COMPARISON OF WOODY SPECIES REGENERATION AND SOIL FERTILITY IN AN INDIGENOUS FOREST AND NEIGHBOURING EXOTIC TREE PLANTATIONS IN MUGUGA FOREST.

BY

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Declaration

This thesis is my own original work and has not been submitted to any other university for the award of a degree.

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Table of Contents

List of Figures

List of Tables

List of Appendices

List of Acronyms

CIFOR	Centre for International Forestry Research
EAAFRO	East African Agriculture and Forestry Research Organisation
FAO	Food and Agriculture Organisation
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Technical Cooperation)
ICRAF	International Centre for Research in Agroforestry
IFS	International Foundation for Science
ITTO	International Tropical Timber Organisation
IUCN	International Union for Conservation of Nature
KEFRI	Kenya Forestry Research Institute
KEFWG	Kenya Forestry Working Group
UNEP	United Nations Environment Programme

Abstract

The regeneration of understory woody vegetation in different plantation forests was investigated in Muguga Forest Station. Species composition, vegetation structure, understory woody species regenerates structure and soil physiochemical characteristic were assessed in five different forest types, the Indigenous forest, Cypress plantation, Eucalyptus plantation, Mixed Acacia-Eucalyptus plantation and Pine plantation. The Eucalyptus, Cypress, Pine and mixed Acacia-Eucalyptus plantations had significantly higher densities of mature trees as compared to Gachuthi indigenous forest ($F_{5, 96}$ = 56.43, p<0.05). The mean densities of immature woody species were only significantly higher in Gachuthi than in the Pine plantation ($F_{5, 298}$ = 2.45, p<0.05) but mean densities for saplings and seedlings did not vary significantly (p>0.05) among the different forest types. Foliar cover and woody species abundance of immature trees showed a significant positive correlation (r = 0.362) in Gachuthi ($t_{0.05\ (2),\ 34}$ = 2.26, p<0.05) and a significant negative correlation (r = -0.414) in the mixed Acacia-Eucalyptus plantation ($t_{0.05\ (2),\ 34}$ = 2.65, p<0.05). The sapling and seedling abundance had no significant correlation to foliar cover (p>0.05) in the different forest types. Soils in the forests studied were classified as clay soils with no significant differences in pH, soil nitrates and organic carbon (p>0.05) among the different forest types. The woody species abundance of immature trees and soil nitrates showed significantly negative correlation in Gachuthi ($t_{0.05\ (2),\ 34}$ = 2.39, p<0.05) while there were no significant correlations in the other forest types. Soil pH, nitrates and organic carbon showed significant (p<0.05) negative correlations to sapling abundance in Gachuthi and significant (p<0.05) positive correlations to sapling abundance in the Pine plantation. Soil pH and seedling abundance showed significant negative correlation (r= -0.35) in the Cypress plantation ($t_{0.05\ (2),\ 34}$ = 2.18, p<0.05) whereas it was not significant among other forest types. In this study, the significantly low percentage foliar cover and higher soil nitrates content in the indigenous forest seemed to favour the survival of seedlings to the immature age class.

CHAPTER ONE: INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

In Africa, large sections of indigenous forest have been cut down to make room for agriculture and human settlement (International Tropical Timber Organisation, 2002). This is because the climatic and edaphic conditions that suit forest ecosystems development also favour agriculture and human settlement, leading to the loss of essential ecosystem goods and services (Hall, 2013). The increasing extent of forested land that has been converted to agriculture and later abandoned as degraded land has necessitated the implementation of reforestation efforts to restore ecosystem function (Zanne and Chapman, 2001). In an effort to restore these goods and services, many reforestation programmes have been carried out using various forest management practices. One of the known reforestation practices is the establishment of fast-growing exotic tree plantations in degraded landscapes mainly of Pine and Eucalyptus trees (Lamb *et al.*, 2005).

The Pine plantations established in sites in the Ecuadorian High Andes Mountains had a dual purpose of providing vegetation cover as well as facilitating indigenous forest regeneration by providing suitable climatic conditions in degraded landscapes (Hofstede *et al.*, 2002). The vegetation cover provided by the fast-growing tree species also helped suppress the establishment of light demanding species such as grasses and allow for seedling establishment of woody species in the understory (Lugo, 1992; Parrotta, 1993). Plantations of fast growing indigenous and exotic species continue to replace vast areas of degraded indigenous forests and agricultural lands in the tropics as they were considered to be the most effective way to meet demands for fuel wood, lumber and biomass (ITTO, 2002). However, the economic and social benefits of plantations have to be weighed against the possible short-term and long-term environmental implications of their establishment.

Over the years there has been growing concern that exotic tree plantations have a detrimental effect on the ecology of a region, however, studies carried out in different regions of the world show conflicting information (Parrotta *et al.*, 1997; Hofstede *et al.*, 2002; Senbeta and Teketay, 2001). Some studies such as those carried out on Pine plantations in the Ecuadorian High Andes Mountains, found little difference in the species diversity of the understory vegetation in the plantations as compared to natural forests (Hofstede *et al.*, 2002). However, Hofstede's (2002) study did find that the natural forests had more organic matter, nitrogen, phosphorous, potassium and soil moisture than the pine plantations. Meanwhile, other studies have found that Eucalyptus species were suspected to deplete soil of nutrients and water and to suppress the growth of vegetation underneath the trees (Lisanework and Michelsen, 1993; Malik and Sharma, 1990).

Some studies also viewed plantations as being useful in re-establishing indigenous forest vegetation in degraded sites (Parrotta, 1992; Alem and Woldemariam, 2009) by providing vegetation cover that suppressed the growth of grasses and other light demanding plants as well as preventing further soil erosion. In areas where plantations were established near existing indigenous forests, the plantations provided suitable conditions for seedling establishment of the indigenous woody species thus enhancing regeneration of the indigenous forest (Parrotta *et al.*, 1997). This means that the establishment of tree plantations can aid in the regeneration of indigenous forests as well as preventing further land degradation.

However, studies carried out on *Eucalyptus* species had found that they can have allelopathic effects on understory vegetation (Espinosa-Garcia *et al.*, 2008; Lisanework and Michelsen, 1993). Tannins in the leaves were suspected to have repressed seedling establishment and therefore suppressed the regeneration of woody vegetation in the understory. It is therefore, of importance in this study to assess the understory regeneration of indigenous woody

vegetation to determine the effects of these plantations on future indigenous forest regeneration.

The aim of the study was to assess the effectiveness of establishment of forest plantations in restoring understory woody species diversity, improving regeneration of indigenous plant species and enhancing soil fertility. To achieve this, species diversity and soil fertility in exotic tree plantations and Indigenous/ natural forests were assessed. The indigenous forest served as a control and provided information on the natural regeneration capability of the ecosystems where there had been limited human interference. To determine if differences existed between the plantations and natural forests, sampling of vegetation and soils was carried out to determine species abundance and composition as well as soil physical and chemical characteristics.

1.2 Literature Review

In Africa, an estimated 350 million hectares have been deforested and another 500 million hectares of primary and secondary tropical forests are degraded (ITTO, 2002). One of the major responses to the degradation had been to undertake some form of reforestation but in most situations the site conditions limited tree establishment; thus plantations of fast-growing trees were established to improve the environmental conditions (Zanne and Chapman, 2001). This was mainly through the use of industrial monocultures involving a limited number of species from a small number of genera, particularly *Cypress, Pine, Eucalyptus* and *Acacia*. However, the environmental impact of fast-growing exotic tree plantations has been internationally controversial (IFS, 1989).

There has been heated debate on the effectiveness of exotic tree plantations in restoring ecosystem goods and services with some studies (Espinosa-Garcia *et al*., 2008; Malik and Sharma, 1990) indicating that monocultures exhaust important resources in the soil such as water and minerals which, in the tropics and subtropics, prevents understory growth and

results in decreased biodiversity and further soil erosion and loss of fertility (FAO, 1992). In contrast, other studies conducted in areas with degraded soils and little vegetation cover have found that fast-growing tree plantations favour the regeneration of undergrowth plants and increase soil fertility (Hofstede *et al.*, 2002; Alem and Woldemariam, 2009). Some studies have reported that artificial rehabilitation could generally accelerate the restoration process on degraded land in China (Harrington and Ewel, 1997).

Studies carried out in the last two decades by Parrotta show increasing evidence that forest plantations can play a key role in long-term forest ecosystem rehabilitation particularly where silviculture management has been neglected. The plantations can, under certain conditions, catalyse or facilitate forest succession in the understory (Parrotta *et al.*, 1997). The catalytic effect of the plantations can be due to changes in understory microclimatic conditions, the suppression of grasses, increased vegetation structural complexity and development of humus and litter layers as well as providing a habitat for seed dispersing animals (Parotta 1992).

1.2.1 Global and Local Deforestation

Deforestation is described as the conversion of forest land to another land use or the long-term reduction of tree canopy cover below the 10% threshold (FAO, 1992) and implies long-term or permanent loss of forest cover. The global forest cover is approximately 4 billion hectares, approximately 31% of the total land cover while in Africa; the total forest cover is approximately 675 million hectares accounting for 17% of the total global forest cover (FAO, 2010). The global rate of deforestation is decreasing with 13 million hectares of forest land converted to agriculture and other uses between 2000 and 2010 as compared to 16 million hectares per year recorded in the 1990s (FAO, 2010). In Africa, the period 2000-2010 the recorded net decrease in forest cover was approximately 1.9million hectares. Studies carried out by Kigomo (2001) estimated Kenya's forests cover to be approximately 2.4million hectares accounting for 3% of the country's land cover. Recent reports put the total forest

cover in Kenya at 3.47 million ha, approximately 6% of the total land area (FAO, 2010); but while this is an improvement on previous forest cover areas, this percentage is still well below the recommended threshold of 10%.

