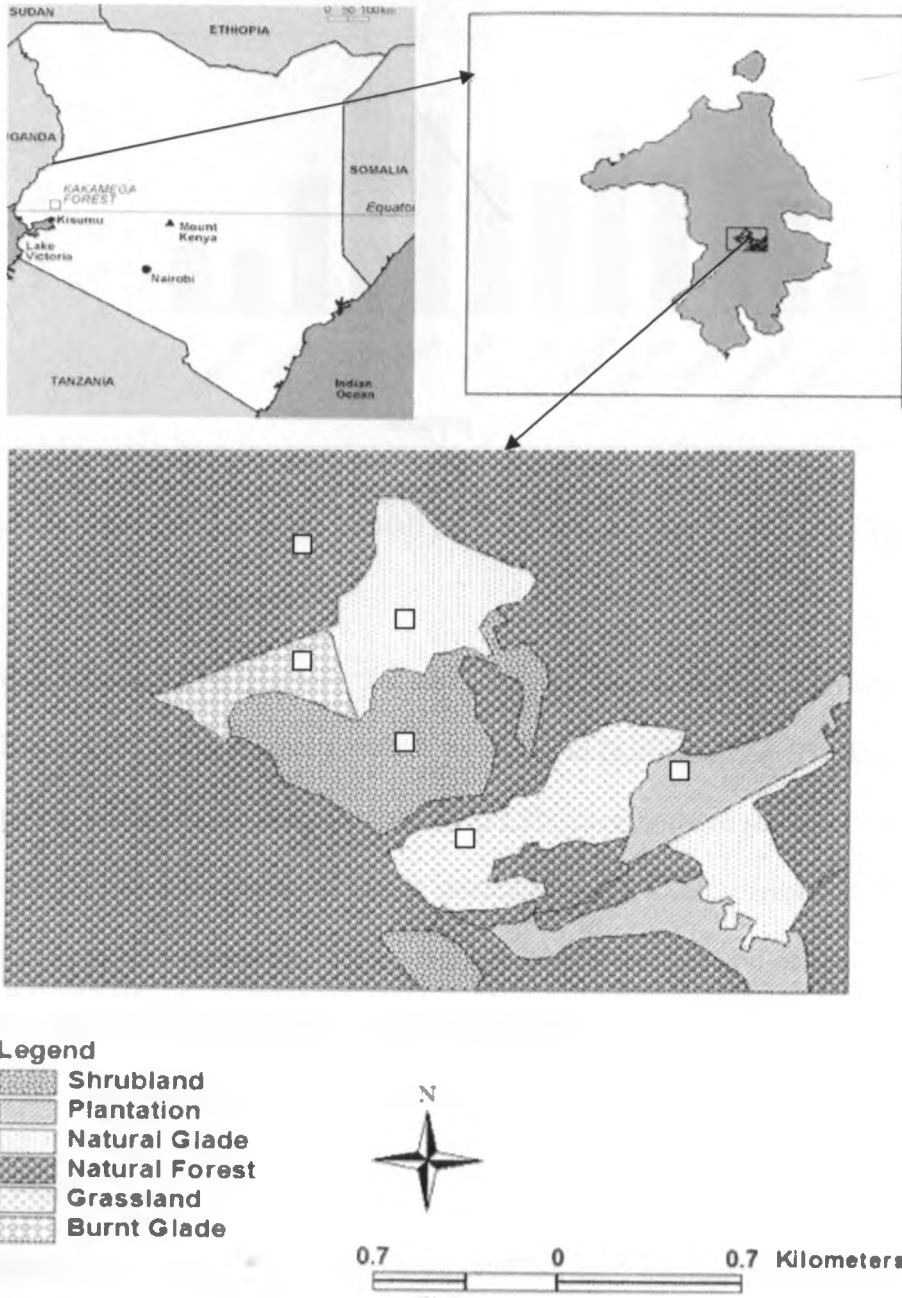
Figure 1: Location of Kakamega forest showing study sites in various vegetation types (the small squares were the sampled sites) (Adapted from Aster Image August, 2008. from Regional Centre for Remote Sensing).
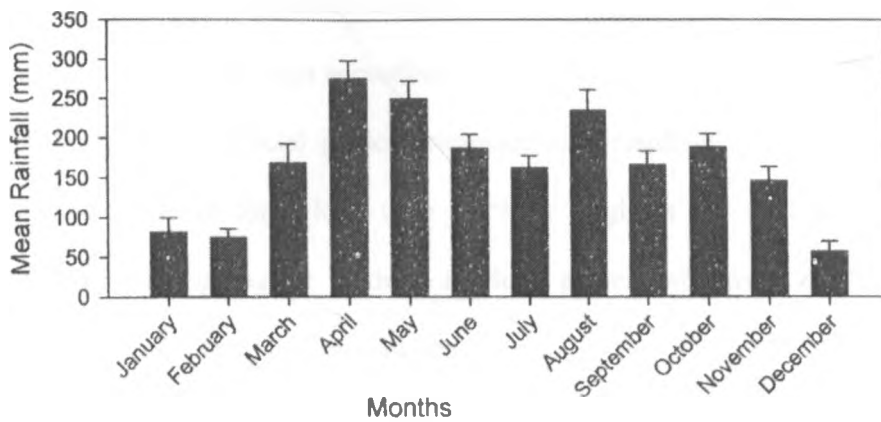
Figure 2: Mean (±SE) monthly rainfall received in Kakamega forest (1982-2001) (Kirika, 2005).

2.1.2 Topography and soils

Kakamega forest has a relatively flat and gently undulating topography except for a few steep hills like Buyangu to the north and Lirhanda to the south (Kirika, 2005). The forest is surrounded to the east by the Nandi escarpment, which rises to 2,200 meters above sea level. The bedrock substrate on which the forest sits consists of basalt, phenolites and ancient gneisses. A layer of clay-loam soils overlies these rock formations. These soils are highly leached and of low fertility, typical of forest soils. The soils are dependant on the decomposition and reincorporation of dead organic matter (Blackett, 1994; Musila, 2007) and are therefore of low fertility.

2.1.3 Flora

Kakamega forest is one of the few remnants of low land tropical forests of the expansive Congolean forest. The flora of the forest is rich in plant diversity with over 380 species of plants identified. Out of these, 150 species are woody trees, shrubs and vines, many of which are of Congolean lowland forest affinities (Kokwaro, 1988; Gathua, 2000). There are also 170 species of other herbs of which 60 are orchids (Blackett, 1994); 9 of these orchids are endemic to Kakamega forest. According to

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Blackett (1994) the plantation forest, glades and riverine forests are attributed to the disturbances that the main forest has been subjected to for the past few decades with an exception of the primary forest. The disturbance has resulted in various vegetation types classified as natural forest, bush land, grassland (glade) and plantation according to Lung (2004). The grassland were of two kinds: natural and artificial glades. Artificial glades originated as a result of disturbance (farming) and natural glades have been there for a long time but their origin is not well understood (Musila, 2007). Succession has been going on in these artificial glades, with most of them now dominated by different plant species from the original ones.

2.1.4 Fauna

Kakamega forest exhibits a high degree of endemism and rarity in its fauna. An estimated 10% to 20% of the fauna is generally endemic to this region (Blackett, 1994). The fauna has strong Central and West African affinities (Bleher, 2004). Animals found here include the bush pig (*Potomochoerus porcus*), Giant forest hog (*Hylochoerus meinertzhageni*), Bushbuck (*Tragelaphus scriptus*), Suni (*Neotragus moschatus*), Clawless otter (*Aonyx capensis*), Giant otter shrew (*potamogale velox*) and Lord Derby's Anomalure (*Anomalurus derbianus*), among others. The primates include the Black and White colobus monkeys (*Colobus guereza*), Blue monkey (*Cercopithecus mitis*), Red tailed monkeys (*Cercopithecus ascanius achmidti*), Olive baboon (*Papio hamadryas anubis*), Potto (*Perodicticus potto*) and few de Brazza's monkeys (*Cercopithecus nuglectus*). At least 28 snake species have been recorded within the forest, including the rare Gold's Cobra (*Pseudohanje goldii*) and other West African species such as the Black-lined green snake (*Hapsidophyrys lineate*), Jameson's Mamba (*Dendroaspis jamesoni kaimosae*), Green bush-viper (*Atheris squamiger squamiger*), Prickly bush-viper (*Atheri hispida*) and Rhinoceros-horned viper (*Bitis nascornis*). The forest has several species of lizard, amphibians and invertebrates (Kirika, 2005). The forest avifauna comprises of 367 species of which, are a mix of lowland and highland species, but with the lowland

species dominating. Two of the species, namely Turner's Eremomela (*Eremomela tuneri*) and Chapins' Flycatcher (*Muscicapa lendu*) are globally threatened (Bennun & Njoroge, 1999). Some species that are disappearing from the forest are Grey parrot (*Psittacus erithacus*), Yellow crested woodpecker (*Mesopicos xantholophus*), yellow mantled weaver (*Ploceus tricolor*) and the Black-billed Turaco (*Turaco schuetti*) (Kokwaro, 1988).

2.2 Study sites

The study was conducted in continuous forests as well as in degraded areas between the Southern and Northern fragments. The whole study was done within a period of eight months, commencing from April 2008 to November 2008. Aspects of the study included; micro-climate (temperature and relative humidity) measurement, soil sampling for physio-chemical analysis, soil seed bank sampling, seedling emergence experiments, seed screening, seed viability tests and seedling recruitment monitoring. Six habitats were identified for the study based on Lung (2004) classification (Table 1).

Table 1: Habitat description according to Lung (2004) classification.

Habitat	Description of land cover
Natural forest	Forest of lowest disturbance level, dense canopy older than 50 years (Plate 1).
Shrubland	Bush areas less than 10m height, interspersed with grass and other herb plus very young secondary forest of less than 10 years (Plate 2).
Secondary grassland	Grassland with single bushes or trees (Plate 3).
Plantation	Plantation of Cypress trees, *Cupressus lusitanica*, grown as monoculture up to 35m (Plate 4).
Natural Glade	Grass, partially of natural origin, used as meadows and roof thatching (Plate 5).
Burnt glade	This was originally natural glade that was subjected to burning (Plate 6).

Plate 1: Natural forest

Plate 2: Shrubland

Plate 3: Secondary grassland

Plate 4: Plantation

Plate 5: Natural Burnt glade

Plate 6: Burnt glade

2.3 General habitat description

The six habitats studied included both the natural and disturbed habitats which were at different stages of succession. The soil texture for the six habitats comprised of sand, clay and silt, with the sand having a higher representative fraction in each habitat (Appendix 2).

2.3.1 Natural forest

The natural forest had clay loam soil at depth 0-30cm and clay loam at depth 30-60cm. The natural forest was observed to be with very minimal human disturbance. The forest floor was littered and had some seedlings on the ground (Plate7). There was succession taking place at every level; from the forest floor to the canopy, making sunlight penetration poor. The forest is dominated by species such as *Celtis africana, Funtumia latifolia, Prunus africana, Ficus sur, Maesa lanceonta, Zenthoxylum glette, Solonum mauritiana* and *Draceana fragrans*.

Plate 7: Seedlings of *Funtumia africana* growing on the floor of the natural forest.

2.3 2 Glade

The natural glade extends right from the natural forest boundary and it has been in existence for over 100 years. Its soil was clay loam at depth 0-30cm and sandy clay loam at depth 30-60cm. The main human activity in the natural glade was cutting grass for hey and thatching. There was also

some grazing taking place although the grasses are not very palatable for grazing. Most of the sedges dominating the natural glade propagate through tubers and rhizomes. Species dominating the natural glade were *Londentia kagerensis, Hypherrenia species* and *Dracaen fragrans*. The natural glade was highly dominated by moulds of ants (Plate 8).

The burnt glade was a portion of the natural glade which had been subjected to burning by the locals for palatable pasture for their livestock. The soil was the same as in the natural glade. This habitat was used extensively for grazing livestock, some sections had been left bear because of over grazing.

Plate 8: Termite moulds in the glades

The burnt glade like the natural glade was dominated by sedges which propagated through tubers and rhizomes. The species dominating in the burnt glade included *Hyperrhenia diplandra, Londetia kagerensis* and *Digitaria abyssinica*. The burnt glade was also highly dominated by moulds of ants.

2.3.3 Plantation

The plantation was artificially grown with *Cupressus lusitanica* after the natural forest that existed there was destroyed through logging. The soil was clay loam at depth 0-30cm and sandy clay loam at depth 30-60cm. The plantation floor was covered with other species which are mainly other herbs

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and climbers (Plate 9). Other species in the plantation included *Justicia flava, Dorstenia species, Afromomum angunstifolia* and *Desmodium repadum*.

Plate 9: Other herbaceous cover in the plantation.

2.3.4 Shrubland

The shrubland is a transitional zone linking two natural forests with clay loam soil at depth 0-30cm and sandy clay loam at depth 30-60cm. The trees species identified in this habitat were; *Albizia gummifera, Blighia unijugata, Bridelia micrantha, Maesa lanceolata* and *Psidium guajava, Antiaris toxicaria, Bischofia javanica, Eucalyptus saligna, Kigelia africana, Maesopsis eminii, Premna angolensis, Prunus africana* and *Vitex keniensis*. There was a high presence of ants in this habitat though no ant moulds were visible in the vicinity. A high activity of mole rats was observed in this habitat.

2.3.5 Secondary grassland

Secondary grassland soil was dominated by clay loam at depth 0-30cm and sandy clay loam at depth 30-60cm. The habitat ran parallel to a riverine forest. It was mainly subjected to constant disturbance because of grass cutting for fodder. The main species growing on this habitat were basically grasses which had been kept short because of constant cutting but there were a few scattered trees of *Albizia gummifera, Blighia unijugata, Bridelia micrantha, Maesa lanceolata and Psidium guajava*.

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2.4 Materials and Methods

2.4.1 Micro-climate (temperature and relative humidity) data collection

Micro-climate data were collected from May 8th to 23rd, 2008. Data loggers (hobos) are instruments used to measure relative humidity, light energy, temperature and other micro-climate parameters. The data logger used were of model H21- 002 manufactured by Onset manufacturers in Japan. For this study the measurements taken were for temperature and relative humidity. The hobos were launched in four habitats; secondary grassland, shrubland, plantation and primary forest to collect data on temperature and relative humidity after every 15 minutes. The data loggers were placed 2 m from the ground, to avoid any water from splashing back on them. Temperature was measured using a minimum and maximum thermometer and recorded each day in each of the two greenhouses used for seedling emergent experiments.

2.4.2 Soil sampling

Soil sampling was done between the month of April and May 2008. Sampling was done in six habitats identified in the study site as secondary grassland, shrubland, burnt glade, natural glade, plantation and primary forest (Figure 1). Three transects of 100 m were established in each habitat. Three quadrats of 5×5 m were systematically established on each transect, at equal distance from each other. The quadrats were sub-divided in 25 sub-quadrats of 1×1 m from which only 10 sub-quadrats were randomly selected using random numbers for soil seed bank sampling. A vegetation survey was done in all sampled habitats on standing vegetation prior to soil sampling. Soil sampling was done by first clearing the above ground vegetation using a machete.

Samples for physio-chemical analysis were taken from each quadrat at a depth of 0-30 cm using a soil auger for analysis of N, P, K, Ca, C, Mg, EC, pH and soil texture from each of the six habitats. There were a total of nine samples from each habitat and 54 samples for the six habitats. The soils were air dried and sieved using a 2 mm seave, ready for analysis. Samples for bulk density

determination were done using cores at a depth of 10 cm, which were randomly sampled in eight points from each habitat.

Soil seed bank samples were taken from the centre of each small quadrat using a metal cube of 20×20×5 cm (2,000 cm^3) from three different depths of 0-5 cm, 5-10 cm and 10-15 cm. The metal cube, whose base was sharp was driven in the ground using a mallet. A small trowel was used to scoop the soil inside the metal cube to the depth of 5 cm covered by the cube, the soils for each sample were put in a plastic paper bag. Soil round the cube was excavated using a small hoe and the metal cube further driven in the ground for the next depth of soil sample. The samples were transported to the greenhouses at the forest station for soil seed bank analysis experiments.

2.4.3 Soil physical chemical analysis

Laboratory analysis was done partly at Kenya Agricultural Research Institute (KARI) Laboratory in Kakamega and at International Centre for Research on Agro-forestry (ICRAF). Each soil sample was analyzed for texture, bulk density (B.D), pH, EC, total Calcium (Ca), Carbon (C), Phosphorus (P), Magnesium (Mg), Potassium (K) and Nitrogen (N).

Soil particle size was analysed by the Hydrometer Method (Bouyoucos, 1962). One hundred grams of each of the air dried soil samples were weighed into 400 ml beakers. These were saturated with distilled water and to each was added 10 ml of 10% calgon solution (sodium hexametaphosphate). The contents were allowed to stand for 10 minutes. The dispersion was transferred to a dispersing cup and 300 ml of tap water added. The suspension was then mixed for 2 minutes with a high speed electric stirrer. The suspension was transferred to a graduated cylinder and the remaining soil rinsed into the cylinder with distilled water. A hydrometer was inserted into the suspension and water added to the 1000 ml mark, after which the hydrometer was removed.

The solution was disturbed by inserting a plunger into the column and moving it up and down the column. About 2-3 drops of amyl alcohol were quickly added to remove the froth and a hydrometer placed gently into the column after 20 seconds. At 40 seconds, the hydrometer and temperature readings of the suspension were taken. After the 40 seconds, the sand had settled and the reading reflected the grams of silt and clay in one liter of the suspension. Using a plunger the contents in the cylinder were again disturbed, it was again allowed to stand for two hours before both hydrometer and temperature readings were taken again. The temperature corrections were made as described by Bouyoucos (1962). In the two hours time, the silt had settled and the hydrometer reading reflected the clay content of the original suspension. The assumption was that organic matter is negligible and the proportions of sand silt and clay were calculated by subtractions from the original sample weight.

Bulk density was determined using the Cone core method (Okalebo, 2002). The core samples were put in an oven after weighing the fresh weight and dried in a 105°C oven for 2 days after which they were re-weighed.

Calculations

Bulk density was calculated as follows (Okalebo, 2002):

$$\text{Bulk density } (gm^{-3}) = (W2g-W1g)/Vcm^3 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(\text{Equation 1})$$

Where,

W1 = fresh weight (g).

W2 = dry weight (g).

V = volume of the core cylinder.

Electrical conductivity and soil pH were measured using conductivity meter (model DDB-303A, manufactured byMonad Electronic in Shanghai China). Electrical conductivity and soil pH

were measured on a 2.5:1 water to soil suspension as described by (Okalebo, 2002). A soil sample of 20 g was put in a plastic bottle, 50 ml deionised water added and put on a shaker for 10 minutes. The mixture was allowed to stand for another 30 minutes to settle until a supermatant (clear liquid above settled soil) formed. The EC was measured first before the pH to avoid contamination of the suspension with Potassium Chloride (KCL) from the pH electrode and readings recorded.

The content of each of the elements N, P, K, Ca, Mg was determined in the acid digest using standard methods described by Anderson & Ingram (1993). Soil samples were first digested with a mixture of hydrogen peroxide, sulphuric acid, selenium and salicylic acid. A soil sample weighing 0.3 grams from each sample was put in a dry digestion tube and labeled. Then 2.5 ml of freshly prepared digestion mixture (3.2 grams salicylic acid in 100 ml sulphuric acid-selenium mixture) was added into each tube and the reagent blanks for each batch of samples. Samples were digested at 110 °C for one hour. They were then removed, cooled and three successive 1 ml portions of hydrogen peroxide added to each tube. Temperature was then raised to 330 °C and heating continued till the color cleared, and the contents were then allowed to cool. Then 25 ml of distilled water was added and mixed until it was saturated with hydrogen peroxide. The contents were cooled, topped up to 50 ml with water and allowed to settle before taking clear solutions from the tube for analysis.

Total N was determined calorimetrically. The acid digest was diluted to a ratio of 1:9 (v/v) with distilled water to match the standard solution (Anderson & Ingram, 1993). Using a micropipette, 0.2 ml of each of the sample's digest was drawn into labeled test tubes. Some 0.5 ml of reagent N1 was added and vortexed. Reagent N1 was prepared as follows: 34 g sodium salicylate, 25 g sodium citrate and 25 g sodium tartrate dissolved in 750 ml water; to the solution was added 0.12 g sodium nitroprusside. To these, 0.5 ml of reagent N2 was added. Reagent N2 was prepared as follows: 30 g of sodium hydroxide dissolved in 750 ml of water, cooled and 10 ml of sodium

hypochlorite added. The contents were topped up to one liter with water and vortexed. The mixture was allowed to stand for 2 hours and its absorbency measured at 650 nm, for total nitrogen.

Calculations

Mean blank values were subtracted from sample values to give corrected concentration for the values.

Nitrogen concentration was in (%):

$$N\% = \frac{[(SNCONC - SNBLNK)SNVOL]0.00001}{SNSOLWT}$$ ....(Equation 2)

Where,

SNCONC = N concentration in soil digest (mg/L)

SNBLNK = N concentration in blank digest (mg/L)

SNVOL = Total Volume of diluted digest (mL)

SNSOLWT = Soil sample weight (g)

P was determined by pH adjustment using Ascorbic acid method (Anderson & Ingram, 1993). Some 5 ml of each of the clear digested samples' solution was drawn using a pipette into 50 ml volumetric flasks. About 20 ml of distilled water was added to each flask. Ten milliliters of ascorbic acid reducing agent was added accordingly. The contents were made to 50 ml by adding water, closed using a stopper and shaken thoroughly. These stood for one hour for full color development and concentration of phosphorus in sample read from absorbance measured at 880 nm wavelength in a calorimeter.

Calculations

P concentration was in (%):

$$P = \frac{[(SPCONC - SPBLNK)SPVOL]}{SPSCLWT} \quad\text{..(Equation 3)}$$

Where,

SPCONC = P concentration in soil digest (mg/L)

SPBLNK = P concentration in blank digest (mg/L)

SPVOL = Total Volume of diluted digest (mL)

SPSOLWT = Soil sample weight (g)

For the determination of K, some 2 ml of the digested sample's solution was put in a 50 ml volumetric flask and distilled water added to 50 ml (Anderson & Ingram, 1993). Starting with the standards, each of the solutions was sprayed into atomic absorption spectrophotometer flame at wavelength 766.5 nm and the amount of K was recorded from the absorbance noted.

Calculations

K concentration was:

$$K = \frac{[(SKCONC - SKBLNK)SKVOL]}{SKSOLWT} \quad\text{...(Equation 4)}$$

Where,

SKCONC = K concentration in soil digest (mg/L)

SKBLNK = K concentration in blank digest (mg/L)

SKVOL = Total Volume of diluted digest (mL)

SKSOLWT = Soil sample weight (g)

Ca and Mg were first extracted from the soil with an excess of ammonium acetate. Five grams of each of the air dried soil samples were weighed into plastic bottles. Blanks and repeat samples were included in the batch of soil samples. Then 100 ml of 1 mole ammonium acetate solution of pH 7 was added. The contents were shaken for 30 minutes and filtered through number 42 Whatman paper. The filtrate of the soil extract (solution A), was used in determination of the content of Ca and Mg. The standard working solutions with known quantities were measured first to calibrate the instrument.

For determination of magnesium, the extract solution 'A' above was first diluted 25- fold (Anderson & Ingram, 1993). To make this dilution, 2ml of soil extract solution 'A' was drawn using a pipette into a 50 ml volumetric flask. Then 5 ml of 5000 parts per million (ppm) were added and 1 mole ammonium acetate used to fill the contents to 50 ml mark. The solution was sprayed into atomic absorption spectrophotometer, readings were recorded from the curves in ppm.

Calculations

Mean blank readings were subtracted from sample readings to obtain net concentration values.

Exchangeable Mg=Exchangeable Mg Concentration-Exchangeable Mg Blank ....

....(Equation 5)

To determine Ca content in the sample digests, 10 ml from each of the digested sample's solution was put in 50 ml volumetric flasks (Anderson & Ingram, 1993). Then 10 ml of 0.15% lanthanum chloride were added to each flask and topped to the 50 ml mark with distilled water. The flask was shaken thoroughly and the solution sprayed onto the atomic absorption spectrophotometer flame at wavelength 422.7 nm. The concentration of Calcium was recorded on the spectrophotometer as indicated by absorbance.

Calculations

Mean blank readings were subtracted from sample readings to obtain net concentration values.

$$\text{Exchangeable Ca} = \text{Exchangeable Ca Concentration} - \text{Exchangeable Ca Blank}$$

....(Equation 6)

Soil samples were analysed for total organic carbon as an indicator of litter decomposition rates. The Walkley and Black (WB) method was used as described by Walkley & Black in 1934. Concentrated sulphuric acid (H_2SO_4) was added to a mixture of soil and aqueous potassium dichromate ($K_2Cr_2O_7$). The heat of dilution raised the temperature to induce a substantial, but not complete, oxidation by the acidified dichromate. Residual dichromate was back titrated using ferrous sulphate. The difference in the added iron sulphate ($FeSO_4$) was compared with a blank titration to determine the amount of easy oxidizable organic carbon. The percentage WB carbon (WBC) was calculated by the formula:

$$WBC = \frac{M \times (V1 - V2)}{W \times 0.30 \times CF}$$ ....(Equation 7)

Where,

M = molarity of the $FeSO_4$ solution (from blank titration),

V1 = volume (ml) of $FeSO_4$ required in blank titration,

V2 = volume (ml) of $FeSO_4$ required in actual titration,

W = weight (g) of the oven-dried soil sample, and

CF = correction factor which is a compensation for the incomplete oxidation and is the inverse of the recovery set by Walkley and Black (1934) to 1.32 (recovery of 76%).

2.4.4 Soil seed bank

The samples for soil seed bank analysis were weighed and recorded. They were a total of 1620 samples with 270 samples from each habitat and 54 samples from each soil depth, for the six habitats. The samples were randomly sorted as odd or even into two equal groups of 810 samples each using the label numbers. The 810 odd samples were used to carry out seedling emergence

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experiments. Each individual sample was put on a metal tray, mixed thoroughly to get a representative sample. Roots, tubers, and bulbs were picked and discarded to avoid any growth from sprouts.

The odd samples were again re-weighed to get a weight of 1 kg which was germinated on germination trays for seedling emergence experiments in two greenhouses to facilitate seedling identification at species level after germination. The germination trays base was perforated to prevent water logging. The environmental conditions in the greenhouse consisted of natural photoperiods and regular watering. The temperatures in the two greenhouses were monitored using the maximum/minimum thermometers whose reading was taken every morning. The two greenhouses had a maximum average temperature of 30°C and a minimum average of 14.5°C. The emerging seeds were counted and recorded after every two weeks from the time of germination, this went on for a period of eight months. The seedling identification was done from two months on wards after germination, identification was done to species level. A plant taxonomist from the National Museums of Kenya helped in identifying the species. Those which could not be identified on the spot were taken to the National Museum of Kenya for identification.

The other 810 even samples were spread on metal trays to dry for two days prior to sieving using a 2 mm sieve after re-weighing to get the dry weight. The coarse sample that remained on the sieve was screened for seeds and the seeds that were hand picked were used in carrying out seed viability tests. The fine sample through the sieve was re-weighed and a representative sub-sample of 30 g taken for further screening using a dissecting microscope for seeds which could not be picked using a naked eye. This was done at the National Museums of Kenya (N.M.K.), Palynology section. A sample of about 3 g from the 30 g sample was evenly spread on a Petri dish and put under a microscope with a magnification of ×1000. A counter was used in counting the number of seeds observed under the microscope. This was repeated for the whole sub-sample of 30 g. The total number of seeds from the

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30 g sub-sample was reached by adding the seed numbers from all the 3 g screened sub-sample. The overall seed total for a full sample was calculated by dividing the original sample weight by 30 g and multiplying it by the number of seeds in the 30g sub-sample.

2.4.5 Seed viability tests

The seed viability tests were done using the lay out procedures by the International Seed Testing Association (ISTA), (Steve *et al.*, 2007). Seeds that had been hand picked from the coarse sample after sieving were soaked in warm water, (40°C) for 15 minutes to break any form of seed dormancy. They were later germinated in a 1% agar in a Petri dish inside a germination chamber at room temperature (20°C). Seeds picked from a single sample were all germinated on one Petri dish. The germination experiment went on for 14 days with the scoring being done after every two days. After every two days, the germinated seeds were counted, recorded and removed from the Petri dish. After the 14 days the ungerminated seeds were subjected to another treatment in an oven with a constant temperature of 25°C for another seven days. Rising of the temperature was to further break any form of seed dormancy. The scoring was done after the seven days and the seeds that had not germinated by then were treated as not viable.

2.4.6 Habitat Species Diversity Analysis

Vegetation survey was done in each of the sampled quadrants, species encountered were counted and identified. Data on abundance value of each species encountered from the vegetation survey in each of the habitats was used in analysing woody species diversity. For comparison of habitat Shannon-Wiener Species Diversity Index was calculated for each habitat (Shannon-Wiener, 1949). The concepts of diversity looked into included; species richness which is the number of species in a community. Evenness as a measure of abundance and heterogeneity as a measure of both species richness and evenness.

The following formula was used:

$$H' = - \Sigma p_i \log p_i \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\text{(Equation 8)}$$

Where,

H' = Diversity

P_i = the proportion of individuals or the abundance of the ith species

$\log$ = natural log base 10

Equitability or evenness was calculated using the following formula:

$$J = \frac{-\Sigma p_i \log p_i}{H' Max} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\text{(Equation 4)}$$

Where,

J= equitability

pi and log are the same as in the formula above.

$H'_{max} = \ln S.$

S= total number of species in the community (richness).

2.4.7 Tests on anthropogenic effects

To test on anthropogenic effects on seedling germination and establishment, 50 quadrats of 1×1 m were established in 5 plots. There were 5 quadrats in an enclosure of 20×20 m and 5 outside for each of the 5 plots. The number of seedlings in each 1×1 m quadrat was counted and recorded. The assessment on seedling germination and counting was done after every two months for six months. After every two months the counting was repeated and the number of seedlings in each 1×1 m quadrat recorded.

2.5 Data analysis

Different statistical methods were used to address different questions. Descriptive statistics (mean, minimum and standard error) were used to describe the various aspects of the data. The data were tested for normality prior to any statistical test using the Kolgomorov-Smirnov test. Variables that did not conform to normal distribution were logarithmically $[X' = \log(X+1)]$ or square root transformed before applying parametric analysis tests because some of the values were very small or even zero. All statistical analysis were done using STATISTICA (2004 Edition; Version 7.0 statSoft Incr.; Tulsa; USA). Means of different variables in the six habitats were compared using Analysis of Variance (ANOVA) and post-hoc Scheffe test of significance.

Soil physico-chemical data (for bulk density, soil moisture content, pH, EC, Ca, Mg, P, K, C and N), seed numbers from the three stratified depths, emergence seedling numbers and Micro-climate (temperature and relative humidity) data from the six habitats were compared among and between the six habitats using one way ANOVA and the post-hoc Scheffe test of significance. Seedling emergence data was used to calculate the diversity indices (Shannon Wiener Index, evenness and equitability) for each habitat. Seed viability for the six habitats was tested using one way ANOVA. The seedling germination and establishment data from fifty quadrats both in fenced and unfenced plots were analysed using one way ANOVA. Percentage life forms square root transformed data for standing vegetation and soil seedling emergence were compared using the independent t-test.

All the statistical analysis were evaluated at the $P < 0.05$ level of significance.

CHAPTER THREE

3.0 RESULTS AND DISCUSSION

3.1 Micro-climate

The micro-climate for the various habitats showed some variation in the four vegetation types (Table 2). The secondary grassland recorded the highest temperature while the shrubland recorded the least temperature (Figure 3). There was significant difference in temperature from the four habitats (one way ANOVA $F_{1,3} = 168095.7$, $P<0.05$). A further Scheffe test revealed significant difference between the secondary grassland and shrubland, plantation and natural forest (post-hoc Scheffe test $P<0.05$).

Table 2: Summary table of temperature (°C) and relative humidity (%) from the four habitats.

Habitat	Temperature mean (°C)	Standard deviation	R.H mean (%)	Standard deviation
Grassland	18.1229	4.2107	93.4474	16.6516
Shrubland	17.294	3.3704	98.358	10.9898
Plantation	17.4787	2.8178	96.4144	12.4864
Forest	17.4823	2.339	101.3266	5.1191
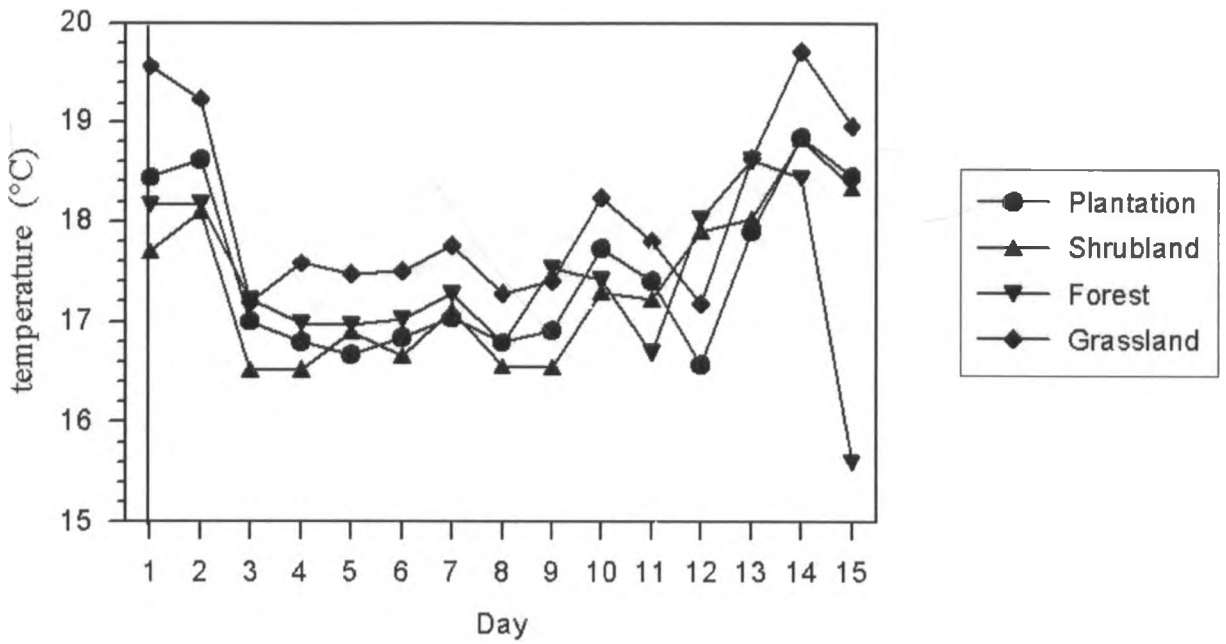
Figure 3: Daily mean temperatures (°C) in the four habitats.

There was a difference in the relative humidity recorded in different vegetation types (Table 2). The grassland recorded the lowest R.H while the natural forest recorded highest values of R.H (Figure 4). There was significant difference in R.H from the four habitats (one way ANOVA $F_{1,3} = 377328.9$, P<0.05). A further post-hoc Scheffe test revealed significant difference in all the four habitats (post-hoc Scheffe test P<0.05).
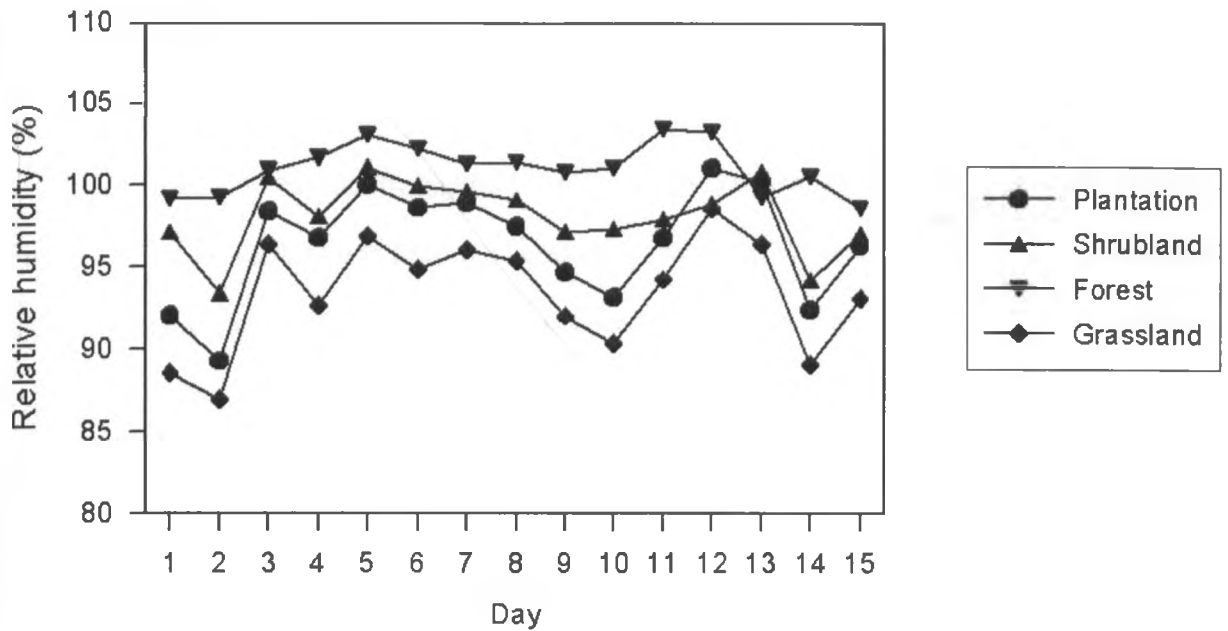
Figure 4: Daily mean relative humidity (%) in the four habitats.