The global and local causes of deforestation vary and include both direct and indirect causes such as population growth, commercial agriculture, urbanisation, lack of enforcement, among others. Population growth for example, results in expansion of human settlements to meet the demands of the rising population and the resultant expansion of human settlements can lead to the clearing of forests (FAO, 2010).

Direct causes of deforestation include commercial logging, uncontrolled forest farming, commercial agriculture, urbanisation, mining and oil exploration, acid rain and fire (Giri, 2007). Commercial logging results in the clearing of large areas of forest faster than the forests are capable of regenerating, leading to a permanent loss of forest cover, this opens up dense forests allowing access to forest farmers (Boucher *et al.*, 2011). Forest farming is usually small scale and leads to the extraction of forest resources as well as further clearing of forests to make way for agriculture. Commercial agriculture to meet growing food demands has led to the expansion of farming land through clearing of forests with large tracts of land cleared to make way for farming and to provide pasture land (FAO, 2001). The concentration of services in urban areas encourages rural to urban migration leading to the expansion of urban areas to facilitate this influx and the expansion of the urban areas has led to encroachment into forest land (FAO, 2010). Increased demand for forest resources such as fuel wood and timber has also led to the clearing of forests to meet this demand. Acid rain and uncontrolled forest fires have also led to loss of forest cover with large, intensive forest fires and increased incidence of acid rain leading to the destruction of fragile forest ecosystems and possibly preventing the regeneration of indigenous forests in these disturbed sites (Giri, 2007). Mining and oil exploration activities require large tracts of land to be

cleared to allow for mining operations, these mining and oil exploration operations also lead to pollution of the environment which hinders regeneration of indigenous vegetation in these disturbed sites (Boucher *et al.*, 2011, Hall 2013).

The indirect causes of deforestation include unsustainable economic strategies, social and political structures, weak policies and enforcement and uncontrolled utilisation of resources (Giri, 2007). Economic strategies that focus on short-term gains act as disincentives to long term sustainable economic planning that would prevent environmental degradation. The social and political structures that lead to inequalities in land tenure have resulted in the marginalisation of the poor, leading to their settlement in forest areas and further deforestation (FAO, 2010). Weak policies and enforcement including lack of enforcement especially to controlling illegal logging, as well as unclear policies on utilisation of forest resources have resulted in increased deforestation (Hall, 2013). In some regions, uncontrolled industrialisation has led to increased deforestation through clearing of forests to provide the necessary energy for industries in form of wood fuel as well as to provide timber for the development of infrastructure (Giri, 2007).

1.2.2 Impacts of Deforestation

The impacts of deforestation are varied and range from ecological, economic to social effects with the loss of biodiversity and the extinction of species being the most notable impact. Many species are lost with the clearing of forests, various species of plants and animals are reliant on the forest ecosystem and large scale destruction of these ecosystems has been hypothesised to lead to the loss of many undocumented species (FAO, 1992). Deforestation leads to fragmentation of the landscape and isolation of the forest area which leads to further extinction. Loss of forest ecosystem goods and services such as food and medicinal resources, water catchments, carbon sequestration and soil erosion control are also impacts of deforestation (FAO, 2010). The forest ecosystems are a source of food for the surrounding

communities in the form of fruits and seeds and the destruction of these habitats leads to a loss of these resources. The roots, bark and leaves of many forest species have medicinal properties and loss of the forests leads to the loss of this important source of medicinal plants (ITTO, 2002).

Carbon sequestration is an important function of the forest ecosystems and large scale deforestation leads to the loss of forest trees as carbon sinks. The loss of forest cover leads to a reduction in the water catchment and underground aquifer replenishment capabilities of the land leading to a reduction in the availability of water resources in a region (Giri, 2007). The loss of forest cover also leads to soil erosion in the exposed landscape as well as increased deposition of sediments in water sources downstream with soil erosion also affecting soil fertility as the most fertile top soil has been removed. Deforestation also results in the loss of forest capital from sustainable timber and non-timber resources (FAO, 2010). Many communities rely on forest resources as a source of income and many of these resources have an economic value that is lost when the forests are clear felled.

1.2.3 Forest Plantations

The increasing pressure on forest resources has necessitated the establishment of commercial tree plantations composed of fast growing tree species so as to provide the requisite forest resources. Forest plantations are defined as forest stands established by planting and/or seeding in the process of afforestation or reforestation (FAO, 2001). They are either of introduced species or indigenous species which meet a minimum area requirement of 0.5ha, tree crown cover of at least 10% of the land cover and total height of mature trees above 5 metres. In Kenya most of the established plantations are of exotic tree species mainly of Cypress, Pine and Eucalyptus species (Kigomo, 2001).

The primary driver for the establishment of forest plantations is to compensate for timber production so as to reduce dependence on indigenous forests. The global reduction in forest

cover has also resulted in an increase in the establishment of plantations (FAO, 2001). Approximately 35% of the global wood supply in the year 2000 came from forest plantations (Brockerhoff *et al.*, 2008) with the plantations providing a source of fast growing tree species that are more economically viable than slower growing alternatives. The establishment of forest plantations is also driven by the need for efficiency in wood production where only the desired tree species are cultivated (Kigomo, 2001). Forest plantations were also established for ecological reasons such as providing vegetation cover on bare land, prevent soil erosion and act as carbon sinks (Brockerhoff *et al.*, 2008). The established plantations provide vegetation cover that can facilitate succession by indigenous tree species as well as preventing erosion by wind or water.

Studies conducted show that plantation forests can either have a positive or negative effect on a habitat (FAO, 1992; Parrotta *et al.*, 1997). Among their merits, the forest plantations can catalyse or facilitate forest succession in the understory (Parrotta *et al.*, 1997). Studies carried out by Parrotta (1993) have shown that the plantations alter understory microclimatic conditions, suppress the establishment of grasses, increase vegetation structural complexity and facilitate the development of humus and litter layers as well as providing a habitat for seed dispersing animals. Soil fertility could be improved by the establishment of plantations through the incorporation of soil nutrients through litter fall and the subsequent organic matter decomposition (Parrotta, 1995; Parrotta *et al.*, 1997). The forest plantations could also facilitate the replenishment of the seed bank through production of seeds and by providing a habitat that attracts seed dispersing animals as well as facilitating seedling establishment in the understory (Parrotta, 1992). Studies carried out have found that the forest plantations have provided a suitable habitat (Evans, 1992) for animals that relied on forest ecosystems as well as providing a habitat for other plant species.

However, plantations have various demerits including their inability to comprehensively substitute all the forest products provided by the indigenous forests (Evans, 1992). This is mainly because the plantations are composed of a small number of species and limited species diversity as compared to indigenous forests. The fast growing species used in forest plantations may also have a negative effect on the remnants of neighbouring indigenous forests (FAO, 1992; Evans, 1992) where the fast growing species spread into the indigenous forest ecosystem, becoming invasive and destabilizing the ecosystem. Some studies have found that the soil fertility under the plantations was poor as compared to an indigenous plantation (Hofstede *et al.*, 2002) and that the plantations could also limit seedling establishment as some Eucalyptus species are suspected to have allellopathic effects that prevent seedling establishment (Espinosa-Garcia *et al.*, 2008).

1.2.4 Regeneration

Regeneration can be described as the recruitment of new individuals of a species into a given habitat and is dependent on the germination of released seeds and establishment of immature individuals. The new recruits are the immature trees, saplings and seedlings collectively known as regenerates (Lamprecht, 1989; Teketay, 2005). Regeneration depends on numerous prerequisites and although preconditions may be greatly varied among different species, there are two that are indispensable: a sufficient volume of viable seeds and appropriate climatic and edaphic conditions for germination and establishment (Lamprecht, 1989). A sufficient volume of seeds is necessary due to the high rate of seed loss through predation and damage during seed dispersal and while in the soil. The large volume of viable seeds released ensures that some of the seeds survive to germinate thus recruiting new individuals to the ecosystem.

Important aspects of regeneration include flowering, seed production and dispersal, incorporation of seeds into the soil (soil seed bank), seed germination and seedling establishment (Teketay, 2005). Abiotic factors that influence forest regeneration include soil

fertility, moisture, light, natural disturbances, anthropogenic disturbances and availability of resources. There are various barriers to forest regeneration and they include poor seed viability, high seed and seedling predation, soil infertility, low propagule numbers, poor seed dispersal, low light levels in the understory, seasonal drought and annual fires (Hooper *et al.*, 2005).

Studies carried out by Kuusipalo *et al.* (1995) have shown that in degraded sites, regeneration of woody species was hindered when these sites were abandoned after intensive agriculture. The degraded sites tended to be overtaken by herbaceous vegetation of mainly grasses which suppressed the establishment of woody species (Kuusipalo *et al.,* 1995). The harsh environmental conditions on these degraded sites such as high temperatures, low humidity and competition for resources also limited seedling establishment. Thus, the establishment of fast growing tree plantations would be of importance in encouraging regeneration of indigenous woody species through the vegetation cover that these plantations provide. The vegetation cover provided helps mitigate the harsh environmental conditions present in a degraded and exposed site.

Previous studies on tropical forest plantations suggested that plantations may facilitate the recruitment, establishment and succession of indigenous woody species (Parrotta 1992, Lugo 1992). These studies suggested that given certain conditions, the forest plantations established on degraded sites could act as succession catalysts thus facilitating the re-colonization of these areas by the indigenous flora. The plantations catalysed forest succession through their influence on the understory microclimatic conditions that led to improved light, temperature and moisture conditions for seedling growth, and development of humus and litter layers that enhanced soil fertility in the degraded sites. The plantations also suppressed the establishment of light-demanding species such as grasses that would have normally prevented germination of the tree seeds and affected seedling survival through

competition for resources as well as providing a habitat for seed dispersing animals thus increasing seed inputs from the neighbouring indigenous forests.