The secondary grassland recorded the highest temperature because it was an open habitat that allowed sun rays to come in uninterrupted (Figure 3). The primary forest high relative humidity compared to the rest of the habitats could be attributed to biological factors such as evaporation and guttation which could have contributed to increased humidity in the atmospher . High relative humidity is unfavourable to seed storage and Germination (http://www.Storing Seed Grain - Maintaining seed viability and vigor.htm 04.21.2008), hence impacting negatively on regeneration by inducing seed rot. There was also very little sun light penetration in the natural forest which could favour the germination of shade tolerant species. This result on variation in micro-climate concurs with Watt (1947) who found out that different vegetation types alter micro-climate.

3.2 Soil properties

The various chemical parameters measured revealed some differences in their means among the six habitats. The natural forest had the highest EC followed by the plantation and the secondary grassland (Figure 5). The lowest E.C was from the burnt glade, followed by natural glade and then shrubland. There was significant difference in the EC between the habitats (one way ANOVA $F_{1,5} = 467.25$, $P<0.05$). A further post-hoc Scheffe test revealed significant difference between the natural forest and burnt glade, natural glade, plantation, shrubland and secondary grassland (post-hoc Scheffe test $P<0.05$). There was no significant difference between: burnt glade and natural glade, and between shrubland and secondary grassland (post-hoc Scheffe test $P>0.05$).
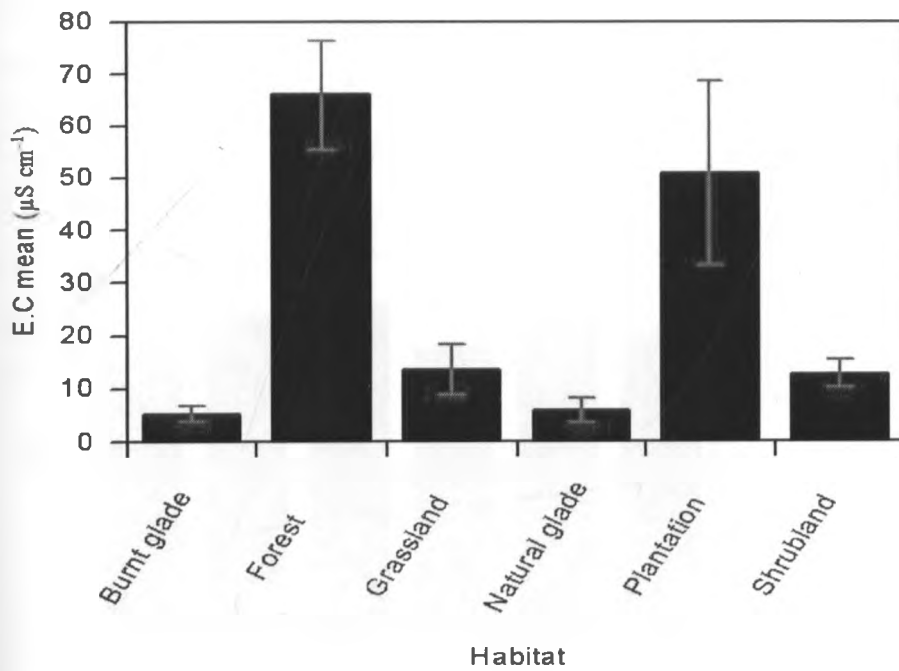
Figure 5: Mean (± SE) soil electrical conductivity (μS cm^{-1}) from the six habitats.

Electrical conductivity (EC) measures are useful as indicators of total quantities of soluble salts and nutrients in soil. The EC ranged between 5.33- 65.89 $\mu S.cm^{-1}$, with the EC from the natural forest being the highest with 65.89 $\mu S.cm^{-1}$, followed by the plantation with 50.89 $\mu S.cm^{-1}$. These two habitats had high nutrient concentration than the other habitats. The burnt glade recorded the

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least EC, this could be attributed to less addition of organic input from litter in this habitat. Therefore low nutrient input in this habitat makes it unfavourable in supporting regeneration because more nutrients are needed for further growth and establishment.

The plantation had the highest pH followed by the secondary grassland and next was the shrubland (Figure 6). The lowest pH was from the natural glade followed by burnt glade and then the natural forest. There was significant difference in the pH of all the habitats (one way ANOVA, $F_{1,5}=$ 20910.7, $P< 0.05$). A further post-hoc Scheffe test revealed significant difference between burnt glade and secondary grassland, plantation, and between natural forest and plantation, and secondary grassland and natural glade and plantation (post-hoc Scheffe test $P<0.05$). There was no significant difference between: the burnt glade and the natural forest, shrubland, natural glade (post-hoc Scheffe test $P>0.05$).
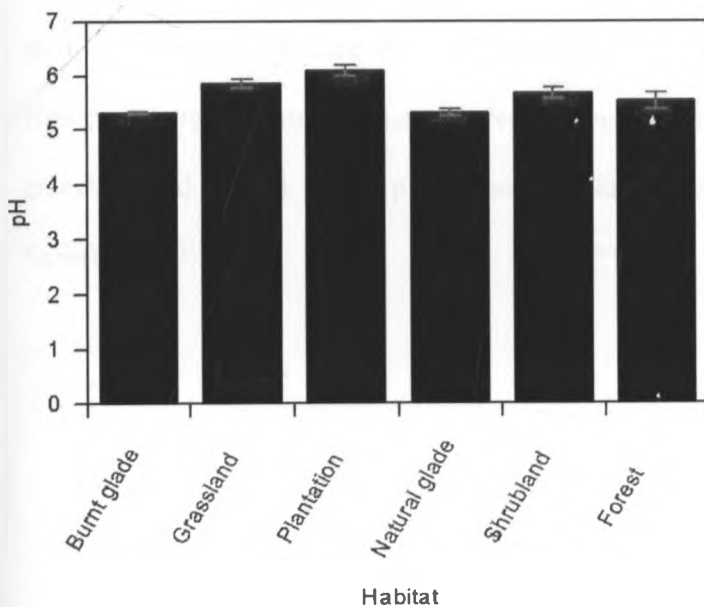
Figure 6: Mean (±SE) soil pH from the six habitats.

The soil pH for the six habitats was below 7 and above 5, hence making the soil weakly acidic in nature. Burnt glade and natural glade had low (4.9-5.2) category pH levels, this is attributable to the constant disturbance that these habitats have been under. This result concurs with a study by Musila, (2007) which revealed that most disturbed areas turn out to be more acidic than intermediate or less disturbed sites. However acidity in soils lowers organic matter decomposition (Etherington, 1974). This is due to the effect of soil pH on the activity of soil micro-organisms involved in decomposition of organic matter. Low organic matter decomposition results into low soil fertility which impairs further growth and establishment of seedlings.

Burnt glade recorded the lowest Ca followed closely by the natural glade, then the shrubland (Figure 7). The plantation had the highest Ca followed by the secondary grassland and then the natural forest. A test of significance on the Ca among the habitats was significant (one-way ANOVA $F_{1,5}$ = 691.2, P< 0.05). A further post-hoc Scheffe test showed significant difference between the burnt glade and natural forest, plantation, secondary grassland and shrubland. There was also significant difference between plantation and shrubland (post-hoc Scheffe test P<0.05). However there was no significant difference between the burnt glade and natural glade, secondary grassland and natural forest, plantation and natural forest, shrubland and natural forest (post-hoc Scheffe test P>0.05).
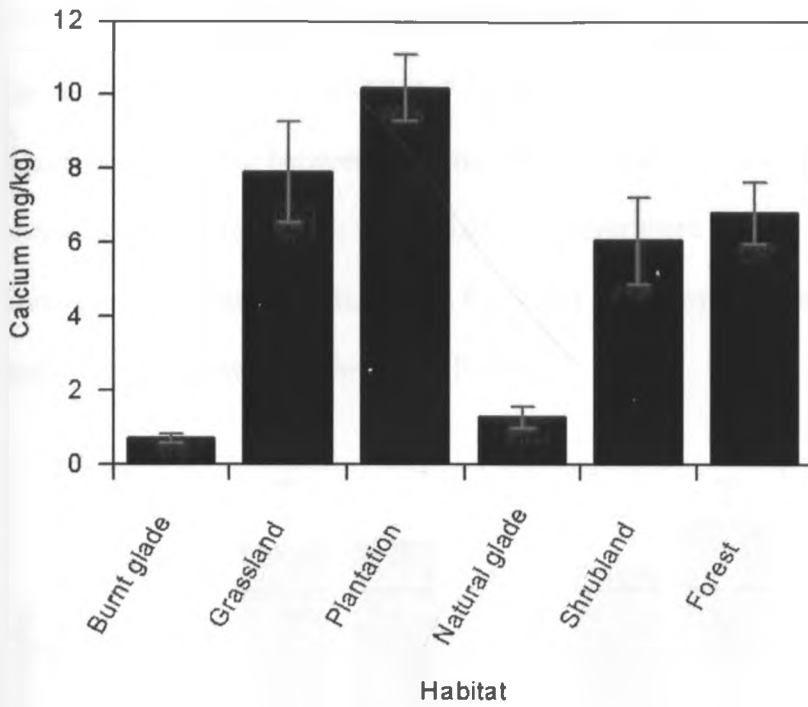
Figure 7: Mean (±SE) soil Calcium (mg/kg) from the six habitats.

According to London (1991) rating of tropical soils the plantation had a high (> 8mg/kg) level of Ca, while the primary forest, secondary grassland and shrubland had medium (4-8mg/kg) levels of Ca, natural glade and burnt glade had the lowest (0.4-4mg/kg) Ca levels category (Landon, 1991). The interpretation for the category high for plantation imply that Ca is sufficient for growth, medium is sufficient for fair to good growth, but low category is insufficient for normal growth and fertilization is required for natural glade and burnt glade for normal growth and regeneration in these habitats (Landon, 1991). The low levels of Ca could be attributable to the fact that most disturbed areas have low extractable Ca as revealed in a study by Musila (2007). The low levels of Ca experienced in the secondary grassland, shrubland, burnt glade, natural glade and plantation could be attributed to disturbance which these habitats have experienced. Also Grecen and Sands (1980) have argued that there is a small loss of K, Ca and Mg in a period of 1-11years after clearing of a forest.

The natural forest had the highest Mg than all the six habitats followed by the plantation which was closely followed by the secondary grassland (Figure 8). The burnt glade had the least Mg followed

closely by the natural glade and then the shrubland. There was significant difference of Mg among the six habitats (one-way ANOVA $F_{1,5} = 668.67$, $P<0.05$). A further post-hoc Scheffe test revealed significant difference between the burnt glade and natural forest, secondary grassland, plantation and shrubland (post-hoc Scheffe test $P<0.05$). However there was no significant difference between: the burnt glade and natural glade, natural forest and secondary grassland, plantation, secondary grassland and shrubland (post-hoc Scheffe test $P>0.05$).

Figure 8: Mean (±SE) soil Magnesium (mg/kg) from the six habitats.

According to the standard recommended rating for tropical forest soils by Landon (1991), primary forest, secondary grassland, plantation and shrubland had medium (2.32-2.98 mg/kg) levels of Mg. The natural glade had a minimal level (0.54 mg/kg) of Mg and the burnt glade had low (0.43 g/kg) Mg level. Category medium for the primary forest, secondary grassland, plantation and shrubland is sufficient for fair to good growth and regeneration (Landon, 1991). The natural glade with minimal and burnt glade low Mg category is insufficient for normal growth and regeneration hence immediate fertilization required (Landon, 1991). The deficiency of Mg experienced could be

attributed to disturbance (grazing and grass harvesting for thatching) which these habitats have been experiencing.

Natural glade recorded the lowest K followed by the burnt glade and then the natural forest (Figure 9). The plantation had the highest K followed by the shrubland and then the secondary grassland. A test on K showed significant difference (one-way ANOVA $F_{1,5} = 878.1$, P <0.05) for all the habitats. A further post-hoc Scheffe test revealed significant difference between burnt glade and plantation and between natural glade and secondary grassland, plantation, shrubland (post-hoc Scheffe test P<0.05). However there was no significant difference between the burnt glade and natural glade (post-hoc Scheffe test P>0.05).
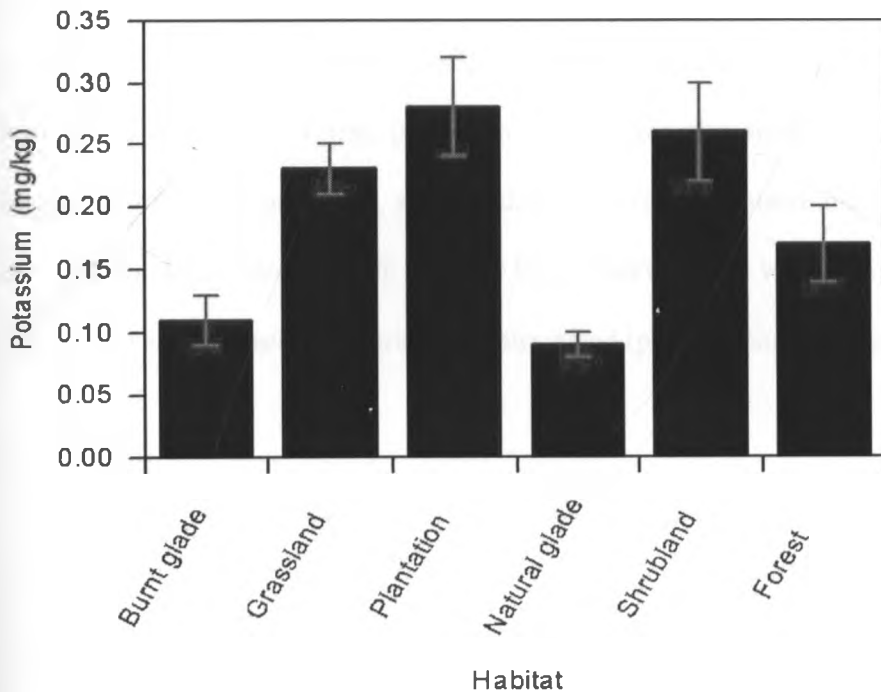
Figure 9: Mean (±SE) soil Potassium (mg/kg) from the six habitats.

According to the standard recommended rating for tropical soils by Landon (1991), burnt glade, secondary grassland, natural forest and natural glade had low (0.09-0.23 mg/kg) K levels, whereas the plantation and shrubland had fairly low K (0.26-0.28 mg/kg) levels. However all the habitats had

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insufficient K for support of regeneration hence fertilization required to boost K level (Landon, 1991). The deficiency could be attributed to K mobility that makes it to be quickly taken up and circulated in the environment while the remaining K is leached to the deeper soil layers. The low levels of Ca, Mg and K experienced in the secondary grassland, shrubland, burnt glade, natural glade and plantation could be attributed to disturbance which these habitats have been under. Grecen and Sands (1980) have argued that there is some loss of K, Ca and Mg in a period of 1-11years after clearing of a forest.

The shrubland recorded a highest P followed by the secondary grassland and then the burnt glade (Figure 10). The natural forest recorded the lowest P followed by the plantation and then the natural glade. Comparison of P among habitats showed significant differences (one-way ANOVA $F_{1,5} = 858.8$, P<0.05). A further post-hoc Scheffe test revealed significant differences between the burnt glade and natural forest, plantation. There were also significant differences between natural forest and secondary grassland, shrubland, and between grassland and plantation, also natural glade and shrubland (post-hoc Scheffe test P<0.05). However there was no significant difference between burnt glade and the secondary grassland, shrubland (post-hoc Scheffe test P>0.05).
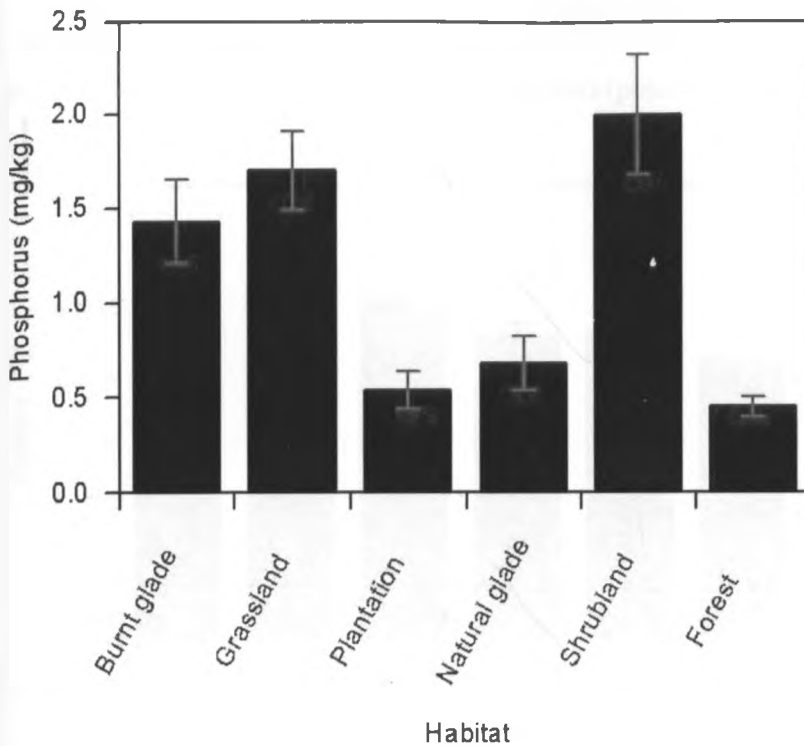
Figure 10: Mean (±SE) soil Phosphorus (mg/kg) from the six habitats.

According to the standard recommended rating by Landon (1991) on tropical forest soils, shrubland had high level of Phosphorus (>15 mg/kg). The natural glade, burnt glade, secondary grassland and plantation had medium levels of phosphorus (5-15 mg /kg). The natural forest had low levels of phosphorus (<5 mg/kg). Shrubland's high level of Phosphorus is sufficient for growth and regeneration (Landon, 1991), though it can cause some imbalance to other essential nutrients such as Mg, Ca, K and soil pH (Lars *et al.*, 2003). However young forests are subject to strong weathering input of P and base cations (Ca, Mg, Na and K) whereas the old forests harness these from the atmosphere. A decline of P in the natural forest and plantation could also be attributed to plant uptake (Sommer, 2000).

The highest C was recorded in the secondary grassland, followed by the plantation and then the shrubland (Figure 11). The lowest C was recorded in the burnt glade followed by the natural forest and then natural glade. Comparison of C among the habitats showed significant difference

(one-way ANOVA $F_{1,5}$=1211.4, P<0.05). A further post-hoc Scheffe test revealed that there was no significant difference between any of the habitats (post-hoc Scheffe test P>0.05).
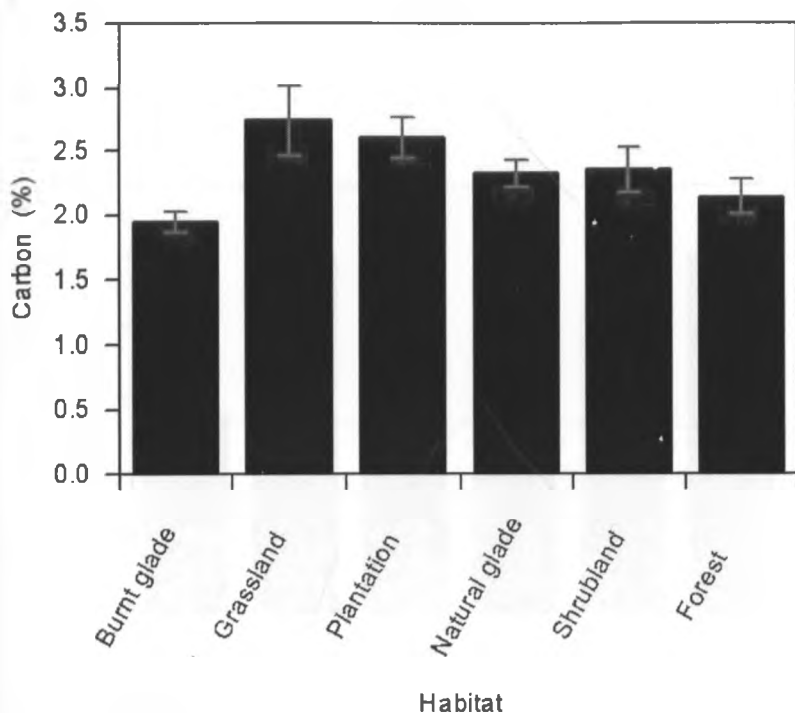
Figure 11: Mean (±SE) soil Carbon (%) from the six habitats.

According to the standard recommended rating by Landon (1991) on tropical forest soils burnt glade had very low carbon level (1.95%) whereas the secondary grassland, plantation, natural glade, shrubland and natural forest had low levels (2.14-2.74%) of carbon. Therewas deficiency of C in all the habitats and this requires fertilization for normal growth and regeneration in these habitats (Landon, 1991). Low C levels could be attributed to low litter accumulation in the various habitats.

The secondary grassland recorded the highest N followed closely by the natural forest and then the plantation (Figure 12). The burnt glade recorded the lowest N followed by natural glade and then the shrubland. Comparison of N from all the habitats showed significant differences (one-way ANOVA $F_{1,5}$= 3751.45, P<0.05). A further post-hoc Scheffe test revealed that there was significant difference between: the burnt glade and natural forest, secondary grassland, plantation, shrubland

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(post-hoc Scheffe test P<0.05). However there was no significant difference between burnt glade and natural glade, natural forest and secondary grassland, plantation and shrubland (post-hoc Scheffe test P>0.05).
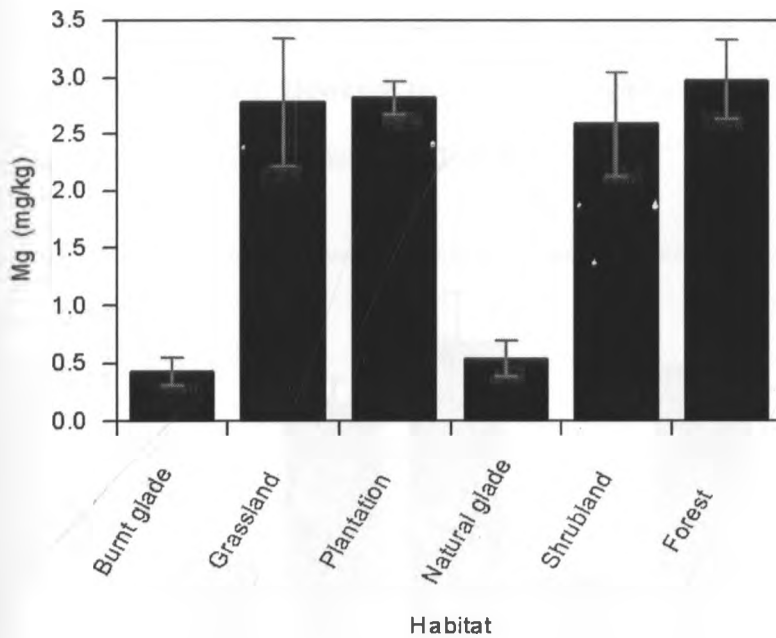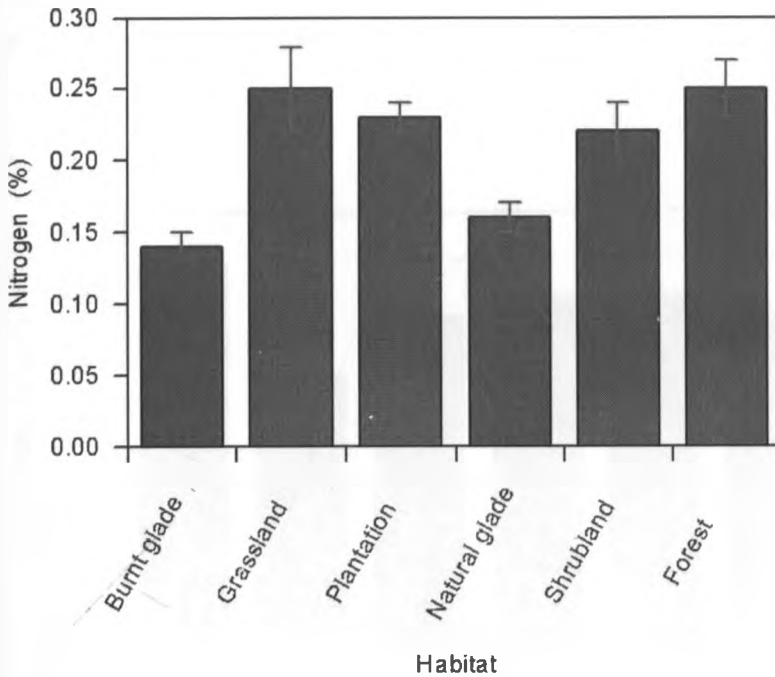

Figure 12: Mean (±SE) soil Nitrogen (%) from the six habitats.

According to the standard recommended rating by Landon (1991) on tropical forest soils, secondary grassland, plantation, shrubland and primary forest had medium (0.22-0.25%) nitrogen levels. This is good for fair to good growth and regeneration (Landon, 1991). Whereas the burnt glade and natural glade had low (0.14-0.16%) levels of nitrogen which could not support normal trees growth. Limited nitrogen supply limits plant growth on young soils (Lars *et al.*, 2003). Nitrogen mean total of 0.2 % is what is needed for trees species growth (Wilde, 1958). The natural forest is likely to be supplementing its Nitrogen deficiency through litter fall (Vincent, 2001; Lars *et al.*, 2003).

The secondary grassland recorded the highest bulk density while the shrubland recorded the least (Figure 13). There was significant difference in bulk density among the six habitats (one way ANOVA $F_{1, 5} = 4691.8$, $P < 0.05$). A further post-hoc Scheffe test showed that there was no significant difference in the bulk density between the secondary grassland and the rest of the habitats, but there was significant difference between the natural forest and burnt glade, natural glade and plantation (post-hoc Scheffe test $P < 0.05$).
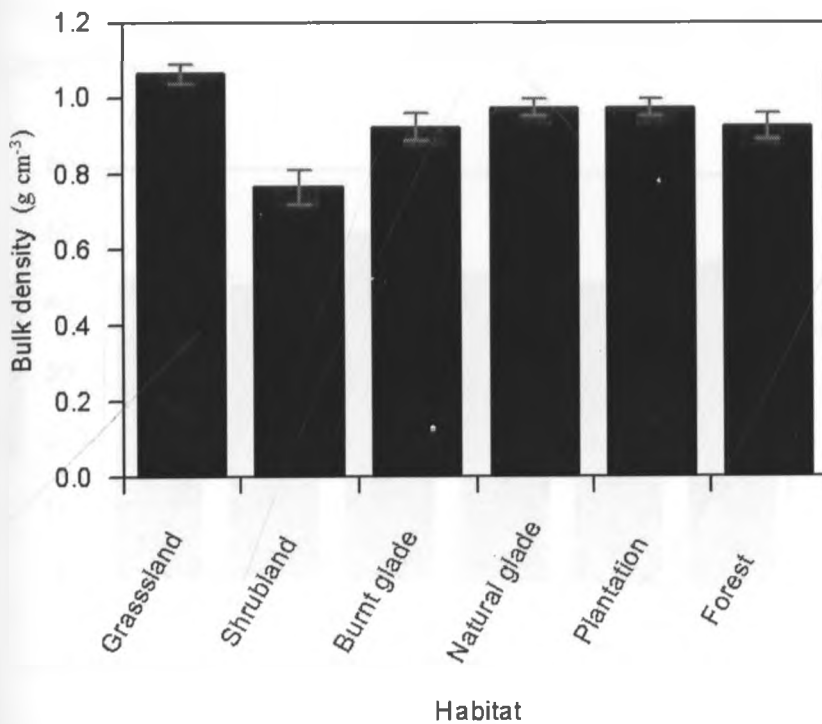
Figure 13: Mean ($\pm$SE) soil bulk density (g cm^{-3}) from the six habitats.

There was generally a high (>0.8 g cm^{-3}) bulk density recorded in all the habitats. The high bulk density signifies soil compaction which also affects soil porosity. The high bulk density in the secondary grassland could be attributed to constant anthropogenic activities such as grass cutting and trampling by grazing animals, this are carried out regularly in this habitat. The shrubland lowest bulk density compared to other habitats could be attributed to the activities of mole rats in this habitat and

other soil micro-fauna. Soil porosity in most of the habitats was attributable to high activity of termites, ants, earth warms and other soil micro-fauna which keep the soil porous. Compacted soils impair seed germination and seedling establishment, hence affecting regeneration (Barik *et al.*, 1996).

The burnt glade recorded the highest moisture while the shrubland recorded the least (Figure 14). There were significant differences in the moisture content among the six habitats (one way ANOVA $F_{1,5}$ =6524.39, P< 0.05). A further post-hoc Scheffe test showed only a significant difference in the moisture content between the burnt glade and the shrubland (post-hoc Scheffe test p<0.05).
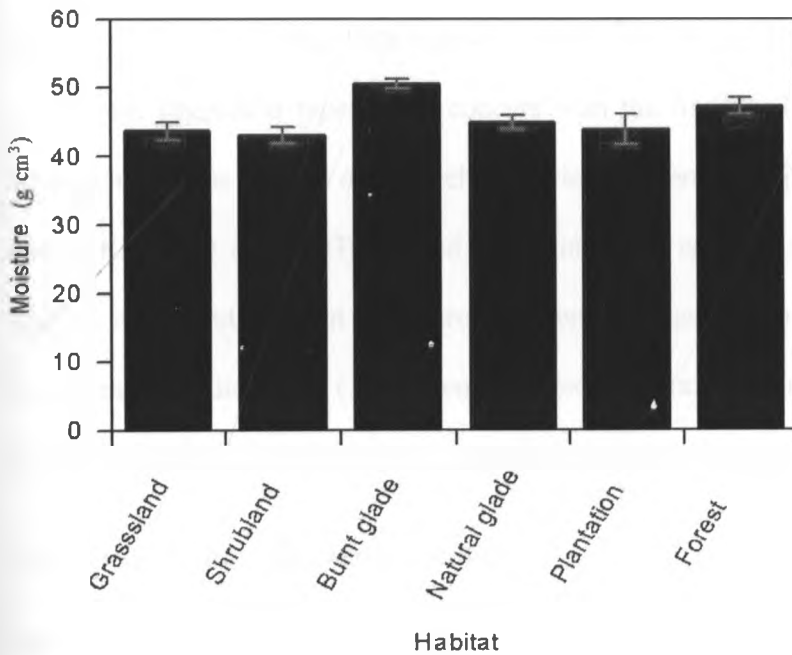
Figure 14: Mean (±SE) soil moisture (g cm^3) content from the six habitats.

This study was done during a rainy season and also the similarity in soil texture for the six habitats hence small variations in water holding capacity. However soil moisture is not likely to be a problem to regeneration in Kakamega forest because there is adequate precipitation throughout the

year. Thomas (2000) has argued that soil moisture is not a problem to regeneration in tropical rain forests.

Generally the soils of all the habitats were well drained, and were sandy clay. Low nutrient elemental composition of soils observed in this study is not uncommon since the concentrations of most nutrient elements are known to be lower in sandy than in clay soils, with loam and silt being intermediate (Whitehead, 2000). In this study it has been revealed that the soil fertility of Kakamega forest is highly depleted and of low fertility. These results are consistent with earlier studies done in the same forest by Musila (2007). Tropical forests are known to be of low fertility with only a few of them being fertile (Bermingham *et al*., 2005).

Soils in Kakamega forest are heterogeneous as exemplified by the soil chemical results from the different sampled sites. Heterogeneity could partly be attributed to disturbance that has resulted in different vegetation types. This concurs with the findings by Musila (2007), who argued that heterogeneity is as a result of hierarchical series of interrelated processes and vegetation at different scales. Klinge *et al*. (2003), argued that rain forest conversion resulted in a disturbance of the nutrient cycle and nutrient loss through biomass export, burning and leaching resulting in soil heterogeneity. Adler *et al*. (2001) demonstrated that grazing as a form of disturbance contributed to soil heterogeneity by increasing plant mortality through trampling and uprooting of seedlings.

3.3 Soil seed bank and seed viability

The total number of seedlings that emerged was 15,676 seedlings, the grassland had the highest number of seedlings, followed by the shrubland. The rest of the habitats had fewer numbers compared to the grassland and shrubland seed totals with the forest recording the least total number. The forest almost had an equal number of seeds in the 0-5 cm and 5-10 cm depths (Appendix 4).

There was a variation in sum total between seed number counts and emergence seedling numbers for the 6 habitats. The seedling emergence experiment had the highest number of seeds in

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secondary grassland, followed by shrubland, plantation, natural glade, burnt glade and the least number was from natural forest. There were significant differences in the emerging seedlings from the three stratified sampling depths for all the six habitats (One way ANOVA: $F_{1, 5} = 2306$, p<0.05). The upper depth (0-5cm) had the largest number of emerging seedlings followed by the middle depth (5-10cm) and lastly the lower depth (10-15cm) (Figure 15).
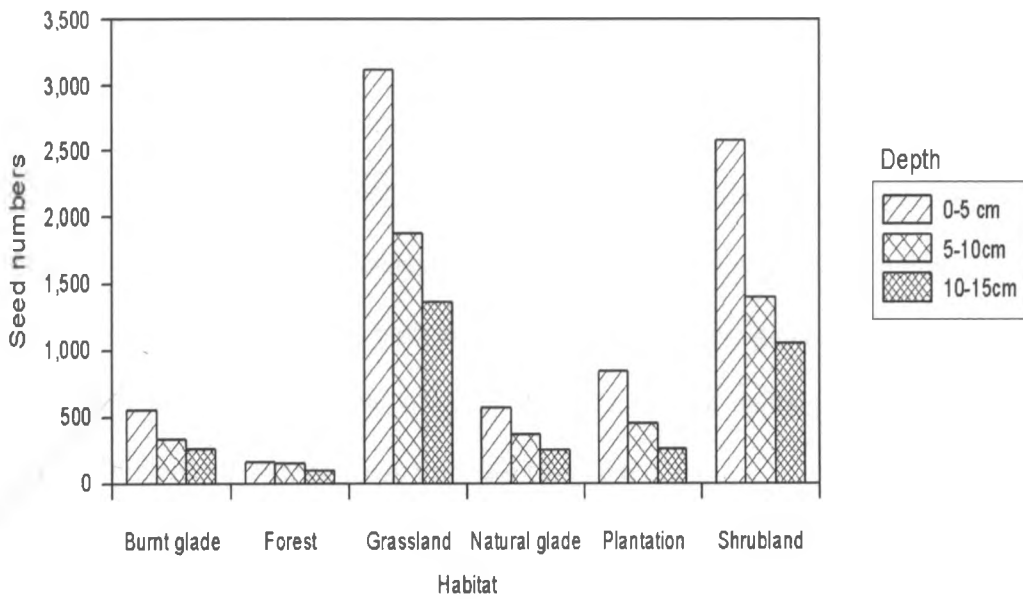
Figure 15: The seed number distribution among the three depths attained through seedling emergence from the six habitats.

There was great variation in species composition from the six habitats, (one way ANOVA $F_{1, 5} = 4.07$ P<0.05) test showed significant difference in the species types for the six habitats. A further post-hoc Scheffe test on the species composition between habitats showed no significant difference between the burnt glade and natural forest, secondary grassland, natural glade, plantation and shrubland (post-hoc Scheffe test P>0.05). However, there was significant difference in species composition between the plantation and grassland (post-hoc Scheffe test P<0.05).

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Total seed count revealed that the shrubland had the highest number of seeds followed by the natural glade then the plantation (Figure 15). Secondary grassland recorded more seeds in the 0-5 cm depth and showed a drastic reduction in the seed numbers as the depth increased. Total seed count for all the six habitats showed significant difference in the mean number of seeds (One way ANOVA: $F_{1,5}$ = 309.3, $P < 0.05$) counted from each habitat. A further post-hoc Scheffe test revealed significant difference in seed numbers from the shrubland with those from the burnt glade and forest (post-hoc Scheffe test < 0.05). However there was no significant difference in the seed numbers between the shrubland and secondary grassland, natural glade and plantation (post-hoc Scheffe test > 0.05).