1.2.5 Seed Dispersal and Soil Seed Bank

Seed dispersal is essential in regeneration to ensure the success of plant reproduction, adaptation, germination as growth away from the parent plant reduces competition for resources and space for development (Mader, 1996). Seed dispersal enables seeds to escape predation and competition for resources as well as increasing the seeds' chances of landing in microsites with suitable conditions for germination, seedling establishment and growth (Teketay, 2005).

Studies carried out by Zanne and Chapman (2001) showed that seed dispersal is essential in disturbed and degraded habitats such as former cultivation areas, especially where these degraded sites bordered indigenous forests. This is because the seedlings and seed bank would have been eliminated during cultivation and the dispersed seeds from the forest remnants would be the main source of propagules of the indigenous woody species. Studies carried out on disturbed habitats showed that the distance of the degraded habitats from indigenous forests influenced the rate and extent of regeneration (Teketay, 2005; Zanne and Chapman, 2001). This showed the importance of seed dispersal and seed dispersal agents in regeneration; the agent of dispersal used by a species would have an effect on the ability of the species to colonise new habitats and the distance seeds of a species would be capable of travelling from the parent plant (Zanne and Chapman, 2001).

The dispersal distance of seeds depended on the agent of seed dispersal and the size of the seeds (Parrotta *et al.*, 1997). Agents of seed dispersal include animals, water, wind and self-propagation. In most dry forests, plant species rely on animal and wind dispersal and studies have shown that wind dispersed seeds tended to travel greater distances than other dispersal methods. However, in forests with closed canopies wind currents would be limited therefore

most of the wind-dispersing species were found to be mainly emergent species (Teketay, 2005). Seed size also influences the dispersal method and the distance travelled with large seeds constrained in their dispersal as they would be too heavy for wind dispersal or dispersal by small animals. Regeneration of woody species within plantations would also be influenced by the attractiveness of sites within the plantation to dispersers such that site which provided food and viable habitats would be more attractive to seed dispersers.

The soil seed bank refers to all viable seeds and fruits on or in the soil and associated litter (Teketay, 2005) as well as the natural storage of seeds, often dormant, within the soil of an ecosystem. The soil seed bank plays an important role in the regeneration of an ecosystem after disturbance and can reflect the history of the vegetation. Seeds can be described according to their longevity in the soil seed bank as transient or persistent. Transient seeds remain viable in the soil seed bank only until the next opportunity to germinate while persistent seeds can survive longer often exceeding one year. They can further be classified as short-term persistent seed banks whose seeds germinate or die within 1-5years and long-term persistent seed banks comprised of species whose seed remain viable in the soil longer than five years (Thompson *et al.*, 1997).

The dynamics of a soil seed bank include seed predation or death, recruitment into the dormant seed bank through seed rain and transferral into the active seed bank. Recruitment of individuals from the seed bank is restricted to periods with favourable soil and climate conditions that control seed germination. Different species have developed various adaptations to improve the seed's likelihood of germination such as seed size and thickness of the seed coat (Teketay, 2005). The density of viable seeds also determines the success of the soil seed bank by providing a suitable number of seeds for germination so as to replace individuals lost from the ecosystem.

1.2.6 Seed Dormancy, Germination and Seedling Establishment

Dormancy can be described as the period of time during which no growth occurs despite conditions being favourable for growth. This requirement helps to ensure that seeds do not germinate until the most favourable growing season has arrived. Species differ in their seed dormancy and their requirements for germination. Seed germination is influenced by the interaction of seed dormancy-releasing factors such as light, moisture and temperature (Teketay, 2005) and this in turn affects seedling emergence and establishment. Soil moisture and water availability is necessary for seed germination and a sufficient amount of water is required to sustain the subsequent seedling establishment and growth. It is for this reason that many species tend to germinate only after heavy rains.

Light requirements for germination differ among different species and seeds are able to detect gaps in the canopy and the depth they were buried in the soil based on the light available. Shade and low light conditions tend to favour seed dormancy and the formation of a persistent soil seed bank while canopy gaps and increased light favour seedling establishment. Light in forest gaps tended to be of higher intensity and longer duration which facilitated vegetation regeneration within the forest gaps (Hubbell and Foster, 1986).

Temperature is closely related to light availability and also influences germination as well as acting as a gauge of the diurnal light fluctuation. Different species have different temperature ranges i.e. maximum and minimum temperatures, within which seed germination is possible and the optimum temperature of a seed allows for maximum germination in the shortest time. Temperature also influences seed dormancy and prevents germination of seeds during extreme climatic conditions of very low or very high temperatures (Teketay, 2005).

1.2.7 Soil Nutrients and Soil Fertility

The nutrients present in a soil are of great importance to the rate and extent of regeneration of woody species and the availability of nutrients in forest ecosystems depends on the efficiency

of nutrient cycles while the form and quantity of the nutrients present in the soil determine the amount taken up by a plant (Whitmore, 1990; Brady and Weil, 2002). The main essential nutrients required by plants are classified into four groups: major non-mineral macronutrients, primary macronutrients, secondary macronutrients and micronutrients (Brady and Weil, 1999). The major non-mineral macronutrients make up 90-95 % of the dry plant weight and they are Carbon, Hydrogen and Oxygen. The primary macronutrients are Nitrogen, Phosphorous and Potassium and are important for plant growth and development. The secondary macronutrients are Calcium, Magnesium and Sulphur; while the micronutrients include Boron, Chlorine, Cobalt, Copper, Iron, Manganese, Molybdenum, Nickel and Zinc.

Nutrients are deposited in the soil through various methods depending on the nutrient and the common input processes are precipitation, deposition of particulate aerosols, decomposition of organic matter, volcanic ash and weathering of bedrock (Whitmore, 1990). The carbon and nitrogen content of a soil have great influence on plant growth and development as availability of soil nitrogen often influences the response of woody vegetation growth in elevated Carbon dioxide conditions. The soil organic matter (determined by calculating the percentage of total organic carbon in the soil) greatly influences the nutrient reserve and the availability of these nutrients for plant uptake as well as influencing soil aggregation, moisture retention and microbial activity.

Soil pH has been found to have an influence on the fertility of soils through its influence on the availability of soil nutrients, the cation exchange capacity in pH-dependent soil colloids (clay or humus), the physical breakdown of root cells, the solubility of toxic nutrient elements in the soil and microbial activity (Brady and Weil, 2002). Soil pH ranges from 3 to 9 and can be classified into 5 categories: strongly acidic (pH < 5.0), moderately to slightly acidic (pH

5.0-6.5), neutral (pH 6.5-7.5), moderately alkaline (pH 7.5-8.5) and strongly alkaline (pH>8.5).

In degraded sites, studies conducted by Bargali *et al.* (1993) found that nutrient content was low thus the regeneration of most woody species was stunted. These degraded sites were mostly dominated by weed species that could survive the low nutrient conditions and were able to outcompete indigenous species for the few soil nutrients available (Bargali *et al.*, 1993). The aim of establishing plantations in many cases was to improve soil fertility in degraded sites through the incorporation of soil nutrients through litter fall and the subsequent organic matter decomposition.

1.2.8 History of Tree Plantations in Muguga Forest

In 1922, Muguga Forest station was opened and the general conversion of the indigenous forest to exotic tree plantations began in 1926 and by the time the East African High Commission acquired the land in 1951, 80% of the estate was under *Acacia mearnsii* (black wattle) (Gachathi and Macharia, 2009). These Acacia trees were clear felled for other plantations and infrastructure and for the purpose of conducting research under the East African Agriculture and Forestry Research Organization (EAAFRO). The two surviving patches of the original natural forest were put under Preservation policy at the Director level by the EAAFRO and this policy has been maintained by the Kenya Forestry Research Institute (KEFRI).

The Pine and Cypress plantations were established in the 1970s by the East African Community as part of the Kenya Tree Bank (Gachathi and Macharia, 2009) while the Eucalyptus plantations were established in the late 1990s and were clear-felled between 2004 and 2006 and the resultant coppice stands were allowed to mature. The exotic tree plantations studied varied in age, with the Pine and Cypress plantations being approximately 40 years old. The age of the coppices in the Eucalyptus stand was found to be between 5-7 years and

in the Mixed Acacia-Eucalyptus stands the coppices were also approximately 5-7 years old (Gachathi and Macharia, 2009).

1.3 Justification

The aim of the study is to assess the effectiveness of different plantation forests in restoring understory woody species diversity and enhancing soil fertility in comparison to indigenous forests. Various studies have been conducted to assess species diversity in the understories of forest plantations; however, few studies have assessed how different exotic tree plantations compare in terms of their ability to facilitate regeneration of indigenous woody species.

The study would be useful in supporting conservation efforts by determining the ecological advantages and disadvantages of different exotic tree plantations and the effectiveness of these forest plantations in enhancing or restoring understory biodiversity and facilitating the regeneration of indigenous species in a degraded ecosystem as well as their influence on soil fertility. The study would also provide information on the viability of different exotic tree plantations in the regeneration of indigenous woody species.

1.4 Main Objective

The primary objective of this study was to determine the impact of indigenous and plantation forests on the regeneration of understory woody vegetation and soil fertility.

1.5 Specific Objectives

- To determine the species composition and vegetation structure in the different forest types.
- To determine the understory woody regenerates structure in the different forest types.
- To determine the influence of plantation forests on soil physiochemical characteristics and soil fertility.

1.6 Hypothesis

The mature woody species structure and soil physiochemical characteristics have no significant effect on understory species composition and woody regenerates distribution.