There was a general reduction in the number of seeds from the top to the deeper levels of the soil in the secondary grassland, natural glade, plantation and shrubland (Figure 16). These habitats recorded the highest number of seeds in the 0-5 cm depth, followed by 5-10 cm depth and the least seeds were from 10-15 cm depth, with an exception of the burnt glade and natural forest. The burnt glade recorded the highest number of seeds from the middle depth (5-10 cm). The natural forest recorded the highest number of seeds from the 10-15 cm depth.
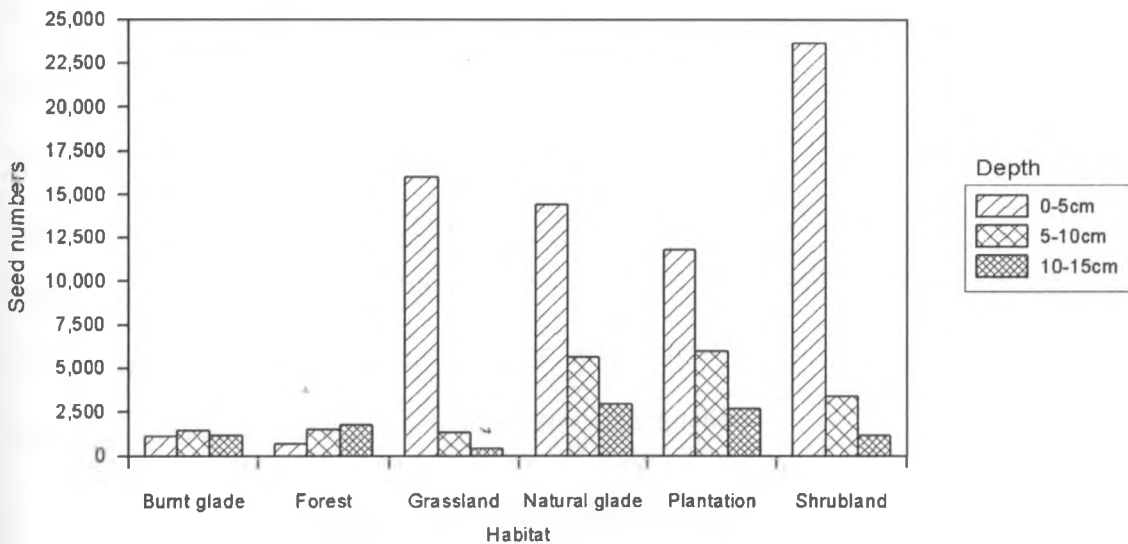
Figure 16: The seed number distribution among the three depths attained through screening samples for total seed count from the six habitats.

There was significant variation in the mean number of seeds from the various depths of different habitats (One-way ANOVA: $F_{1, 5} = 309.3$, $P < 0.05$). The emergence seedling experiments revealed a variation from total seed count on burnt glade and natural forest depths. This was good for comparison purposes of the two techniques employed. The seedling emergence experiment had the highest number of seeds from the secondary grassland, followed by shrubland, plantation, natural glade, burnt glade and the least number was from the natural forest (Appendix 4). The total seed count had the highest number of seeds from the shrubland, natural glade, plantation, secondary grassland, burnt glade and lastly was the natural forest (Appendix 5).

There was a difference in total seed numbers from the various habitats as revealed by the two techniques; total seed count and seedling emergent technique. The variations are attributed to seed viability of each habitat, seedling emergence experiment only took into account viable seeds while the total count incorporated both viable and unviable seeds. The results of the least number of seeds coming from the forest is consistent with Valbuena *et al.* (2001), who found that large undisturbed forests are not known to have high seed bank densities of pioneers and weeds unless a disturbance occurres at intervals less than those of plant and seed longevity. There was generally a reduction in the seed numbers with depth from the secondary grassland, natural glade, plantation, and shrubland. These habitats recorded highest seed numbers from the 0-5cm depth. This is consistent with studies done on soil seed bank by Adler *et al.* (2001). The high number of seeds in this depth is attributable to the organic matter accumulation on the soil surface of the habitat. Putwain and Gillham (1990) emphasized that a high percentage of about 96% of seed banks of heather and other sedge species from the top 50mm layer was due to high litter accumulation.

The burnt glade had the smallest number of seeds found in the 0-5cm depth. This could be attributed to the destruction of the above ground matter by the fire. The following depths (5-10cm) and (10-15cm) followed the same trend as the other habitats except for the natural forest. This is

because the fire effect only affected the top layer of the burnt glade but could not penetrate deep into the soil layers. The forest recorded the highest number of seeds in the lowest depths and a lower number in the 0-5cm depth, this could be attributable to seasonality, because at the time of sampling the forest floor had a lot of seedlings which are likely to have germinated from the seeds of the 0-5cm depth. The seeds in the 5-10cm depth were slightly less than those in the 10-15cm depth.

Presence of more seeds in the deeper layers of the natural forest soil bank might suggest that there is some secondary seed dispersion taking place in the soil, this needs further investigation. Increased soil depths impair seed germination by altering moisture, air, light and temperature, hence making seeds to remain in a state of dormancy for long (Thomas, 2000; Gutterman *et al.*, 2007). For example light germinators rely on light to break seed dormancy. The average depth of seeds in the soil indicates their distribution and longevity in the soil (Abdella *et al.*, 2007). The distribution of seeds in various soil depths is attributable to several biotic factors such as the activity of ants, mole rats and other soil micro-fauna.

3.3.1 Species composition for the six habitats

The total number of emerging seedlings was 15, 676 (Appendix 4), out of which 15,060 were identified in 43 distinct taxas (species and genera) and recorded, but 616 were too small for identification and died before identification stage hence denoted as unknown. The burnt glade was dominated by *Hydrocotyle mannii* , *Fibristylis dichotoma*, the rare most species was *hildebradtii* which had only one species followed by *Conyza sumatrensis, Glycine wightii* and *Urera lobota* had only two species for each.

Natural forest seed bank was mainly dominated by *Conyza sumatrensis*. It had a number of trees that included *Celtis africana, Celtis durandii, Funtumia africana, Prunus african, Ficus sur, Trema oriantis* and *Zenthoxylum glettee*. The secondary grassland was dominated by *Leonotis nepataefolia* which counted up to 3748 individuals, this was followed by *Galinsoga parvifilia* with

773 individuals and *Fibristylis dichotoma* with 747 individuals, which were garden weeds. No tree was identified in the secondary grassland soil seed bank. The natural glade was dominated by *Fibristylis dichotoma*. The plantation was dominated by *Lantana camara* and *Commelina bengalensis*. The shrubland was mainly dominated by *Hydrocotyle mannii* and *Fibristylis dichotoma*.

The burnt glade soil seed bank was dominated by other herbs followed by graminoids and shrubs (Appendix 7). The climbers recorded the least percentage, followed by the trees, then the unknown. The natural forest soil seed bank was dominated by other herbs, followed by shrubs then trees. There was no climber in the forest soil seed bank; graminoids had the least percentage followed by the unknown. The secondary grassland soil seed bank was dominated by shrubs, followed by the graminoids and then other herbs. No tree was identified in the secondary grassland soil seed bank, the least was climber. Natural glade was dominated by graminoids, followed by the other herbs then unknown. The climbers recorded the least percentage, followed by trees and shrubs.

The plantation was dominated by shrubs then other herbs and trees. The least percentage was from the unknown, then graminoids and least was climbers. The shrubland was dominated by graminoids, then other herbs, followed by shrubs then unknown. The trees had the least percentage followed by the climbers.
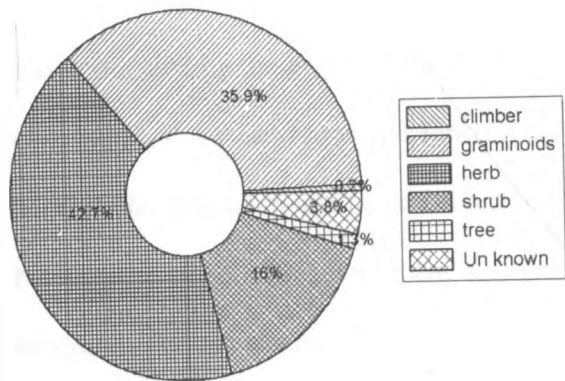
Burnt glade % life forms
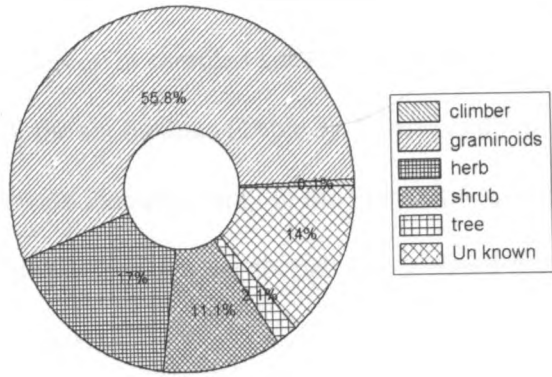
Natural glade % life forms
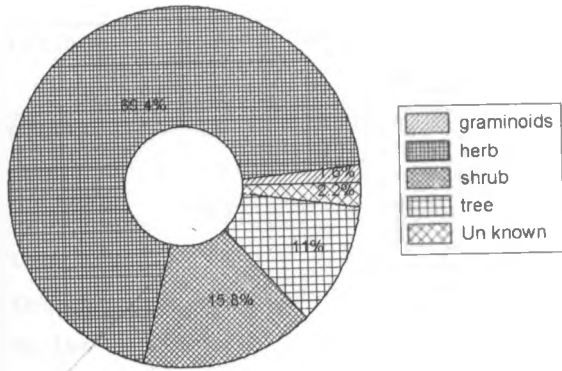
Forest % life forms
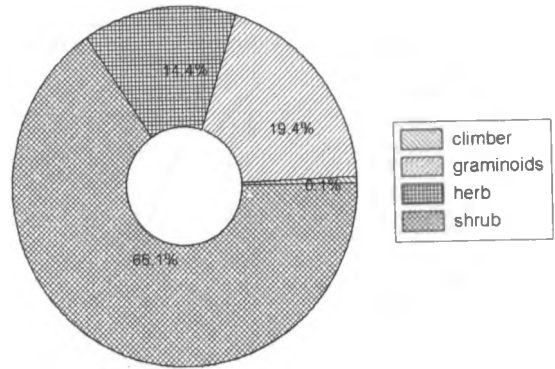
Grassland % life forms
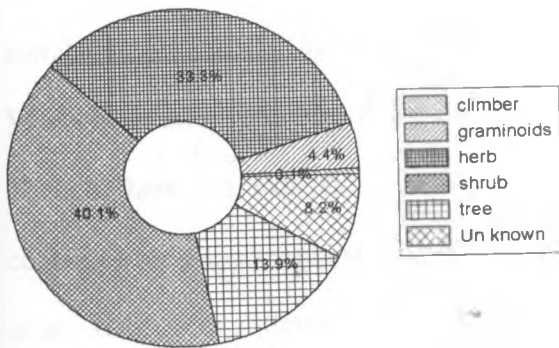
Plantation % life forms
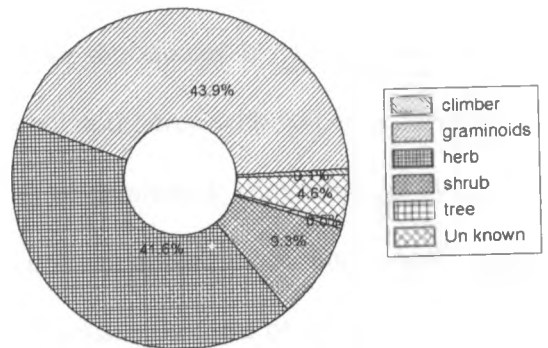
Shrubland % life forms

Figure 17: Percentages of life forms from the soil seed bank of the six habitats.

The burnt glade, natural forest and shrubland were dominated by other herbaceous life form (Figure 17). The secondary grassland and plantation were dominated by shrubs, whereas the natural glade was dominated by the graminoids. The vegetation survey in sampled sites revealed that graminoids, other herbs, shrubs and trees life forms were in all the six habitats (Table 3). Ferns occurred only in burnt glade, plantation and natural forest, orchids were identified only in the plantation. Comparison between the standing vegetation and soil seed bank life forms in the six habitats revealed significant difference (Independent t-test, t =2.089, d.f = 82, P<0.05).

Table 3: Life form percentages of standing vegetation in sampled sites for the six habitats

Life form	Grassland %	Shrubland %	Burnt glade %	Natural glade %	Plantation %	Forest %
Climbers	1.0	3.0	5.6	4.3	13.8	15.1
Ferns	1.0	0	0.3	0	2.4	1.4
Grasses	40.1	30.3	22.1	14.6	2.4	0.7
Other herbs	35.4	38.4	50.9	59.4	19.2	10.9
Orchids	0	0	0	0	0.3	0
Shrubs	8.3	16.2	12.4	16.0	23.0	23.5
Trees	14.1	12.1	8.8	5.7	38.8	48.4

A comparison between the standing vegetation and the soil seed bank revealed a poor correlation for all the habitats. This is in agreement with the studies by Thomas, (2000) and Valbuena *et al.* (2001) who found out that standing vegetation differed with soil seedbank species. Though there are exceptions as found mainly in annual-dominated communities, they often contained early succession species but do not represent late or dominant succession species (Robert *et al.*, 2000). The difference is due to seed dispersal mechanisms (in form of mechanical ejection, passive form, fire, wind, water and animals), seed burial and predation (Bakker *et al.*, 1996). The soil seed banks of various habitats were generally dominated by the other herbaceous species. This could be attributed to easy dispersal ability of the other herbaceous species by the various dispersal agents

such as wind and water because of their light weight. It can also be attributed to the fact that most wood species are recalcitrant.

Given that other herbs, graminoids and shrubs have small-sized seeds, they tend to produce seeds in large quantities and end up dominating the soil seed bank (Obiri *et al.*, 2005). These results concur with other studies indicating that other herbaceous species dominate the soil seed banks while only a few woody species are capable of accumulating long-lived seeds in the soil (Abdella *et al.*, 2007). Most of the woody species seeds are big in size hence more vulnerable to predation than small seeds (Obiri *et al.*, 2005). It has also been shown that degraded natural forest habitats are most of the time invaded by non-wood plants such as ferns, vines, grasses and shrubs at the expense of woody species, which may take decades to recruit (Verheyen *et al.*, 2003). This implies that other herbaceous species have better chances of recovery than woody species from the soil seed banks in the event of disturbance (Jose & Fernsandez, 1999). This is hardly surprising considering that seed bank density and dominance by weeds increases with continuous farming (Jose & Fernsandez, 1999).

The secondary grassland soil seed bank life forms included shrubs, sedges and other herbs as exhibited by germination experiments (Figure 17). However, the vegetation survey revealed very few scattered trees and shrubs in this habitat (Table 3). The variation in this habitat could be attributed to the fact that grass seeds which are small in size accumulate in the 0-3cm soil depth (Markus *et al.*, 2002) and therefore most of them had germinated by the time sampling was done. Most of other herbs in this habitat were garden weeds which could have been brought in by the shamba system practices in the early nineties (Tsingalia, 1988). The shrubland soil seed bank had large percentage sedges followed by other herbs, with a few trees and shrubs as exhibited by the emergence seedling experiments but the vegetation survey revealed a large number of shrubs and trees in the habitat. The burnt glade soil seed bank was dominated by other herbaceous species unlike

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the natural glade which was dominated by sedges. This could be attributed to suppression of the sedges by the fire prompting other herbaceous species to dominate. The burnt glade had a very small percentage of the unknown species compared to the natural glade. This could be attributed to the effect of the fire in breaking of seed dormancy (Barik *et al*, 1996), hence facilitating quick germination of the seeds.

The natural forest soil seed bank was dominated by other herbaceous species, contrary to Leckie *et al.* (2000) whose work revealed that forest seed bank is dominated by forest species. Most of the forest shade tolerant trees maintain seedlings rather than seed banks. A study by Piroznikov (1983) revealed that while the number of other herbaceous species remain relatively constant in different years, the number of woody species fluctuate widely. However sedges dominated the soil seed bank in the shrubland followed by grasses. This could be attributed to grazing, since cattle go for palatable grasses leaving behind the sedges. The sedges were therefore able to grow and shed seeds, hence become dominant. The plantation soil seed bank was dominated by other herbs. A proportion of shrubs were of invasive species like *Lantana camara*. These are likely to have set in after logging of the primary forest, just before the re-planting with *Cuppresus lucitanica*. The soil seed bank and the above ground vegetation variations could be attributed to seed viability. It was generally found that the seeds from all the habitats had a viability that ranged between 1.3-33.8%. This is a very low score considering that for well germinating seeds the germination should be at least between 50-55% (http://www.Storing Seed Grain - Maintaining seed viability and vigor.htm).

3.3.2 Shannon Wiener Index, Evenness and Equitability for the six habitats.
The plantation had the highest number of individual woody species, followed closely by the natural forest, then burnt glade, grassland, natural glade and lastly shrubland (Table 4). However the natural forest had the highest number of taxa, followed closely by plantation then secondary grassland, burnt glade, natural glade and lastly shrubland. Plantation had the highest diversity, followed closely by

natural forest, then natural grassland, burnt glade, natural glade and the shrubland. There was no significant difference in diversity and evenness for all the six habitats (One sample t-test, t =5.1651, d.f = 5, P<0.05).

Table 4: Shannon Wiener Index, Evenness and Equitability for the six habitats.

	Taxas	Individuals	Dominance D	Shannon H′	Evenness	Equitability J
Grassland	13	26	0.1124	2.372	0.8249	0.925
Shrubland	6	12	0.1944	1.705	0.9165	0.9513
Burnt glade	11	30	0.1222	2.231	0.8466	0.9306
Natural glade	7	24	0.184	1.798	0.8627	0.9241
Plantation	35	141	0.03385	3.447	0.897	0.9694
Forest	36	138	0.04768	3.301	0.7537	0.9211

The lack of significance difference in the habitats evenness was due to minimal dominance in all the habitats. The habitats were heterogeneous, with the plantation, followed by natural forest recording high diversity. The high diversity could be attributed to minimal disturbance in these two habitats. Availability of woody species in all the habitats is evidence that the soil seed bank is capable of facilitating regeneration in all habitats despite the fact that the soil seed bank in secondary grassland din't have any trees seedling.