CHAPTER TWO: STUDY AREA, MATERIALS AND METHODS

2.1 Study Area

The forest blocks studied are located 26km Northwest of Nairobi in Kiambu County at the geographical coordinates: 01^0 13'South, 036^0 38'East and 01^0 12'South, 036^0 37'East and at an elevation of 2015metres above sea level (Gachathi and Macharia, 2009). The indigenous forest blocks studied included Gatwikira (13ha) located at the south-east corner of Muguga Forest station and Gachuthi (30ha) located at the north-east corner of the Muguga Forest Station (Figure 2). The forest blocks studied fall within the Kenya Forestry Research Institute (KEFRI) estate and human settlements around the indigenous and plantation forests were observed.

2.1.1 Climate and Rainfall

Muguga Forest Estate has a mean annual rainfall of 990mm (Muguga Meteorological Station). The area has a bimodal rainfall pattern with the long rains in March to May and the short rains starting in October to December (Figure 1). The long rains season is characterised by mist, extensive cloud cover and low temperatures. The long rains account for, on average, 50% of the total annual rainfall and the short rains account for a further 28% with the remaining 22% total rainfall occurring as off-season rain incidence. The dry seasons may be prolonged and drought conditions can be severe (Gachathi and Macharia, 2009).

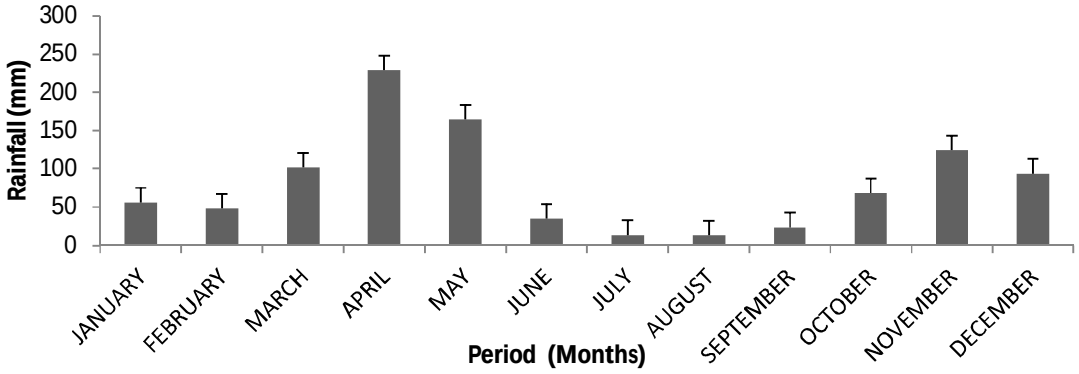

Figure 1: Mean Rainfall in Muguga forest (2000 – 2011)
(Data courtesy of Muguga Forest Station, Meteorological Department)

Muguga forest station has an average temperature of 16^0 C with daily temperatures rarely exceeding 28^0 C or falling below 8^0 C (Muguga Meteorological Station). The mean annual temperatures at Muguga over the period 1995-1999 was a maximum of 21.4^0 C, a minimum of 4.7^0 C and an overall mean of 13.5^0 C. Muguga is situated near the equator thus the day length variations are small but the seasonal changes in cloud cover have a marked effect on the actual number of sunshine hours. The mean daily sunshine hours for 1995-1999 ranged between 6.2 and 6.6 hours (Gachathi and Macharia, 2009).

2.1.2 Soils and Topography

In general, the area has gently sloping hills and clay-loam soils that are well drained. The fertile soils in the area are derived mainly from lava and are generally very deep but become shallow on steep slopes and ridge tops where the underling rock is exposed (Gachathi and Macharia, 2009). The lava known as Limuru Quartz Trachyte is a highly porphyritic rock that weathers to a soft light grey stone, often to considerable depths. The infertile soils mainly derived from volcanic ash (tuffs) are typically shallow and of a dark brown colour with clay-loam texture and drainage of these soils is seasonally impeded. The soil pH ranged from 6.2 - 6.5 in the 0-18 cm depths (Gachathi and Macharia, 2009).

2.1.3 Flora and Fauna

Muguga forest was part of a once vast Upland Dry forest that extended to the Aberdares and Mt. Kenya ecosystems and formed a transitional zone between the lower Croton plateau forests of the Nairobi area and the dry, montane Cedar forests. It was a dense, dry, upland, evergreen forest dominated by *Juniperus procera, Olea europaea africana, Calodendrum capense* and *Croton megalocarpus* (Gachathi and Macharia, 2009). The indigenous forest covers an area of approximately 60ha and is divided into two forest patches with Gatwikira situated in the Southeast corner of the forest estate and Gachuthi situated in the Northwest section.

A recent tree inventory and species checklist was carried out in 2009 of the two indigenous forest blocks of Gatwikira and Gachuthi (Gachathi and Macharia, 2009) and a total of 96 species representing 85 genera in 46 families of trees and shrubs were recorded in both indigenous forests. In Gatwikira, *Vepris simplicifolia* was the most dominant and widely distributed species, accounting for 33.7% of all trees. In Gachuthi, *Euclea divinorum* was the most dominant and widely distributed, accounting for 17.6% of all trees.

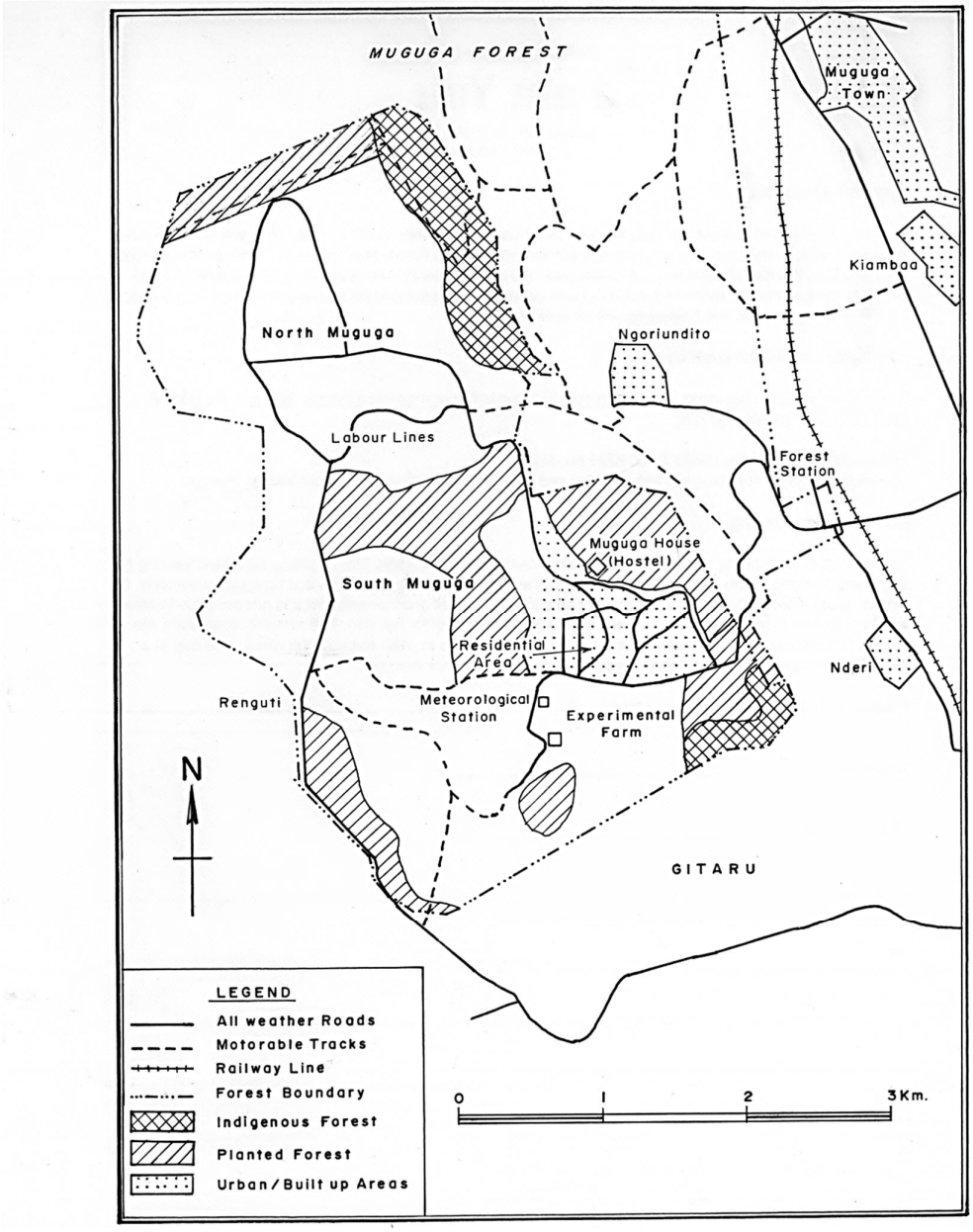

Figure 2: Location of indigenous and plantation forests in Muguga forest station

2.2 Methods

2.2.1 Sampling Layout

Sampling points were randomly placed along transects identified during reconnaissance to ensure that plots were established in the most representative parts of the forests. Sampling plots measuring 50m×50m were laid out in each of the forest blocks studied i.e. the indigenous forests and the plantation forests and in each of the forest types to be studied, two sampling plots were established 100 metres apart. The 50m×50m quadrats were laid out using four pegs and four lengths of rope of 50m each and a set square was used to ensure that the four corners of the quadrat were at 90^0 angles. The 50m×50m quadrats were then further subdivided into 10m×10m quadrats and quadrats to be sampled were selected using the Brun system (Lamprecht, 1989). The 10m×10m quadrats to be sampled were selected by laying down diagonals from the centre of the 50m×50m quadrat to the four corners; the 9 quadrats (shaded in black) that fell along these diagonals were then selected for sampling (Figure 3) The immature trees and saplings present in the selected quadrats were then sampled. Each of the selected 10m×10m quadrats was then further subdivided into 1m×1m quadrats and ten of these 1m×1m quadrats were randomly selected for seedling sampling.