3.3.2 Seed viability

Seed viability was highest in the grassland and lowest in the plantation (Figure 18). There was significant difference in the germination percentages for the six habitats (One-way ANOVA: F1, 5 = 6.712, P< 0.05). The soil seed bank was found to be of very low viability that ranged between 1.3% to 33.8%. Temperature increase treatment from 20°C to 25°C revealed a germination increase of 5.2% from grassland, 2.3% from forest, 0.7% from shrubland and 0.2% from plantation. There was

no germination realized as a result of temperature increase on seeds from the burnt glade and natural glade.
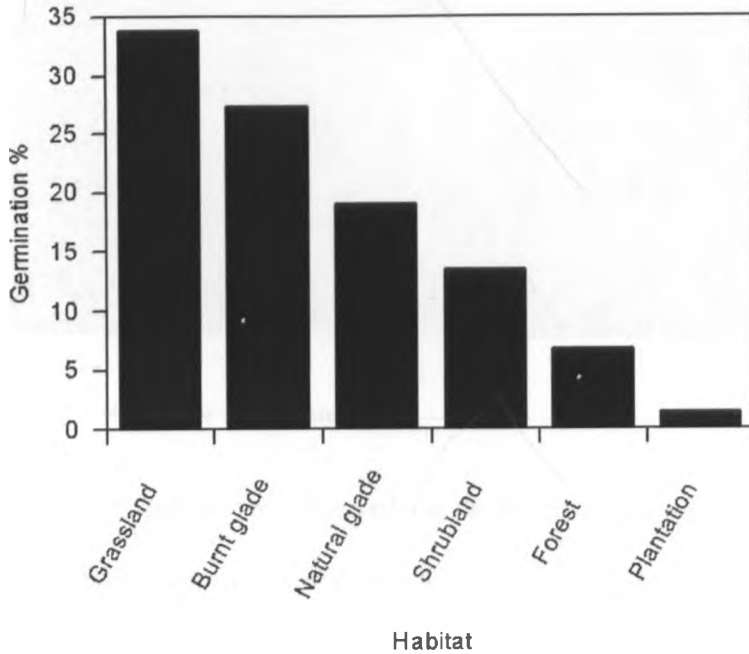
Figure 18: Percentage seed viability for the six habitats

The seed viability realized was far below the standard seed viability which is in the range of 50% to 55% (http://www.Storing Seed Grain - Maintaining seed viability and vigor.htm). The low rate in seed viability may be attributed to high relative humidity, seed predation (Plate 10) as observed on seeds during screening. The recommended relative humidity level for storage of most seed species is up to 30% (http://www.Storing Seed Grain - Maintaining seed viability and vigor.htm 04.21.2008), yet the different habitats experience relative humidity as high as 100%, which makes most of the seeds to rot.
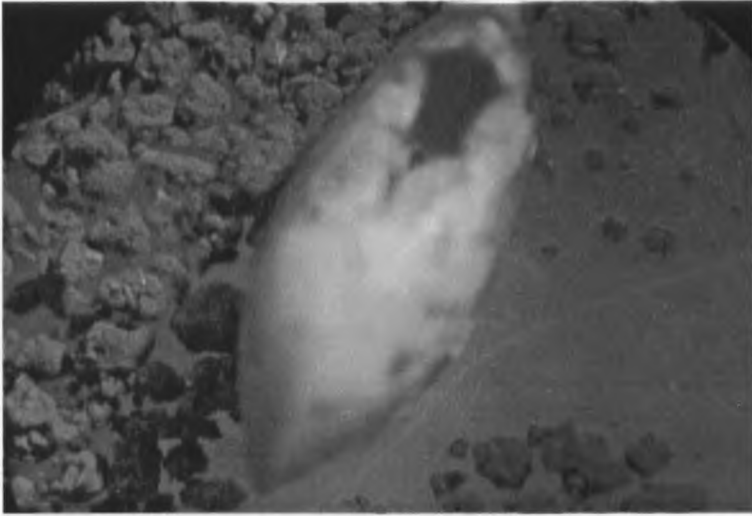
Plate 10: A predated seed

Predation was observed on seeds mainly from the secondary grassland, shrubland, burnt glade and natural glade during screening. The predation is presumably caused by ants, termites and other soil micro-fauna in these habitats. Studies by Forget *et al*. (1998) revealed that seed longevity and viability is prevented more by predators. Robert *et al*. (2000) has shown that most of the seeds are rapidly lost through predation and disease hence only a small fraction is viable. Seed predation may be very high when other resources such as small micro-fauna are scarce, but it reduces when other food resources are in abundance for predators (Poiani & Dixon, 1995). Seed predation differs also according to species (Forget *et al*., 1998). For areas in which seed predation is high, species with low predation may have a major competitive advantage over species that suffer high predation.

Studies by Kirika (2005) revealed that plant pollination is low in heavily fragmented forest areas, and this is caused by migration of birds from such areas. This in return has an effect on plants that mainly rely on such birds for complete fertilization hence producing seeds which are not completely fertilized and thereby resulting into unviable seeds (Kirika, 2005).

3.4 Anthropogenic effects on seed germination and seedling establishment

Total number of seedlings counted in the initial stage as the plots were established varied slightly with the numbers in the enclosed plots recording a slightly lower number of seedlings (Figure 19). The two consecutive counts after the initial count had the enclosed plots recording high counts than the uneclosed plots. The final number of seedlings in the enclosure was higher (668 seedlings) compared to seedlings outside the enclosure (163 seedlings). There was significant difference in seedling germinations in the enclosed and unenclosed plots for the three consecutive counts (one-way ANOVA: $F_{1,2} = 135.59$, $P < 0.05$).
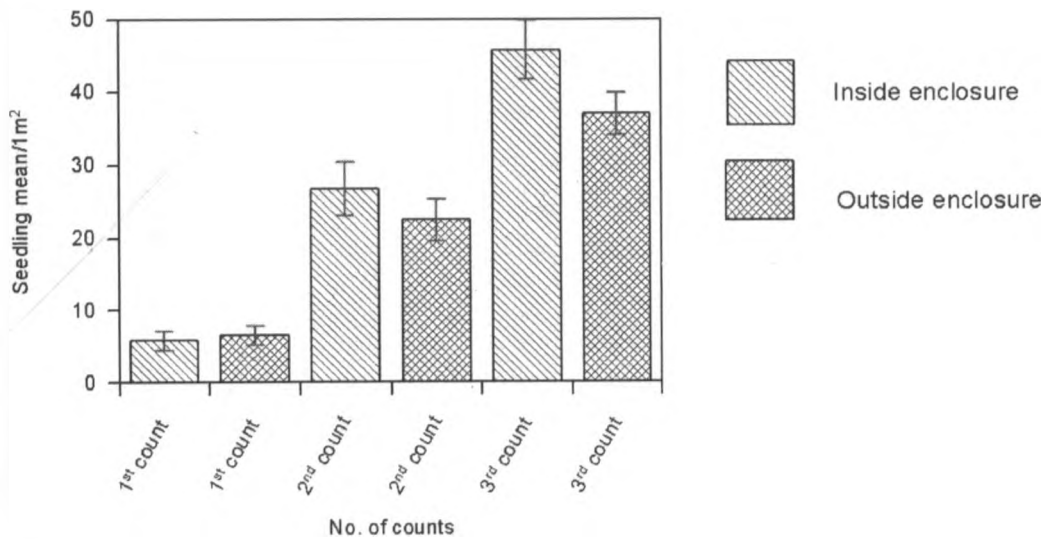
Figure 19: Mean (±SE) of emerging seedling counts per $1m^2$ from fenced and unfenced plots.

The enclosed plots had a high number of seedlings which implies that minimizing disturbance contributed to higher levels of seed recruitment and establishment. This result concur with Liu *et al.* (2009), who has shown that fencing alone allows seeds in the existing seed bank to germinate and establish. Disturbance from grazing, results in soil compaction which impairs seed germination and emergence in heavily compacted soils. Soil compaction is also a leading cause of

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soil degradation that also has a negative impact on seedling growth and establishment (Dalling *et al.*, 1997). Disturbance in this case mainly grazing, has been deemed to be of negative effect to the soil and consequently the vegetation, for it affects both seedling recruitment and establishment (Adler *et al.*, 2001). Grazing in particular reduces the recruitment and establishment of seedlings through uprooting and trampling, hence increasing their mortalities.

CHAPTER FOUR

4.0 CONCLUSSION AND RECOMMENDATIONS

4.1 General Conclusions

Changes of vegetation (as a result of disturbance) have been found to be modifying the micro-climate of the various Kakamega forest habitats. Soils in the fragmented parts of Kakamega forest are highly depleted. The depletion is to such an extent that some habitats, like the burnt glade and natural glade, cannot effectively support seedling germination and establishment adequately. Seed depth stratification in the various habitats decreased with depth, and more seeds were in the top layer. Deeper layers had the least number of seeds in all the habitats with an exception of the natural forest and the burnt glade. There was a poor correlation between the above ground cover and the soil seed bank for the six habitats. The soil seed bank of Kakamega forest is depleted and of low viability and is therefore not adequately reliable for the regeneration of the depleted areas. Seed predation which is presumably by ants and rodents may be one of the contributing factors to low levels of seed viability in various habitats (Robert *et al*., 2000).

High moisture content in the forest may have contributed a great deal in lowering the seed viability in the forest because of the high relative humidity of up to 100% yet the recommended humidity for effective seed storage is 30%. However the temperature experienced in the forest are good for seed germination and growth. Slow rate of regeneration in the shrubland is attributed to anthropogenic activities that have been found to be the main contributors to soil depletion and low regeneration of seedlings through soil compaction and increased seedling mortality through grazing and trampling.

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4.2 Recommendations

1. There is need for trees restoration project in the degraded areas in order to enhance the soil fertility.

2. The recommended appropriate way of restoration is by indigenous trees seedling planting in the heavily depleted areas like the secondary grassland.

3. There is need for the management of the forest (Kenya Forest Service) to come out forcefully to alleviate anthropogenic activities in the degraded areas in order to facilitate regeneration efforts.

4. Total clearing of the forest through logging and shamba systems should be discouraged because it paves way for invasive species and garden weeds that end up dominating the soil seed bank.

5. Further research investigations are recommended on:

   - Spatial and temporal variation in the soil seed bank in Kakamega forest.

   - Impacts of vegetation change to soil composition in Kakamega forest.

   - Effects of soil compaction in Kakamega forest.

   - Soil seedbank predation in Kakamega forest

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APPENDICES

Appendix 1: Soil chemical results (E.C, pH, Ca, Mg, K, P, C and N from the six habitats.

Habitat	EC	pH in water	Exchangeable calcium (mg/kg)	Exchangeable magnesium (mgl/kg)	Exchangeable potassium (mgl/kg)	Extractable phosphorus (mg /kg)	Total soil organic carbon (%)	Total soil Nitrogen %
Burnt glade	7	5.36	0.82	0.53	0.14	2.07	2.18	0.15
Burnt glade	6	5.21	0.69	0.19	0.09	2.71	2.04	0.15
Burnt glade	3	5.35	0.33	0.19	0.21	1.32	1.78	0.13
Burnt glade	4	5.36	1.04	0.9	0.13	1.03	1.93	0.14
Burnt glade	6	5.3	0.83	0.48	0.11	1.43	1.97	0.12
Burnt glade	4	5.36	1.43	1.14	0.08	1.52	2.17	0.15
Burnt glade	7	5.28	0.5	0.2	0.1	1.2	2.03	0.15
Burnt glade	6	5.2	0.5	0.12	0.09	1.29	2.02	0.15
Burnt glade	5	5.3	0.29	0.08	0.04	0.33	1.44	0.09
Forest	48	5.97	8.24	3.93	0.39	0.54	2.26	0.25
Forest	68	5.11	3.42	1.6	0.03	0.75	1.48	0.13
Forest	85	6.04	9.4	3.49	0.2	0.34	2.14	0.26
Forest	64	6.04	9.87	3.81	0.22	0.21	2.42	0.29
Forest	69	5.17	5.01	2.18	0.17	0.42	1.91	0.31
Forest	61	5.31	5.12	2.75	0.07	0.45	1.95	0.23
Forest	72	4.79	4.42	1.32	0.1	0.32	1.83	0.24
Forest	70	5.42	5.96	3.61	0.15	0.43	2.75	0.25
Forest	56	5.78	9.79	4.13	0.16	0.57	2.53	0.32
Grassland	12	6.01	5	4.73	0.19	2.98	1.21	0.12
Grassland	14	5.98	11.37	3.74	0.24	1.54	3.33	0.29
Grassland	15	5.95	9.48	3.99	0.26	1.98	2.91	0.27
Grassland	21	5.89	10.37	3.44	0.24	1.07	2.42	0.25
Grassland	12	6.15	10.68	4.61	0.33	1.43	3.66	0.34
Grassland	7	5.24	0.24	0.3	0.1	1.07	1.88	0.13
Grassland	8	5.75	3.19	0.74	0.21	2.33	2.49	0.28
Grassland	13	5.92	11.43	1.87	0.33	1.61	3.76	0.32
Grassland	20	5.74	9.43	1.58	0.21	1.33	2.97	0.29
Natural glade	9	5.34	3.27	1.42	0.1	1.19	2.94	0.21
Natural glade	8	5.38	1.12	0.27	0.08	0.94	1.81	0.13
Natural glade	5	5.42	1.49	0.87	0.1	1.17	2.19	0.14
Natural glade	8	4.87	0.74	0.35	0.06	0.33	2.4	0.17
Natural glade	3	5.31	0.9	0.17	0.07	1.14	2.26	0.16
Natural glade	4	5.38	1.85	0.96	0.1	0.44	2.45	0.19
Natural glade	4	5.41	0.84	0.23	0.06	0.31	2.37	0.16
Natural glade	8	5.28	0.38	0.12	0.15	0.11	2.27	0.14
Natural glade	5	5.29	0.94	0.48	0.07	0.45	2.22	0.17
Plantation	35	5.68	5.37	2.23	0.42	0.1	2.34	0.19
Plantation	40	6.47	12.39	2.82	0.32	0.32	2.62	0.24
Plantation	74	6.14	10.6	2.97	0.38	0.32	2.77	0.24
Plantation	61	6.32	11.69	2.8	0.29	0.21	2.8	0.24

Continuation of Appendix 1

Habitat	EC	pH in water	Exchangeable calcium (mg/kg)	Exchangeable magnesium (mgl/kg)	Exchangeable potassium (mgl/kg)	Extractable phosphorus (mg /kg)	Total soil organic carbon (%)	Total soil Nitrogen %
Plantation	37	6.22	9.16	2.71	0.27	0.82	2.14	0.22
Plantation	47	5.73	8.01	3.26	0.07	0.84	1.95	0.18
Plantation	26	6.11	13.16	3.59	0.15	0.66	3.2	0.26
Plantation	66	6.34	13.36	2.85	0.39	0.85	3.33	0.27
Plantation	72	5.76	8.18	2.19	0.24	0.74	2.28	0.19
Shrubland	17	5.9	8.66	3.76	0.3	1.58	3.33	0.26
Shrubland	12	5.42	3.61	1.76	0.11	1.64	2.06	0.2
Shrubland	15	5.19	11.57	2.94	0.39	1.61	2.6	0.24
Shrubland	11	5.51	3.42	1.63	0.41	0.99	2.38	0.23
Shrubland	14	5.81	10.14	5.16	0.13	2.72	2.9	0.31
Shrubland	12	5.91	4.8	3.38	0.35	1.75	1.63	0.13
Shrubland	8	5.52	2.32	1	0.37	4.27	2.18	0.2
Shrubland	14	5.48	2.36	1.13	0.11	1.6	2.07	0.21
Shrubland	12	6.15	7.65	2.56	0.13	1.86	2.03	0.16

Appendix 2: Soil types and clay, silt and loam percentages from the six habitats at depths 0-30cm and 30-60cm.

	Habitat	Sample ID	Depth cm	%sand	%clay	%silt	soil type
1a	Burnt glade	BG1	0-30	57.0	33.0	10.0	Clay loam
	Burnt glade	BG2	0-30	49.0	34.0	17.0	Clay loam
	Burnt glade	BG3	0-30	54.0	33.0	13.0	Clay loam
	Burnt glade	BG4	0-30	58.0	30.0	12.0	Clay loam
	Burnt glade	BG5	0-30	54.0	35.0	11.0	Clay loam
	Burnt glade	BG6	0-30	56.0	35.0	9.0	Clay loam
	Burnt glade	BG7	0-30	58.0	30.0	12.0	Clay loam
	Burnt glade	BG8	0-30	67.0	26.0	7.0	Sand Clay Loam
	Burnt glade	BG9	0-30	52.0	35.0	13.0	Loam
2a	Forest	F1	0-30	58.0	32.0	10.0	Clay Loam
	Forest	F2	0-30	62.0	30.0	8.0	Sand Clay Loam
	Forest	F3	0-30	54.0	31.0	15.0	Clay loam
	Forest	F4	0-30	53.0	34.0	13.0	Clay loam
	Forest	F5	0-30	56.0	34.0	10.0	Clay loam
	Forest	F6	0-30	54.0	32.0	14.0	Clay loam
	Forest	F7	0-30	49.0	31.0	20.0	Clay loam
	Forest	F8	0-30	67.0	27.0	6.0	Sand Clay Loam
	Forest	F9	0-30	56.0	24.0	20.0	Loam
3a	Grassland	GL1	0-30	72.0	25.0	3.0	Sand Clay Loam
	Grassland	GL2	0-30	62.0	30.0	8.0	Sand Clay Loam
	Grassland	GL3	0-30	56.0	36.0	8.0	Clay loam
	Grassland	GL4	0-30	57.0	34.0	9.0	Clay loam
	Grassland	GL5	0-30	60.0	31.0	9.0	Clay loam
	Grassland	GL6	0-30	48.0	43.0	9.0	Clay loam
	Grassland	GL7	0-30	58.0	32.0	10.0	Clay loam
	Grassland	GL8	0-30	55.0	32.0	13.0	Clay loam
	Grassland	GL9	0-30	59.0	31.0	10.0	Clay loam
4a	Natural glade	NG1	0-30	59.0	31.0	10.0	Clay loam
	Natural glade	NG2	0-30	57.0	35.0	8.0	Clay loam
	Natural glade	NG3	0-30	54.0	39.0	7.0	Clay loam
	Natural glade	NG4	0-30	58.0	35.0	7.0	Clay loam
	Natural glade	NG5	0-30	54.0	38.0	8.0	Clay loam
	Natural glade	NG6	0-30	52.0	34.0	14.0	Clay loam
	Natural glade	NG7	0-30	55.0	34.0	11.0	Clay loam