Sampling was carried out during the Wet season (Oct-Dec 2012) and Dry season (Jan-Feb 2013).

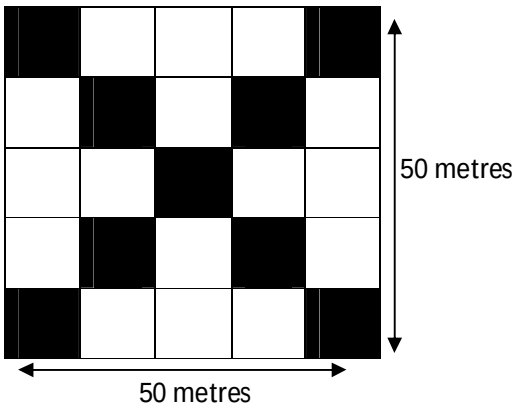

Figure 3: Diagrammatic representation of sampling design layout with quadrats selected for sampling shaded in black

2.2.2 Woody Species Assessment

In the 50m×50m sampling plots, all the mature trees present with Diameter at breast height≥5cm and Height≥3metres were sampled. The species, number of individuals, diameter at breast height (150cm from the ground) of each tree, height and percentage foliar cover were measured and recorded. The percentage foliar cover of the mature trees in each forest studied was estimated using a densitometer or a canopy cover grid (Lemmon, 1956).

In the selected 10m×10m quadrats the immature trees of DBH<5cm and height of 1-3metres and saplings of height<1metre were sampled; the species and number of individuals present were also counted and recorded.

The 10m×10m subplots were further subdivided into 1m×1m quadrats where ten quadrats were randomly selected. In each of the selected 1m×1m quadrats, seedlings of height< 30 cm were sampled; the species and number of individuals present were recorded.

The understory woody regenerates structure was determined using height classes in three vertical tiers: <0.3m (seedlings), 0.3-1m (saplings), 1-3m (immature).

The following parameters were calculated from the data collected, using formulae described by Brower, Zar and von Ende (1990) and Lamprecht (1989):

$$Density\ of\ Species\ i\ =\ \frac{Number\ of\ individuals\ of\ Species\ i}{Area\ (m^2)} \qquad \text{Equation 1}$$

$$Relative\ Density\ (\%)\ =\ \frac{Density\ of\ a\ Species\ i}{\sum Density\ of\ all\ Species}\ \times 100 \qquad \text{Eq. 2}$$

$$Frequency\ of\ Species\ i\ =\ \frac{Number\ of\ Samples\ in\ which\ Species\ i\ occurs}{Total\ number\ of\ Samples\ taken} \qquad \text{Eq. 3}$$

$$Relative\ Frequency\ (\%)\ =\ \frac{Frequency\ of\ a\ Species\ i}{\sum Frequency\ of\ all\ Species}\ \times 100 \qquad \text{Eq. 4}$$

$$Dominance\ =\ Density\ of\ Species\ i\ \times\ Average\ Dominance\ value\ of\ Species\ i \qquad \text{Eq. 5}$$

Where:

$$Average\ Dominance\ Value\ of\ Species\ i = \frac{\sum Basal\ area\ (m^2)\ of\ individuals\ of\ Species\ i}{Number\ of\ individuals\ of\ Species\ i}$$

Eq. 6

$$Relative\ Dominance\ (\%) = \frac{Dominance\ of\ a\ Species\ i}{\sum Dominance\ of\ all\ Species} \times 100$$

Eq. 7

The Importance Value of each species in the different forest habitats was determined as:

$$Importance\ Value = Relative\ Density + Relative\ Frequency + Relative\ Dominance$$

Eq. 8

The Vertical stratification of the mature trees in each of the forests was determined using selected tree height classes to show the lower canopy (3m-10m), middle canopy (10m-20m) and upper canopy (20m-30m).

Canopy cover classes for the mature trees were classified according to the percentage of the sky that was obscured by the tree canopies. The canopy cover classes followed that of Avery and Burkary (1994):

Open Canopy = 10% - 39%

Moderately Closed Canopy = 40% - 69%

Closed Canopy = 70% - 100%

Species Diversity was calculated using the Shannon-Wiener diversity index.

$$H' = -\sum p_i log p_i$$

Eq. 9

Where $p_i = n_i/N$

p_i is the proportion of the total number of individuals occurring in species *i*

Sørensen's similarity index was used for comparison among the different forest types using the following formula (Sørensen, 1948):

$$S = \frac{2a}{2a+b+c} \quad \text{Eq. 10}$$

Where a = the number of species present in both sample A and B

b = the number of species present in sample A only

c = the number of species present in sample B only

2.2.3 Soil nutrients sampling and analysis

In each of the selected 10m×10m quadrats, soil samples were collected by digging into the soil up to a depth of 30cm using a machete. The samples were then placed in polythene bags and labelled before being transported back to the Department of Botany's laboratory located in the University of Nairobi. The soils were air-dried for two days before being sieved through a two millimetre sieve to remove roots and leaves (Okalebo *et al.* 1993). The soil samples were then analysed for various parameters such as soil texture, pH, total Nitrogen, Organic Carbon, Phosphorous, Potassium, Calcium and Magnesium.

2.2.3.1 Soil texture analysis

Soil texture was determined using the Hydrometer method (Bouyoucos 1951; Day 1953). A 51.0g of air-dried soil was passed through a 2mm sieve and weighed before being transferred to a "milkshake" mix cup. 50ml of Sodium hexametaphosphate along with 100ml of distilled water was added and mixed with a stirring rod and the sample was left to settle for 30 minutes. The soil suspension was then stirred for 15 minutes with the multi-mix machine and transferred from the cup to the glass cylinder. With the hydrometer in the suspension, distilled water was added to the soil suspension until the volume was 1,130ml and then the hydrometer was removed. The top of the cylinder was covered and inverted several times until all soil was in suspension before being placed on a flat surface to settle, and the time it was placed on the flat surface was noted. The soil hydrometer was immediately placed into the suspension and the first reading on the hydrometer was taken at 40 seconds after the

cylinder was set down. The hydrometer was then removed and the temperature of the suspension was recorded using a thermometer. After the first hydrometer reading, the suspension was left to stand for three hours before a second hydrometer and temperature reading was taken. The first reading measured the percentage of silt and clay in the suspension while the second reading indicated the percentage of 2 micron (total) clay in the suspension. The results were corrected to a temperature of 20^0 Centigrade where for every degree over a temperature of 20˚ C, 0.2 units were added to the hydrometer reading before computation and for every degree under 20˚ C, 0.2 units were subtracted from hydrometer reading (Bouyoucos 1951; Day 1953). In addition, 2.0˚ C were subtracted from every hydrometer reading to compensate for the dispersing agent added.

Sample calculations were carried out as illustrated in the following example:

1 a. Hydrometer reading at 40 seconds, H_1

b. Temperature at 40 seconds, T_1

2 a. Hydrometer reading at 3 hours, H_2

b. Temperature at 3 hours, T_2

3. Temperature correction added to hydrometer reading = 0.2 (T-68˚ F) where T=˚Fahrenheit.

4. Salt correction added to hydrometer reading = -2.0

SAND = $100.0 - [H_1 + 0.2\,(T_1 - 68) - 2.0]^2 = \%\, Sand$

CLAY = $100.0 - [H_2 + 0.2\,(T_2 - 68) - 2.0]^2 = \%\, Clay$

SILT = $100.0 - (\%\, sand + \%\ clay) = \%\, Silt$

The percentages by weight of sand, silt and clay for the soils used were tabled showing individual composition for each soil sample collected at different positions.

2.2.3.2 Soil pH determination

The pH (reaction) of the soil was determined, using a pH meter and glass electrodes. The pH of the soil was determined using 1 part of soil to 2.5 parts of distilled or deionised water e.g.

10.0g of soil to 25ml of water. The soil/water mixture was shaken for 30 minutes using a mechanical shaker and then the suspension was allowed to settle for another 30 minutes so as to give a layer of fairly clear supernatant water above a lower layer containing soil in suspension. The two electrodes of the pH meter were lowered into the partly settled solution with the glass electrode in the lower layer containing suspended soil but the reference electrode in the clear supernatant liquid. Then the pH of the supernatant solution of the two samples was read (Black, 1965 and Okalebo *et al.*, 1993). The soil pH ranges from 3 to 9 and can be classified into 5 categories: strongly acidic (pH < 5.0), moderately to slightly acidic (pH 5.0-6.5), neutral (pH 6.5-7.5), moderately alkaline (pH 7.5-8.5) and strongly alkaline (pH>8.5).

2.2.3.3 Soil organic Carbon

The Organic Carbon content of the soil was determined by the Walkley-Black method (Krebs, 1989). The soil sample was ground and passed through a 0.5mm sieve to increase homogenization of the sample and facilitate oxidation. A soil sample was carefully weighed to give 0.5g and put into an Erlenmeyer (conical) flask and oxidised using 10.0ml of Potassium dichromate. The soil-dichromate mixture was then digested using 20ml of concentrated Sulphuric acid before being allowed to cool for about 20minutes. Distilled water was then added to bring the volume to 200ml then 5.0ml of Orthophosphoric acid (H_3PO_4) was added to remove any unused potassium dichromate before adding 5.0ml Diphenylamine sulphonate indicator. The soil mixture was then titrated with Ferrous sulphate which turned the solution from turbid dark blue colour to a clear pale green when the end point was reached. The percentage of the carbon on the soil was calculated using the following formula (Black, 1965):

$$\%Carbon = \frac{(M.e\ dichromate - M.e\ FeSO4)}{Weight\ of\ soil\ in\ grams} \times 0.3 \qquad \text{Eq. 11}$$

M.e. = Milli-equivalent

2.2.3.4 Soil total Nitrogen

Soil total Nitrogen was determined using the Kjedahl Method (Black, 1965); a wet digestion method in which the sample is digested for several hours with concentrated sulphuric acid so that all the nitrogen is converted to ammonium. A 5.0g sample of soil is carefully weighed out and placed in the Kjedahl flask where it is then digested using concentrated Sulphuric acid (the efficiency of digestion is improved by adding Potassium and Copper sulphates to raise the temperature of the digest and a Selenium catalyst to improve oxidation). This converts the Nitrogen in the soil to Ammonium and the amount of ammonium present is then determined through distillation of the soil digest with an alkali before titration of the ammonium (Black, 1965).