Continuation of Appendix 2

	Habitat	Sample ID	Depth cm	%sand	%clay	%silt	soil type
	Natural glade	NG8	0-30	54.0	35.0	11.0	Clay loam
	Natural glade	NG9	0-30	55.0	37.0	8.0	Clay loam
5a	Plantation	PL1	0-30	52.0	41.0	7.0	Clay loam
	Plantation	PL2	0-30	66.0	24.0	10.0	Sand Clay Loam
	Plantation	PL3	0-30	64.0	26.0	10.0	Loam
	Plantation	PL4	0-30	60.0	26.0	14.0	Loam
	Plantation	PL5	0-30	56.0	35.0	9.0	Clay loam
	Plantation	PL6	0-30	66.0	24.0	10.0	Sand Clay Loam
	Plantation	PL7	0-30	59.0	29.0	12.0	Loam
	Plantation	PL8	0-30	66.0	24.0	10.0	Sand Clay Loam
	Plantation	PL9	0-30	67.0	23.0	10.0	Sand Clay Loam
6a	Shrubland	SL1	0-30	54.0	34.0	12.0	Clay loam
	Shrubland	SL2	0-30	58.0	24.0	18.0	Loam
	Shrubland	SL3	0-30	56.0	34.0	10.0	Clay loam
	Shrubland	SL4	0-30	63.0	25.0	12.0	Sand Clay Loam
	Shrubland	SL5	0-30	55.0	33.0	12.0	Clay loam
	Shrubland	SL6	0-30	54.0	35.0	11.0	Clay loam
	Shrubland	SL7	0-30	62.0	25.0	13.0	Sand Clay Loam
	Shrubland	SL8	0-30	56.0	32.0	12.0	Clay loam
	Shrubland	SL9	0-30	57.0	31.0	12.0	Clay loam
1b	Burnt glade	BG1	30-60	54.0	34.0	12.0	Clay loam
	Burnt glade	BG2	30-60	63.0	31.0	6.0	Sand Clay Loam
	Burnt glade	BG3	30-60	55.0	32.0	13.0	Clay loam
	Burnt glade	BG4	30-60	56.0	32.0	12.0	Clay loam
	Burnt glade	BG5	30-60	54.0	39.0	7.0	Clay loam
	Burnt glade	BG6	30-60	58.0	34.0	8.0	Clay loam
	Burnt glade	BG7	30-60	60.0	34.0	6.0	Sand Clay Loam
	Burnt glade	BG8	30-60	56.0	37.0	7.0	Clay loam
	Burnt glade	BG9	30-60	57.0	34.0	9.0	Clay loam
2b	Forest	F1	30-60	57.0	34.0	9.0	Clay loam
	Forest	F2	30-60	58.0	33.0	9.0	Clay loam
	Forest	F3	30-60	59.0	34.0	7.0	Clay loam
	Forest	F4	30-60	57.0	34.0	9.0	Clay loam
	Forest	F5	30-60	56.0	38.0	6.0	Clay loam
	Forest	F6	30-60	56.0	34.0	10.0	Clay loam
	Forest	F7	30-60	59.0	34.0	7.0	Loam
	Forest	F8	30-60	59.0	34.0	7.0	Clay loam
	Forest	F9	30-60	59.0	34.0	7.0	Clay loam

Continuation of Appendix 2

	Habitat	Sample ID	Depth cm	%sand	%clay	%silt	soil type
3b	Grassland	GL1	30-60	63.2	26.8	9.9	Sand Clay Loam
	Grassland	GL2	30-60	57.0	32.0	11.0	Loam
	Grassland	GL3	30-60	69.0	28.0	3.0	Sand Clay Loam
	Grassland	GL4	30-60	69.0	20.0	11.0	Clay loam
	Grassland	GL5	30-60	71.0	20.0	9.0	Clay loam
	Grassland	GL6	30-60	69.0	20.0	11.0	Clay loam
	Grassland	GL7	30-60	60.0	28.0	12.0	Sand Clay Loam
	Grassland	GL8	30-60	57.0	24.0	19.0	Loam
	Grassland	GL9	30-60	58.0	22.0	20.0	Loam
	Grassland	NG1	30-60	58.0	24.0	18.0	Clay loam
4b	Natural glade	NG2	30-60	59.0	26.0	15.0	Sand Clay Loam
	Natural glade	NG3	30-60	58.0	32.0	10.0	Sand Clay Loam
	Natural glade	NG4	30-60	58.0	32.0	10.0	Sand Clay Loam
	Natural glade	NG5	30-60	64.0	26.0	10.0	Sand Clay Loam
	Natural glade	NG6	30-60	57.0	20.0	23.0	Loam
	Natural glade	NG7	30-60	55.0	34.0	11.0	Clay loam
	Natural glade	NG8	30-60	57.0	30.0	13.0	Clay loam
	Natural glade	NG9	30-60	54.0	34.0	12.0	Clay loam
5b	Plantation	PL1	30-60	69.0	28.0	3.0	Sand Clay Loam
	Plantation	PL2	30-60	68.0	20.0	12.0	Clay loam
	Plantation	PL3	30-60	66.0	26.0	8.0	Sand Clay Loam
	Plantation	PL4	30-60	68.0	21.0	11.0	Sand Clay Loam
	Plantation	PL5	30-60	70.0	20.0	10.0	SL
	Plantation	PL6	30-60	61.0	30.0	9.0	Sand Clay Loam
	Plantation	PL7	30-60	59.0	21.0	20.0	Loam
	Plantation	PL8	30-60	56.4	23.0	20.6	Loam
	Plantation	PL9	30-60	56.1	33.0	11.0	Clay loam
6b	Shrubland	SL1	30-60	58.0	27.0	15.0	Loam
	Shrubland	SL2	30-60	59.0	28.0	13.0	Sand Clay Loam
	Shrubland	SL3	30-60	56.0	33.0	11.0	Clay loam
	Shrubland	SL4	30-60	57.0	31.0	12.0	Clay loam
	Shrubland	SL5	30-60	58.0	32.0	10.0	Clay loam
	Shrubland	SL6	30-60	55.0	28.0	17.0	Loam
	Shrubland	SL7	30-60	56.0	33.0	11.0	Clay loam
	Shrubland	SL8	30-60	54.0	30.0	16.0	Clay loam
	Shrubland	SL9	30-60	55.0	38.0	7.0	Clay loam

Appendix 3: Chemical parameter means for pH, EC (μS cm^{-1}), Ca (mg/kg), Mg (mg/kg), K (mg/kg), P (mg /kg), C (%), and Nitrogen (%) from the six habitats.

Habitat	Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.	SE
Burnt glade	EC	9	5.33	3.00	7.00	1.41	0.47
	pH	9	5.30	5.20	5.36	0.06	0.02
	Ca	9	0.71	0.29	1.43	0.36	0.12
	Mg	9	0.43	0.08	1.14	0.37	0.12
	K	9	0.11	0.04	0.21	0.05	0.02
	P	9	1.43	0.33	2.71	0.66	0.22
	C	9	1.95	1.44	2.18	0.23	0.08
	N	9	0.14	0.09	0.15	0.02	0.01
Grassland	EC	9	13.56	7.00	21.00	4.72	1.57
	pH	9	5.85	5.24	6.15	0.26	0.09
	Ca	9	7.91	0.24	11.43	4.07	1.36
	Mg	9	2.78	0.30	4.73	1.68	0.56
	K	9	0.23	0.10	0.33	0.07	0.02
	P	9	1.70	1.07	2.98	0.63	0.21
	C	9	2.74	1.21	3.76	0.83	0.28
	N	9	0.25	0.12	0.34	0.08	0.03
Plantation	EC	9	50.89	26.00	74.00	17.71	5.90
	pH	9	6.09	5.68	6.47	0.29	0.10
	Ca	9	10.21	5.37	13.36	2.72	0.91
	Mg	9	2.82	2.19	3.59	0.44	0.15
	K	9	0.28	0.07	0.42	0.11	0.04
	P	9	0.54	0.10	0.85	0.30	0.10
	C	9	2.60	1.95	3.33	0.47	0.16
	N	9	0.23	0.18	0.27	0.03	0.01

Continuation of Appendix 3

Habitat	Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.	SE
Natural glade	EC	9	6.00	3.00	9.00	2.24	0.75
	pH	9	5.30	4.87	5.42	0.17	0.06
	Ca	9	1.28	0.38	3.27	0.86	0.29
	Mg	9	0.54	0.12	1.42	0.44	0.15
	K	9	0.09	0.06	0.15	0.03	0.01
	P	9	0.68	0.11	1.19	0.43	0.14
	C	9	2.32	1.81	2.94	0.30	0.10
	N	9	0.16	0.13	0.21	0.03	0.01
Shrubland	EC	9	12.78	8.00	17.00	2.59	0.86
	pH	9	5.65	5.19	6.15	0.30	0.10
	Ca	9	6.06	2.32	11.57	3.51	1.17
	Mg	9	2.59	1.00	5.16	1.37	0.46
	K	9	0.26	0.11	0.41	0.13	0.04
	P	9	2.00	0.99	4.27	0.96	0.32
	C	9	2.35	1.63	3.33	0.52	0.17
	N	9	0.22	0.13	0.31	0.05	0.02
Forest	EC	9	65.89	48.00	85.00	10.48	3.49
	pH	9	5.51	4.79	6.04	0.46	0.15
	Ca	9	6.80	3.42	9.87	2.53	0.84
	Mg	9	2.98	1.32	4.13	1.06	0.35
	K	9	0.17	0.03	0.39	0.10	0.03
	P	9	0.45	0.21	0.75	0.16	0.05
	C	9	2.14	1.48	2.75	0.39	0.13
	N	9	0.25	0.13	0.32	0.06	0.02

Appendix 4: Summary on seedling emergence and seedling number distribution in the three stratified depths from the six habitats per 1kg of soil.

Habitat	Depth			
	0-5 cm	5-10cm	10-15cm	Grand Total
Burnt glade	547	331	263	1141
Forest	159	149	96	404
Grassland	3120	1879	1358	6357
Natural glade	568	370	255	1193
Plantation	843	450	257	1550
Shrubland	2579	1399	1053	5031
Grand Total	7816	4578	3282	15676

Appendix 5: Summary on screened seed number distribution in the three stratified depths from the six habitats.

Habitat	depth			
	0-5cm	5-10cm	10-15cm	Grand Total
Burnt glade	1099	1456	1167	3722
Forest	698	1515	1783	3996
Grassland	15992	1322	443	17757
Natural glade	14404	5625	2943	22972
Plantation	11772	5946	2690	20408
Shrubland	23653	3374	1160	28187
Grand Total	67618	19238	10186	97042

Appendix 6: Summary table of species individual numbers found in each of the six habitats.

Species	Life form	Burnt glade	Forest	Grass land	Natural glade	Plant-ation	Shrubs land
					Habitat		
Glycine wightii	climbers	2	-	6	1	1	6
Digitalia veluntina	grass	16	-	112	22	1	96
Digitaria abysinica	grass	51	1	115	29	1	36
Oplismenus compositus	grass	-	-	64	-	-	7
Acalypha racemosa	other herb	-	-	-	-	14	-
Achyranthus aspera	other herb	73	-	-	8	11	-
Biophytum pertsiana	other herb	22	-	-	8	-	-
Celtis africana	other herb	-	2	-	-	-	-
Chamaescrista hildebradtii	other herb	1	-	-	2	-	26
Commelina bengulensis	other herb	-	-	-	94	274	-
Commelina spp	other herb	3	-	3	4	-	-
Conyza sumatrensis	other herb	2	287	1	11	-	25
Dissotis senegalensis	other herb	-	-	-	17	-	-
Dorsteni brownii	other herb	-	-	7	5	47	5
Galinsoga parvifolia	other herb	-	-	773	4	-	4
Hydrocotyle mannii	other herb	399	1	80	82	134	2088
Justicia flava	other herb	-	-	10	-	2	-
Oxalis corrisculata	other herb	5	-	3	1	5	19
Urena lobota	other herb	2	-	39	-	30	26
Cyperas	sedge	-	-	-	1	-	-
Desmodium adscendews	sedge	-	-	-	6	32	-
Fibristylis dichotoma	sedge	350	6	747	698	35	2032
Kyllinga alba	sedge	9	-	197	17	-	145
Lantana camara	shrubs	-	6	10	-	443	7
Leonotis nepataefolia	shrubs	172	-	3748	44	14	269
Phyllanthus acidus	shrubs	14	1	228	102	42	175
Phyllanthus fischeri	Shrubs	-	-	-	-	3	-
Plectranthus spp.	Shrubs	-	1	-	-	-	-
Polystachya	Shrubs	4	58	214	8	120	41
Maesa lanceonta	trees	-	-	-	-	3	-
Acacia abyssinica	trees	13	-	-	19	3	12
Celtis durandii	trees	-	4	-	-	-	-
Cupressus lusitanica	trees	-	-	-	-	4	-
Ficus asparata	trees	-	4	-	-	-	-
Ficus sur	trees	-	2	-	-	4	-
Funtumia africana	trees	-	1	-	-	-	-
Harungana madagascarienses	trees	-	-	-	-	11	-
Polyscias fulva	trees	-	1	-	-	-	-
Prunus africana	trees	-	-	-	-	3	-
Psiadium guajava	trees	-	-	-	10	19	-
Trema oriantis	trees	3	32	-	-	169	12
Zenthoxylum glettee	trees	-	2	-	-	-	-
Unknown		45	9	-	194	127	241

Appendix 7: Life form percentages of the soil seed bank for the six habitats

Life form	Burnt glade %	Forest %	Grassland %	Natural glade %	Plantation %	Shrubland %
climbers	0.2	0	0.1	0.1	0.1	0.1
graminoids	35.9	1.6	19.4	55.8	4.4	43.9
other herb	42.7	69.4	14.4	17.0	33.3	41.6
shrubs	16.0	15.8	66.1	11.1	40.1	9.3
trees	1.3	11.0	0	2.1	13.9	0.5
Unknown	3.8	2.2	0	14.0	8.2	4.6

Appendix 8: List of species identified in the six habitats

Family	Species	Life form	Author
Acanthaceae	*Justicia flava*	other herb	Vahl
Amaranthaceae	*Achyranthus aspera*	other herb	L. Devil's Horse whip
Apocynaceae	*Funtumia africana*	trees	(Benth.)stapf
Araliaceae	*Polyscias fulva*	trees	(Hiern) Harms (P.ferruginea (Hiern)Harms)
Balsaminaceae	*Biophytum petersianum*	other herb	Klotzsch
Balsaminaceae	*Oxalis corniculata*	other herb	L. (O. radicosa A. Rich.)
Caesalpinaceae	*Chamaescrista hildebradtii*	other herb	(Vatke) Lock (Cassia hildebrandtii Vatke
Commelinaceae	*Commelina benghalensis*	other herb	L.
Commelinaceae	*Commelina spp*	other herb	L.
Compositae (Asteraceae)	*Conyza sumatrensis*	other herb	(Retz.) E.H. Walker (c.floribunda H.B.K., Erigeronfloribundum (H.B.K) SCH.Bip.)
Compositae (Asteraceae)	*Galinsoga parviflora*	other herb	Cav.
Euphobiaceae	*Acalypha racemosa*	other herb	Baill. (A. Panicultata miq)
Euphobiaceae	*Phyllanthus acidus*	shrubs	L.
Euphobiaceae	*Phyllanthus fischeri*	Shrubs	Pax
Guttiferae	*Harungana madagascariensis*	trees	Poir.
Labiatae (Lamiaceae)	*Leonotis nepetifolia*	shrubs	(L.) Ait.f.(inc. L. AFRICA(P.Beauv.)Briq.)
Labiatae (Lamiaceae)	*Plectranthus spp.*	Shrubs/other herb	H.
Malvaceae	*Urena lobota*	other herb	L.
Melastomataceae (Ochnaceaee)	*Dissotis senegambiensis*	other herb	(Guill. & Perr.) Triana
Mimosaceae	*Acacia abyssinica*	trees	Benth.spp.*calophylla* Brena
Moraceae	*Dorstenia brownii*	other herb	Rendle
Moraceae	*Ficus asparata*	trees	
Moraceae	*Ficus sur*	trees	Forssk.
Myrsinaceae	*Maesa lanceolata*	Shrubs/trees	Forssk.

Continuation of Appendix 8

Family	Species	Life form	Author
Orchidsaceae	*Polystachya*	Shrubs/other herb	Hook
Papilionaceae (Febacea)	*Desmodium adscendens*	other herb	(sw.) DC.
Papilionaceae (Febaceae)	*Glycine wightii*	climbers	(wight & Arn.) Verdc
Rosaceae	*Prunus africana*	trees	(Hook.f.) kalkm.
Rutaceae	*Zanthoxylum gillettii*	trees	(De wild.) waterm.
Ulmaceae	*Celtis africana*	trees	Burm.f.
Ulmaceae	*Celtis durandii/gomphophylla*	trees	Bak.
Ulmaceae	*Trema orientalis*	trees	(L.) Bl.
Umbelliferae (Apiaceae)	*Hydrocotyle mannii*	other herb	Hook.f.
	Cuppresus lucitanica	trees	
	Cyperus	sedge	
	Digitalia veluntina	grass	
	Digitaria abysinica	grass	
	Fibristylis dichotoma	sedge	
	Kyllinga alba	sedge	
	Lantana camara	shrubs	
	Oplismenus compositus	grass	
	Unknown		

Appendix 9: Grassland standing vegetation species and life forms

Species	Life form	Species No.
Combretum paniculata	climbers	1
Thunbergia alata	climbers	1
Pteridium aquilifolium	ferns	2
Brachiaria brizantha	grass	5
Centera asiatica	grass	4
Cynodon dactylon	grass	4
Cyperus species	grass	4
Desmodium ramosissimum	grass	5
Dichondra repens	grass	5
Digitaria abyssinica	grass	5
Eragrostis experata	grass	1
Eragrostis tenuifolia	grass	1
Fimbristelis lithoralis	grass	1
Kyllinga alba	grass	45
Passpalum species	grass	4
Pennisetum cladestinum	grass	1
Pennisetum cladestinum	grass	1
Settaria sphacelata	grass	1
Sporobolus pyramidalis	grass	1
Sporobolus pyramidalis	grass	2
Acanthus pubescens	other herb	1
Achyranthes aspera	other herb	1
Ageratum conyzoides	other herb	4
Aspilia pluriseta	other herb	3
Barleria venticulosa	other herb	1
Bidens pilosa	other herb	4
Blumea species	other herb	3
Chamaecrista mimosoides	other herb	1
Commelina africana	other herb	1
Commelina bengalensis	other herb	1
Conyza sumatrensis	other herb	4
Crassocephalum vitellinum	other herb	5
Crotalaria species	other herb	2
Desmodium species	other herb	1
Desmodium copper	other herb	2
Desmodium species	other herb	2
Dychoriste radicans	other herb	3
Guizotia scabra	other herb	3
Indigofera species	other herb	1
Leonotis nepetaefolia	other herb	2
Phyllanthus amarus	other herb	4

Continuation of Appendix 9

Species	Life form	Species No.
Ruellia patula	other herb	1
Spermacoce princei	other herb	1
Spilanthes mauritiana	other herb	5
Triumfetta rhomboidea	other herb	6
Urera lobata	other herb	6
Acalypha ornata	shrubs	1
Indigofera (tanganyikensis)	shrubs	2
Indigofera arecta	shrubs	1
Lantana camara	shrubs	2
Lantana trifoliata	shrubs	2
Microglossa pyrifolia	shrubs	1
Ocimum gratissimum	shrubs	1
Piper umbellata	shrubs	1
Sida rhomboidea	shrubs	1
Vernonia amygdalina	shrubs	2
Vernonia auriculifera	shrubs	2
Albizia gummifera	trees	2
Antiaris toxicaria	trees	1
Bischofia javanica	trees	1
Blighia unijugata	trees	2
Bridelia micrantha	trees	2
Eucalyptus saligna	trees	1
Kigelia africana	trees	2
Maesa lanceolata	trees	2
Maesopsis eminii	trees	1
Premna angolensis	trees	1
Prunus africana	trees	5
Psidium guajava	trees	5
Vitex keniensis	trees	1