If a 10.0g sample was used to give 250ml of digest from which a 50ml aliquot was distilled, then the percentage N in the sample was:

$$\frac{Ml\ acid \times 5 \times 0.14}{Weight\ of\ soil\ in\ mg} = N\% \qquad \text{Eq. 12}$$

Assuming a reading of 30ml of 0.01N acid and 10.0g of soil, then the calculation was:

$$\frac{Mg\ N}{Mg\ soil} = \frac{30 \times 5 \times 0.14}{100} = 21\% \qquad \text{Eq. 13}$$

2.2.3.5 Soil Phosphorous content

The soil Phosphorous content was determined using the Colorimetric determination method (Black, 1965; Okalebo *et al*., 1993). Some 5 ml of each of the clear digested soil samples' solution created during the Kjedahl digestion was drawn using a pipette into 50ml volumetric flasks. About 20ml of distilled water and 10ml of Ascorbic acid reducing agent was added to each flask. The contents were made to 50ml by adding water, closed using a stopper and shaken thoroughly. These were stood for one hour for full colour development and the concentration of phosphorus in the sample read from absorbance measured at 880 nm wavelength in a calorimeter.

2.2.3.6 Determination of Soil content of Potassium, Calcium and Magnesium

The soil content of the exchangeable cations such as Potassium, Calcium and Magnesium was determined through soil extraction using an excess of Ammonium acetate (Okalebo *et al.*, 1993). Five grams of each of the air dried soil samples were weighed into plastic bottles to which 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 was used in determination of the content of K, Ca and Mg. For determination of potassium and calcium, each of the extracts was diluted ten times and 5ml of the diluted soil extract solution was drawn using a pipette into 50ml volumetric flasks before 1ml of 26.8% lanthanum chloride solution was added. The contents were then diluted to the 50ml mark with 1 mole ammonium acetate extraction solution and the solution was then sprayed into the atomic absorption spectrophotometer flame for determination of K and Ca. Absorbencies were measured to determine the amounts of each element. The standard working solutions with known quantities were measured first to calibrate the instrument. For determination of magnesium, 2ml of the soil extract solution was drawn using a pipette into a 50ml volumetric flask. Then 5ml of 5000 parts per million (ppm) were added and I mole ammonium acetate used to fill the contents to 50ml mark. The solution was sprayed into atomic absorption spectrophotometer for determination of Magnesium. The content of K, Mg and Ca. in soil were expressed in Percentage milli-equivalent (m.e.%).

2.2.4 Soil seed bank sampling and analysis

In each of the selected 10m×10m quadrats, soil samples were obtained by digging into the top soil up to a depth of 10 cm; the samples were then placed in polythene bags, labelled and transported to the laboratory. The soils were then air-dried for two days, sieved through a two millimetre sieve to remove roots and leaves before being subjected to seed screening tests and seedling emergence experiments (Okalebo *et al.* 1993).

2.2.4.1 Seedling emergence experiments

Seedling emergence experiments involved the germination of soil samples in a greenhouse. The soil samples collected for soil seed bank tests were air dried for 2 days and sieved to remove roots and branches. Each soil sample was thoroughly mixed before a 1 kilogram sample was weighed out and placed in a germination tray. The soil samples were then placed in a greenhouse to facilitate germination where the environmental conditions in the greenhouse consisted of natural photoperiods and regular watering. The emerging seedlings were identified, counted and recorded every two weeks from the time of germination, for a period of 6 months.

2.2.4.2 Seed screening experiments

Seed screening of the soil samples was carried out in the laboratory using a dissecting microscope. The soil samples were air dried for 2 days and then weighed to give the dry weight before being sieved through a 2mm sieve. The sieved samples provided a coarse sample and a fine sample where the coarse sample was what remained in the sieve and the fine sample was composed of the soil that could pass through the sieve. The coarse sample was then screened for all seeds visible to the naked eye. The fine sample was then reweighed (original sample weight) and a representative sample of 30 grams was taken for screening under a Dissecting microscope. A 3g subsample was obtained from the 30g sample and spread evenly on a Petri dish and observed under the microscope at a magnification of X1000. All seeds found in the subsample were counted and recorded. Another subsample was prepared and a seed count carried out; this was repeated until the entire 30g sample had been screened. The overall seed total was then calculated as:

$$Overall\ seed\ total = \frac{Original\ sample\ weight}{30g\ representative\ sample} \times Number\ of\ seeds\ in\ the\ 30g\ sample$$

Eq. 14

2.3 Statistical Analysis

Data was analysed using SPSS 17.0 and all hypotheses were tested at α=0.05. The density values of mature trees, immature trees, saplings and seedlings were subjected to single-factor ANOVA to determine if there were significant differences in density among the different forest types studied. Post hoc analysis using Tukey's test was used to determine where the variations in densities were to be found.

The foliar coverage and mean density values of mature trees in the different forests were subjected to Pearson's correlation analysis to determine if foliar cover and density changes were correlated. Changes in concentrations of soil nitrogen and soil organic carbon were also subjected to correlation analysis. The foliar cover and woody species abundance of understory regenerates were also subjected to correlation analysis to determine if foliar cover and understory woody species composition correlated. The Student's t-test was used to evaluate the significance of the correlation coefficient r at α=0.05 (Zar, 2010).

Species diversity values of the different forests studied were analysed using the PAST program and compared amongst the different forest types using Shannon-Weiner. The Student's *t*-test was used to determine if there were significant differences in species diversity among the different forest types and all hypotheses were tested at α=0.05.

The soil nutrients were analysed using Kruskal-Wallis non-parametric tests to determine if there were significant differences among the different forest types. The soil nutrients and abundance of understory regenerates were also subjected to Pearson's correlation analysis to determine if soil nutrients and woody species abundance of understory regenerates correlated. The Student's t-test was used to evaluate the significance of the correlation coefficient r at α=0.05

CHAPTER THREE: RESULTS

3.1 Woody Species Characterisation and Composition

3.1.1 Mature Woody Species Composition

A total of 1424 woody species individuals were recorded comprising 67 species and belonging to 40 families. The mature woody species recorded had heights greater than 3metres. The dominant species in each habitat was determined using the species density while canopy characteristics were described using canopy foliar cover.

The indigenous forest, Gachuthi was dominated by *Euclea divinorum* at 50± 3 trees per hectare, *Pittosporum viridiflorum* (42± 3 trees/ha) and *Vepris simplicifolia* (38± 7 trees/ha). The mean percentage foliage cover of mature woody species was 35% and the overstory canopy was classified as an open canopy. Gatwikira was dominated by *Vepris simplicifolia* (230 ± 7) trees/ha and other species commonly found were *Vepris trichocarpa* (54±3 trees/ha) and *Grewia similis* (50±7 trees/ha). The mean foliar cover was 66% and the overstory canopy was classified as a moderately closed canopy.

The Eucalyptus plantation comprised of *Eucalyptus grandis* at density of 534 ± 42 trees/ha and importance value of 300%. The mean foliar cover was 53% and the canopy was classified as moderately closed. The Mixed Acacia-Eucalyptus plantation forest was dominated by *Eucalyptus grandis* at density of 498 ±104 trees/ha and *Acacia mearnsii* at density of 206 ±42 trees/ha. The plantation was also comprised of a few individuals of *Eucalyptus globulus* with density of 4 trees/ha, with an importance value of 2.42%. The mean foliar cover was 55% and the canopy was classified as a moderately closed canopy.

The Pine plantation comprised of *Pinus patula* at density of 154 ± 10 trees/ha and importance value of 300 %. The mean foliar cover was 60% and the canopy was classified as moderately closed. The Cypress plantation comprised of *Cupressus lusitanica* at density of 400± 48

trees/ha and importance value of 300%. The mean foliar cover was 86% and the canopy of the plantation was classified as a closed canopy.

Table 1: Mean density and percentage foliar cover for the different forest types (standard error in parentheses)

	Mean Density	**Mean Percentage foliar cover**
Gachuthi	15 (2.85)	34.76 (3.68)
Gatwikira	29 (6.71)	66.12 (5.02)
Eucalyptus plantation	534 (42.00)	53.46 (2.95)
Mixed Acacia-Eucalyptus plantation	283 (104.15)	55.00 (3.02)
Pine plantation	154 (10.00)	59.60 (3.61)
Cypress plantation	400 (48.00)	85.98 (2.75)

The Eucalyptus plantation had the highest mean density of mature trees while Gachuthi forest had the lowest whereas the mean percentage foliar cover was highest in the Cypress plantation and lowest in Gachuthi (Table 1).

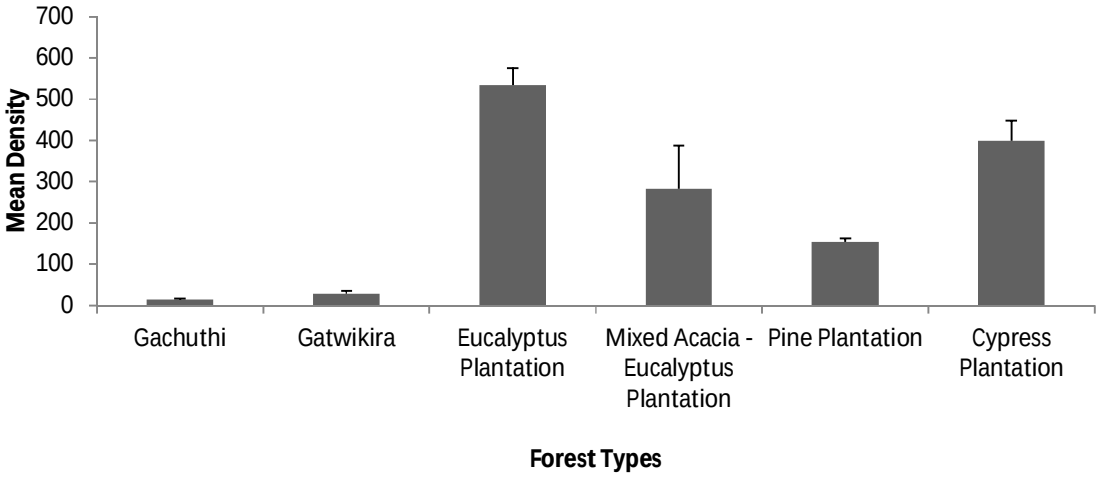

Figure 4: Mean Density (± SE) of mature woody species in the different forest types in Muguga forest

There was a significant difference in the mean density of mature woody species among the different forest types ($F_{5,\ 96}$ = 56.43, p<0.05). Gachuthi indigenous forest differed significantly from the Eucalyptus, mixed Acacia-Eucalyptus, Pine and Cypress plantations while Gatwikira indigenous forest differed significantly from the Eucalyptus, mixed Acacia-Eucalyptus and Cypress plantations. The Eucalyptus plantation differed significantly from the

mixed Acacia-Eucalyptus and Pine plantation whereas the Pine plantation differed significantly from the Cypress plantation (Table 2).

Table 2: Results of one-way ANOVA showing significant differences in mean densities of mature trees for the different forest types

	***F* test**					
	Gachuthi	Gatwikira	Eucalyptus plantation	Mixed Acacia-Eucalyptus plantation	Pine plantation	Cypress plantation
Gachuthi		ns	***	***	*	***
Gatwikira			***	***	ns	***
Eucalyptus plantation				***	***	ns
Mixed Acacia-Eucalyptus plantation					ns	ns
Pine plantation						**
Cypress plantation						

ns= not significant; ***p*<0.05; **** *p* <0.01; ***** *p* <0.001

The mean percentage foliar cover differed significantly among the different forest types ($F_{5, 96}$ = 56.43, p<0.05). The Cypress plantation differed significantly from all the other forest types whereas Gachuthi differed significantly from Gatwikira, Eucalyptus, mixed Acacia-Eucalyptus and Cypress forests (Table 3).

Table 3: Results of one-way ANOVA showing significant differences in mean percentage foliar cover of mature trees for the different forest types

	***F* test**					
	Gachuthi	Gatwikira	Eucalyptus plantation	Mixed Acacia-Eucalyptus plantation	Pine plantation	Cypress plantation
Gachuthi		***	**	***	***	***
Gatwikira			ns	ns	ns	**
Eucalyptus plantation				ns	ns	**
Mixed Acacia-Eucalyptus plantation					ns	***
Pine plantation						***
Cypress plantation						

ns= not significant; ***p*<0.05; **** *p* <0.01; ***** *p* <0.001

The vertical stratification of the different forests studied showed that the indigenous forests had several canopy strata comprising of lower, middle and upper canopy while the plantation

forests tended to have the mature trees mainly represented in a single stratum (Figure 5). In the indigenous forests the lower canopy had the highest density of mature trees with Gachuthi at a density of 142 trees/ha and Gatwikira at 540 trees/ha where the different strata were dominated by different species. In Gachuthi, the lower canopy was dominated by *Pittosporum viridiflorum* at 24 trees/ha and *Euclea divinorum* at 22 trees/ha; the middle canopy was dominated by *Euclea divinorum* at 20 trees/ha and *Vepris simplicifolia* at 10 trees/ha, while the upper canopy was dominated by *Pittosporum viridiflorum* at 10 trees/ha followed by *Euclea divinorum* and *Vepris simplicifolia* both at 8 trees/ha. In Gatwikira the lower canopy was dominated by *Vepris simplicifolia* at 198 trees/ha followed by *Grewia similis* at 50 trees/ha; the middle canopy was dominated by *Vepris simplicifolia* at 26 trees/ha and *Zanthoxylum usambarense* at 14 trees/ha, while the upper canopy was dominated by *Olea europaea africana* at 40 trees/ha followed by *Warbugia ugandensis* at 18 trees/ha.

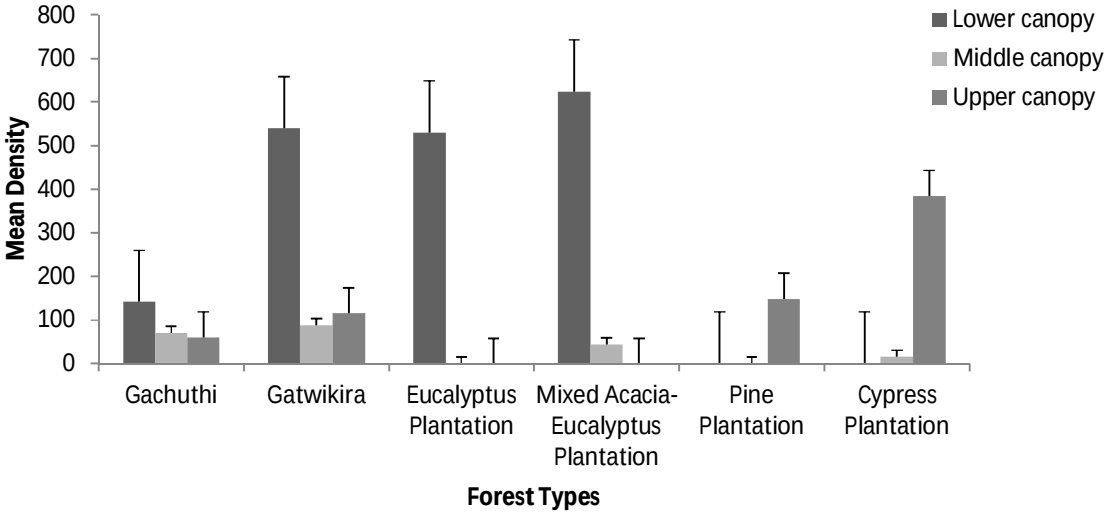

Figure 5: Vertical distribution of mature trees in the different forest types showing mean density (± SE) of trees in each canopy layer

The plantations had little vertical stratification with the mature trees predominantly forming a single canopy layer with few scattered individuals in the other strata. The mature trees in the Eucalyptus plantation and the Pine plantation formed a single canopy layer. In the Eucalyptus plantation, *Eucalyptus grandis* formed a single lower canopy at a density of 530 trees/ha

while the Pine plantation formed a single upper canopy of *Pinus patula* at a density of 148 trees/ha. The mature trees in the Mixed Acacia-Eucalyptus plantation and the Cypress plantation formed two canopy layers; however one canopy layer dominated over the other. In the Mixed Acacia-Eucalyptus plantation, the highest density of mature trees was found in the lower canopy which was dominated by *Eucalyptus grandis* at 430 trees/ha and *Acacia mearnsii* at 194 trees/ha while the middle canopy comprised of *Eucalyptus grandis* at 32 trees/ha and *Acacia mearnsii* at 12 trees/ha. In the Cypress plantation, the high density of mature trees was found in the upper canopy *Cupressus lusitanica* at 384 trees/ha with some trees present in the middle canopy at a density of 16 trees/ha (Figure 5). Species diversity of the mature trees ranged from 0 to 2.80 in the different forest types (Table 4).

Table 4: Diversity indices for mature trees in the different forest types in Muguga forest

Forest Type	**No. of Species**	**Abundance**	**Shannon index H'**
Gachuthi	28	137	2.738
Gatwikira	36	389	2.803
Eucalyptus plantation	1	267	0
Mixed Acacia-Eucalyptus plantation	3	354	0.636
Pine plantation	1	77	0
Cypress plantation	1	200	0

3.1.2 Immature Woody Species

The immature woody species in the indigenous forest Gachuthi were comprised primarily of *Vepris simplicifolia* at 303±3 stems/ha followed by *Euclea divinorum* at 295±2 stems/ha and *Clausena anisata* at 217±3 stems/ha. In Gatwikira, the immature woody species present were dominated by *V. simplicifolia* at 459±5 stems/ha followed by *C. anisata* at 292±3 stems/ha. The Eucalyptus plantation comprised mainly of *Eucalyptus grandis* at a density of 122±4 stems/ha followed by *E. divinorum* at 86±3 stems/ha and *Triumfetta tomentosa* at 50±2stems/ha. The mixed Acacia-Eucalyptus plantation comprised of *Cestrum aurantiacum* at 220±16 stems/ha and *Solanum incanum* at 95±2 stems/ha. The immature woody species in

the Pine plantation comprised mainly of *T. tomentosa* at 445±8 stems/ha followed by *Hibiscus fuscus* at 358±8 stems/ha and *Vernonia lasiopus* at 291±7 stems/ha. The immature woody species in the Cypress plantation comprised mainly of *T. tomentosa* at 250±5 stems/ha followed by *Erythrococca bongensis* at 78±7 stems/ha and *Abutilon mauritianum* at 77±5 stems/ha.