Appendix 10: Shrubland standing vegetation species and life forms

species	life form	Species No.
Glycine wightii	climbers	2
Stephania abyssinica	climbers	1
Brachiaria brizantha	grass	3
Carex conferta	grass	2
Centera asiatica	grass	4
Cynodon dactylon	grass	1
Cyperus species	grass	1
Dichondra repens	grass	3
Digitaria abyssinica	grass	3
Eragrostis tenuifolia	grass	2
Hydrocotyle sibthorp	grass	1
Hyparrhenia species	grass	1
Kyllinga alba	grass	1
Lactuca species	grass	1
Melinis (Rhynchelytron) repens	grass	3
Panicum maximum	grass	1
Passiflora edulis	grass	1
Passpalum species	grass	2
Ageratum conyzoides	other herb	1
Blumea species	other herb	1
Conyza species	other herb	1
Conyza sumatrensis	other herb	3
Crassocephalum vitellinum	other herb	3
Desmodium species	other herb	2
Desmodium copper	other herb	2
Desmodium species	other herb	4
Desmodium ramosissimum	other herb	3
Desmodium repandum	other herb	2
Desmodium salicifolia	other herb	2
Dychoriste radicans	other herb	1
Hibiscus fuscus	other herb	1
Justicia flava	other herb	2
Laggera (elatior)	other herb	1
Pseudarthia hookeri	other herb	1
Spermacoce princei	other herb	1
Stephania abyssinica	other herb	2
Triumfetta rhomboidea	other herb	2
Urera lobata	other herb	3
Clerodendrum myricoides	shrubs	1

Continuation of Appendix 10

species	life form	Species No.
Dovyalis macrocalyx	shrubs	1
Hoslundia opposita	shrubs	1
Indigofera (tanganyikensis)	shrubs	1
Lantana trifoliata	shrubs	2
Maytenus heterophylla	shrubs	3
Ocimum gratissimum	shrubs	1
Pavetta oliveriana	shrubs	1
Pavonia urens	shrubs	1
Sida rhomboidea	shrubs	2
Spermacoce princei	shrubs	1
Vernonia auriculifera	shrubs	1
Albizia gummifera	trees	1
Blighia unijugata	trees	2
Bridelia micrantha	trees	3
Maesa lanceolata	trees	1
Psidium guajava	trees	3
Rubus steudneri	trees	2

Appendix 11: Burnt glade standing vegetation species and life forms

Species Name	Life form	Species No.
Convulvulus kilimandscharica	climbers	5
Ipomoea mombassana	climbers	4
Ipomoea species	climbers	1
Passiflora edulis	climbers	4
Tiliacora funifera	climbers	1
Vigna species	climbers	4
Pteridium aquilifolium	ferns	1
Brachiaria brizantha	grass	4
Brachiaria species	grass	4
Cynodon dactylon	grass	5
Digitaria abyssinica	grass	6
Digitaria macrophylla	grass	1
Eragrostis experata	grass	6
Eragrostis species	grass	6
Eragrostis tenuifolia	grass	6
Geophilla repens	grass	6
Hyparrhenia species	grass	6
Hyparrhenia diplandra	grass	6
Panicum maximum	grass	3
Panicum trichocladum	grass	4
Sporobolus pyramidalis	grass	6
Themeda triandra	grass	6
Sida alba	other herb	1
Ageratum conyzoides	other herb	1
Aspilia pluriseta	other herb	6
Becium obovatum	other herb	3
Blumea axillaris	other herb	3
Centera asiatica	other herb	6
Chamaecrista mimosoides	other herb	6
Commelina species	other herb	2
Commelina africana	other herb	1
Conyza sumatrensis	other herb	1
Crassocephalum montuosum	other herb	6
Crassocephalum rubens	other herb	6
Crassocephalum vitellinum	other herb	6
Crotalaria incana	other herb	4
Crotalaria species	other herb	3

Continuation of Appendix 11

Species Name	Life form	Species No.
Crotalaria species	other herb	3
Desmodium intortua	other herb	5
Desmodium repandum	other herb	2
Desmodium vaicinatum	other herb	1
Dissotis brazzae	other herb	6
Dissotis senegalensis	other herb	6
Dychoriste radicans	other herb	4
Eriosema scio	other herb	1
Guizotia scabra	other herb	6
Heliochrysum species	other herb	1
Hypericum peplidifolium	other herb	4
Indigofera colutea	other herb	5
Indigofera volkensi	other herb	5
Inula decipiens	other herb	4
Laggera axillaris	other herb	6
Leucas calostachys	other herb	6
Leucas grandis	other herb	6
Leucas reflexa	other herb	5
Orobanche minor	other herb	1
Pentas longiflora	other herb	3
Phyllanthus amarus	other herb	1
Pseudarthia hookeri	other herb	5
Rhynchosia species	other herb	1
Rhynchosia parkeri	other herb	6
Tephrosia intrapta	other herb	1
Thalictrum rhynchoanum	other herb	2
Triumfetta rhomboidea	other herb	2
Urera lobata	other herb	5
Vernonia (karaguensis)	other herb	6
Gardenia ternifolia	shrubs	3
Acanthus eminens	shrubs	2
Acanthus pubescens	shrubs	1
Combretum paniculata	shrubs	4
Ficus asperifolia	shrubs	2
Hoslundia opposita	shrubs	1
Indigofera (tanganyikensis)	shrubs	3
Indigofera arecta	shrubs	3
Indigofera spicata	shrubs	6
Microglossa pyrifolia	shrubs	1
Ocimum lamiifolium	shrubs	6
Rubus pinnata	shrubs	3
Rubus steudneri	shrubs	3
Solanum mauritianum	shrubs	3
Alangium chinense	trees	2
Albizia grandibracteata	trees	6
Bersama abyssinica	trees	2

Continuation of Appendix 11

Species Name	Life form	Species No.
Erythrina abyssinica	trees	1
Maesa lanceolata	trees	5
Piliostigma thonningii	trees	4
Prunus africana	trees	1
Psidium guajava	trees	3
Ritchiea albersii	trees	1
Sapium ellipticum	trees	2
Vitex doniana	trees	3

Appendix 12: Natural glade standing vegetation species and life forms

Species Name	Life form	Species No.
Clematis simensis	climbers	2
Convulvulus kilimandscharica	climbers	1
Ipomoea mombassana	climbers	4
Ipomoea species	Climbers	3
Stephania abyssinica	climbers	4
Tiliacora funifera	climbers	4
Brachiaria brizantha	grass	6
Brachiaria species	grass	5
Cynodon dactylon	grass	5
Digitaria macrophylla	grass	6
Eragrostis experata	grass	3
Eragrostis species	Grass	2
Eragrostis tenuifolia	grass	3
Geophilla repens	grass	2
Hyparrhenia species	grass	6
Hyparrhenia diplandra	grass	6
Passpalum species	grass	4
Rhynchelytron repens	grass	1
Sporobolus pyramidalis	grass	6
Themeda triandra	grass	6
Alysicarpus glumacens	other herb	3
Aspilia pluriseta	other herb	6
Becium obovatum	other herb	6
Blumea axillaris	other herb	6
Bothriocline tomentosa	other herb	6
Centera asiatica	other herb	6
Chamaecrista hildebrandti	other herb	1
Chamaecrista mimosoides	other herb	6
Conyza sumatrensis	other herb	6
Crassocephalum montuosum	other herb	6
Crassocephalum rubens	other herb	6
Crassocephalum vitellinum	other herb	6
Crotalaria incana	other herb	5
Crotalaria species	other herb	5
Desmodium intortua	other herb	5
Dissotis brazzae	other herb	6
Dissotis senegalensis	other herb	6
Dychoriste radicans	other herb	6
Eriosema scio	other herb	9
Eriosema species	other herb	6
Guizotia scabra	other herb	6
Heliochrysum odora	other herb	6
Heliochrysum species	other herb	6
Hypericum peplidifolium	other herb	4
Indigofera (swarziensis/garokarne)	other herb	6
Indigofera colutea	other herb	5

Continuation of Appendix 12

Species Name	Life form	Species No.
Inula decipiens	other herb	6
Laggera axillaris	other herb	6
Leonotis nepetaefolia	other herb	2
Leucas calostachys	other herb	6
Leucas grandis	other herb	6
Leucas reflexa	other herb	6
Lippia grandiflora	other herb	4
Mimulopsis solmsii	other herb	6
Oplismenus hirtellus	other herb	2
Orobanche minor	other herb	6
Pentas longiflora	other herb	5
Phaulopsis imbrigata	other herb	5
Pseudarthia hookeri	other herb	6
Rhynchosia minima	other herb	4
Rhynchosia species	Other herb	3
Sida alba	other herb	1
Tephrosia intrapta	other herb	6
Triumfetta rhomboidea	other herb	6
Urera lobata	other herb	4
Vernonia (karaguensis)	other herb	5
Vernonia species	other herb	6
Vernonia hymenolepis	other herb	3
Acanthus eminens	shrubs	1
Clerodendrum myricoides	shrubs	6
Combretum paniculata	shrubs	2
Dombeya burgessiae	shrubs	1
Erythrococca fischeri	shrubs	1
Gardenia ternifolia	shrubs	3
Hoslundia opposita	shrubs	6
Indigofera spicata	shrubs	6
Microglossa pyrifolia	shrubs	6
Ocimum lamiifolium	shrubs	6
Pavonia urens	shrubs	2
Phyllanthus fischeri	shrubs	3
Plectranthus barbatus	shrubs	2
Rubus pinnata	shrubs	5
Rubus steudneri	shrubs	5
Scolopia zeyheri	shrubs	1
Sida rhomboidea	shrubs	2
Solanum mauritianum	shrubs	4
Trimeria grandifolia	shrubs	2
Vernonia auriculifera	shrubs	3
Albizia grandibracteata	trees	2
Bridelia micrantha	trees	2
Clausena anisata	trees	1
Erythrina abyssinica	trees	3

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Species Name	Life form	Species No.
Maesa lanceolata	trees	6
Piliostigma thonningii	trees	4
Vitex doniana	trees	6

Appendix 13: Plantation standing vegetation species and life forms

Species Name	Life form	Species No.
Asparagus racemosus	climbers	3
Cyphostemma species	Climbers	1
Dioscorea schimperiana	climbers	2
Hewittia sublobata	climbers	5
Keetia guineense	climbers	6
Momordica foetida	climbers	1
Mondia wightii	climbers	3
Passiflora edulis	climbers	1
Paullinia pinnata	climbers	3
Peponium vogeloides	climbers	2
Periploca linearifolia	climbers	2
Piper guineensis	climbers	6
Smilax krausiana	climbers	4
Stephania abyssinica	climbers	4
Thunbergia alata	climbers	2
Tiliacora funifera	climbers	4
Toddalia asiatica	climbers	2
Asplenium species	ferns	5
Pellea adinodoides	ferns	4
Brachiaria brizantha	grass	2
Carex conferta	grass	2
Settaria sphacelata	grass	5
Dorstenia species	Other herb	3
Achyranthes aspera	other herb	3
Asystasia gangetica	other herb	5
Desmodium intortua	other herb	6
Desmodium ramosissimum	other herb	4
Desmodium repandum	other herb	6
Desmodium salicifolia	other herb	6
Hibiscus caryophyllus	other herb	3
Hibiscus vitifolius	other herb	3
Isoglossa laxata	other herb	3
Phaulopsis imbrigata	other herb	6
Solanum nigrum	other herb	1
Triumfetta rhomboidea	other herb	6
Umbelliferae (Ferula communis)	other herb	2
Vernonia brachycalyx	other herb	3
Zehneria scabra	other herb	11
Orchids species	orchids	1
Acalypha ornata	shrubs	2
Acanthus pubescens	shrubs	2
Afromomum angustifolium	shrubs	6
Allophyllus feruginus	shrubs	6
Dombeya burgessiae	shrubs	1
Dovyalis macrocalyx	shrubs	2
Dracaena fragrans	shrubs	1

Continuation of Appendix 13

Species Name	Life form	Species No.
Drypetes gerrardii	shrubs	3
Erythrococca fischeri	shrubs	6
Hoslundia opposita	shrubs	1
Lantana camara	shrubs	2
Maytenus heterophylla	shrubs	4
Phyllanthus fischeri	shrubs	6
Piper umbellata	shrubs	6
Rawsonia lucida	shrubs	3
Rubus pinnata	shrubs	4
Rubus steudneri	shrubs	5
Rytigina bugoyensis	shrubs	6
Rytigina neglecta	shrubs	6
Scolopia zeyheri	shrubs	4
Solanum mauritianum	shrubs	3
Syzygium guineense	shrubs	3
Turraea holstii	shrubs	2
Vernonia auriculifera	shrubs	1
Acrocarpus fraxinifolius	trees	2
Alangium chinense	trees	5
Albizia grandibracteata	trees	1
Bersama abyssinica	trees	3
Bischofia javanica	trees	5
Blighia unijugata	trees	1
Bridelia micrantha	trees	5
Celtis africana	trees	6
Chrysophyllum viridifolium	trees	2
Clausena anisata	trees	6
Cupressus lusitanica	trees	6
Diospyros abyssinica	trees	5
Ficus exasperata	trees	5
Ficus sur	trees	4
Ficus thonningii	trees	1
Funtumia latifolia	trees	6
Harungana madagascariense	trees	3
Kigelia africana	trees	1
Lepidotrichilia volkensi	trees	3
Maesa lanceolata	trees	2
Maesopsis eminii	trees	4
Markhamia lutea	trees	6
Morus mesozygia	trees	3
Olea capensis	trees	5
Polyscias fulva	trees	6
Premna angolensis	trees	1
Prunus africana	trees	5
Psidium guajava	trees	4
Spathodea campanulata	trees	6

Continuation of Appendix 13

Species Name	Life form	Species No.
Teclea nobilis	trees	2
Trema orientalis	trees	5
Trichilia emetica	trees	6
Trilepisium madagascariense	trees	5
Vitex fischeri	trees	5
Zanthoxyllum gilettii	trees	5
Zanthoxyllum mildbraedii	trees	3

Appendix 14: Natural forest standing vegetation species and life forms

Species Name	life form	Species No.
Asparagus racemosus	climbers	2
Glycine wightii	climbers	2
Hewittia sublobata	climbers	5
Keetia guineense	climbers	6
Paullinia pinnata	climbers	3
Peponium vogeloides	climbers	6
Periploca linearifolia	climbers	4
Piper guineensis	climbers	6
Secamone punctulata	climbers	3
Stephania abyssinica	climbers	1
Tiliacora funifera	climbers	3
Toddalia asiatica	climbers	2
Asplenium species	ferns	3
Pellea adinodoides	ferns	1
Dichondra repens	grass	1
Settaria sphacelata	grass	1
Asystasia gangetica	other herb	6
Crassocephalum rubens	other herb	1
Crassocephalum vitellinum	other herb	2
Drymaria cordata	other herb	2
Hibiscus caryophyllus	other herb	2
Isoglossa laxata	other herb	6
Justicia flava	other herb	1
Mimulopsis solmsii	other herb	1
Phaulopsis imbrigata	other herb	5
Phyllanthus amarus	other herb	2
Vernonia brachycalyx	other herb	3
Acalypha ornata	shrubs	1
Acanthus pubescens	shrubs	1
Afromomum angustifolium	shrubs	6
Allophyllus feruginus	shrubs	4
Boehmeria macrophylla	shrubs	3
Caesalpinia volkensi	shrubs	1
Dombeya burgessiae	shrubs	2
Dovyalis macrocalyx	shrubs	5
Dracaena fragrans	shrubs	4
Drypetes gerrardii	shrubs	2
Maytenus heterophylla	shrubs	3
Pavetta oliveriana	shrubs	3
Pavetta tarennoides	shrubs	3
Piper umbellata	shrubs	6
Rawsonia lucida	shrubs	2
Rubus pinnata	shrubs	1
Rytigina bugoyensis	shrubs	6
Rytigina neglecta	shrubs	6
Scolopia zeyheri	shrubs	2

Continuation of Appendix 14

Species Name	life form	Species No.
Solanum mauritianum	shrubs	3
Syzygium guineense	shrubs	2
Turraea holstii	shrubs	1
Albizia gummifera	trees	1
Aningeria altissima	trees	2
Antiaris toxicaria	trees	6
Apodytes dimidiata	trees	2
Blighia unijugata	trees	2
Cassipourea malosana	trees	3
Casaeria gladiiformis	trees	6
Celtis africana	trees	2
Chaetachme aristata	trees	2
Chrysophyllum viridifolium	trees	5
Clausena anisata	trees	14
Craibia brownii	trees	5
Croton macrostachyus	trees	3
Diospyros abyssinica	trees	3
Erythrina abyssinica	trees	1
Fagaropsis angolensis	trees	1
Ficus exasperata	trees	6
Ficus sur	trees	4
Ficus thonningii	trees	1
Funtumia latifolia	trees	6
Lepidotrichilia volkensi	trees	16
Maesopsis eminii	trees	1
Markhamia lutea	trees	5
Morus mesozygia	trees	2
Peddiea fischeri	trees	4
Polyscias fulva	trees	5
Prunus africana	trees	1
Ritchiea albersii	trees	2
Sapium ellipticum	trees	4
Spathodea campanulata	trees	1
Teclea nobilis	trees	6
Trema orientalis	trees	1
Trichilia emetica	trees	3
Trilepisium madagascariense	trees	6
Zanthoxyllum gilettii	trees	2
Zanthoxyllum mildbraedii	trees	4

Appendix 15: Results of tests of significance

	Test	F/t- value	Hypothesis test results P≤ 0.05
Temperature	ANOVA	168095.7	There was significant difference
Relative humidity	ANOVA	377328.9	There was significant difference
EC	ANOVA	467.25	There was significant difference
pH	ANOVA	20910.7	There was significant difference
Ca	ANOVA	691.2	There was significant difference
Mg	ANOVA	6668.67	There was significant difference
K	ANOVA	878.1	There was significant difference
P	ANOVA	858.8	There was significant difference
C	ANOVA	12114	There was significant difference
N	ANOVA	3751.45	There was significant difference
B.D	ANOVA	4691.8	There was significant difference
Soil moisture	ANOVA	6524.39	There was significant difference
Emerging seedling	ANOVA	2306	There was significant difference
Species composition	ANOVA	4.07	There was significant difference
Seed counts	ANOVA	309.3	There was significant difference
Comparison of standing & soil seedbank life forms	t-test	2.089	There was significant difference
Diversity	t-test	5.1651	There was significant difference
Seed viability	ANOVA	6.712	There was significant difference
Enclosed & enclosed plots seed numbers	ANOVA	135.59	There was significant difference