The mean density of immature woody species was higher in the plantation forests in comparison to the indigenous forest (Figure 6). The Pine plantation had the highest mean density of immature woody species at 141±24 stems/ha. The lowest mean density of immature trees was noted in the Eucalyptus plantation at 61±9 stems/ha (Figure 6).

Results of ANOVA analysis showed there was a significant differences in mean density of immature trees among the different forest types studied ($F_{5, 298} = 2.45$, $p<0.05$). Tukey's post hoc analysis showed that the mean density of Gachuthi ($M = 76.21$, $SD = 118.65$) differed significantly from the mean density of the Pine plantation ($M = 141.98$, $SD = 160.66$).

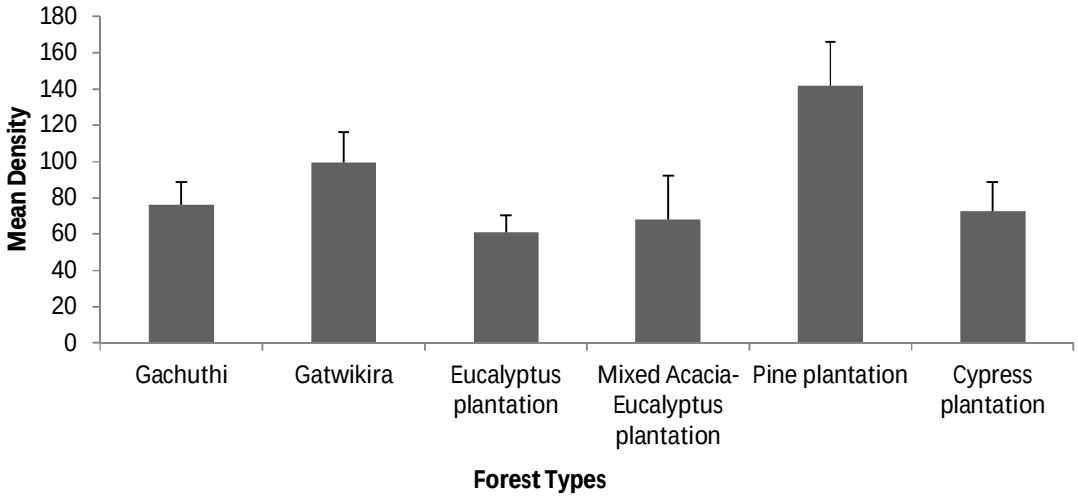

Figure 6: Mean Density (± SE) of immature woody species in the different forest types

Species diversity indices of immature woody species in the different forest types ranged from 1.98-2.79. Comparison of Shannon's diversity indices among the different forest types found that diversity in the indigenous forests differed significantly from the plantation forests (Table 5).

Table 5: Results of *t*-tests comparing species diversity of immature woody species in the different forest types (two-tailed *t*-test, *p*=0.05)

	***t* test**					
	Gachuthi	Gatwikira	Eucalyptus plantation	Mixed Acacia-Eucalyptus plantation	Pine plantation	Cypress plantation
Gachuthi		2.74**	8.92***	8.79***	12.92***	9.53***
Gatwikira			6.547***	6.67***	9.43***	7.26***
Eucalyptus plantation				ns	ns	ns
Mixed Acacia-Eucalyptus plantation					ns	ns
Pine plantation						ns
Cypress plantation						

ns= not significant; ***p*<0.05; **** p* <0.01; ***** p* <0.001

The indigenous forests Gachuthi and Gatwikira had the highest similarity of immature woody species at 0.62; the Cypress plantation was the most similar to the indigenous forests at 0.37 while the Pine plantation was least similar to the indigenous forests at 0.29.

3.1.3 Saplings

In the indigenous forest Gachuthi, the saplings mainly comprised of *Euclea divinorum* at a density of 850±7 saplings/ha followed by *Vepris simplicifolia* at 552±7 saplings/ha and *Clausena anisata* at 383±3 saplings/ha. In Gatwikira forest, the saplings comprised mainly of *C. anisata* at 453±11 saplings/ha followed by *Pterolobium stellatum* at 436±8 saplings/ha and *Elaeodendron buchananii* at 153±11 saplings/ha. The saplings present in the Eucalyptus plantation comprised mainly of *Euclea divinorum* at 245±6 saplings/ha, *Maerua triphylla* at 217±9 saplings/ha and *Eucalyptus grandis* at 89±5 saplings/ha. The mixed Acacia-Eucalyptus plantation comprised of *Erythrococca bongensis* at 608±7 saplings/ha followed by *Grewia similis* at 73±7 saplings/ha and *Zanthoxylum usambarense* at 61±3 saplings/ha. The Pine plantation comprised of *Hibiscus fuscus* species at 50±2 saplings/ha followed by *Rubus pinnatus* at 50±3 saplings/ha and *C. anisata* at 36±1 saplings/ha. The Cypress plantation was comprised mainly of *Erythrococca bongensis* species at 239±7 saplings/ha

followed by *Triumfetta tomentosa* at 94±6 saplings/ha. Figure 7 shows that the indigenous forest had the highest mean density of saplings with Gatwikira at 127±30 saplings/ha and Gachuthi at 119±25 saplings/ha. The lowest mean density of saplings was recorded in the Pine plantation at 39±6 saplings/ha. There were no significant differences in mean densities between the indigenous and plantation forests ($F_{5, 275} = 1.03$, $p>0.05$).

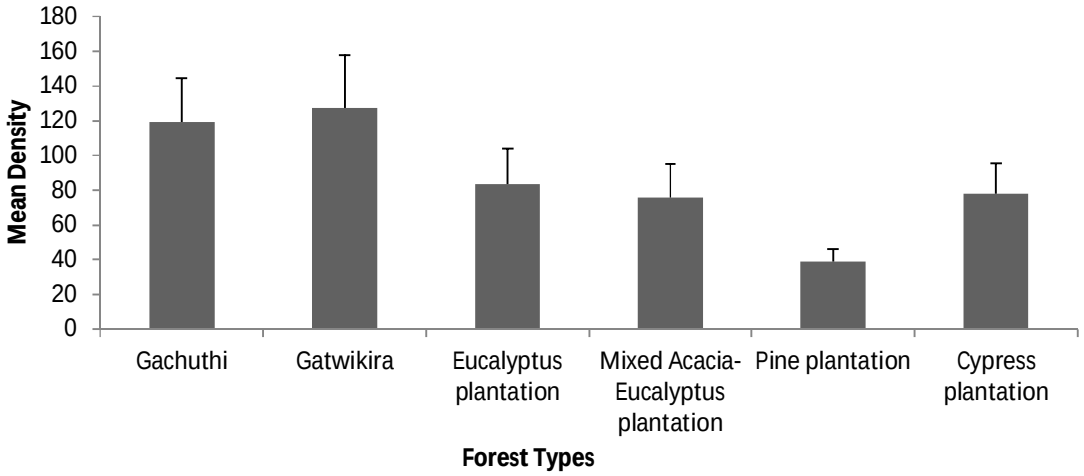

Figure 7: Mean Density (± SE) of saplings in the different forest types

Species diversity of saplings in the different forest types ranged from 1.84-2.35 and species diversity differed significantly among the different forest types (Table 6).

Table 6: Results of *t*-tests comparing species diversity of saplings in the different forest types (two-tailed *t*-test, p=0.05)

	***t* test**					
	Gachuthi	Gatwikira	Eucalyptus plantation	Mixed Acacia-Eucalyptus plantation	Pine plantation	Cypress plantation
Gachuthi		3.92***	6.22***	4.28***	3.48***	3.26***
Gatwikira			2.84**	ns	ns	ns
Eucalyptus plantation				ns	ns	-2.62**
Mixed Acacia-Eucalyptus plantation					ns	ns
Pine plantation						ns
Cypress plantation						

ns= not significant; ***p*<0.05; **** p <0.01; ***** p <0.001

Sørenson's similarity index shows that the mixed Acacia-Eucalyptus plantation was the most similar to the indigenous forests at 0.55 while the Pine plantation was the least similar to the indigenous forests at 0.19.

3.1.4 Seedlings

In the indigenous forest Gachuthi, the seedlings mainly comprised of *Euclea divinorum* at density of 12,806±25 seedlings/ha followed by *Vepris simplicifolia* at 5,972±10 seedlings/ha and *Clausena anisata* at 4,222±10 seedlings/ha. In Gatwikira forest, the seedlings comprised mainly of *Pterolobium stellatum* at 8,361±48 seedlings/ha followed by *C. anisata* at 5,888±35 seedlings/ha and *Erythrococca bongensis* at 833± seedlings/ha.

The seedlings present in the Eucalyptus plantation comprised mainly of *Euclea divinorum* at 2,027±13 seedlings/ha followed by *Maerua triphylla* at 1,805±17 seedlings/ha. The mixed Acacia-Eucalyptus plantation comprised of *Erythrococca bongensis* at 4,527±14 seedlings/ha followed by *Clausena anisata* at 1,555±12 seedlings/ha and *Cestrum aurantiacum* at 861±14 seedlings/ha. The Pine plantation mainly comprised of *C. anisata* species at 777±94 seedlings/ha and *Abutilon mauritianum* at 333±5 seedlings/ha. The Cypress plantation was comprised mainly of *E. bongensis* at 1,445±11 seedlings/ha followed by *Vernonia lasiopus* at 667±30 seedlings/ha and *Clausena anisata* at 667±11 seedlings/ha.

The mean density of seedlings was higher in the indigenous forests as compared to the plantation forests with Gachuthi at 387±98 seedlings/ha and Gatwikira 413±32 seedlings/ha. The Pine plantation had the lowest densities at 106±42 seedlings/ha (Figure 8). Results of ANOVA analysis determined that densities of seedlings did not vary significantly among the different forest types ($F_{5, 237} = 1.42$, $p>0.05$).

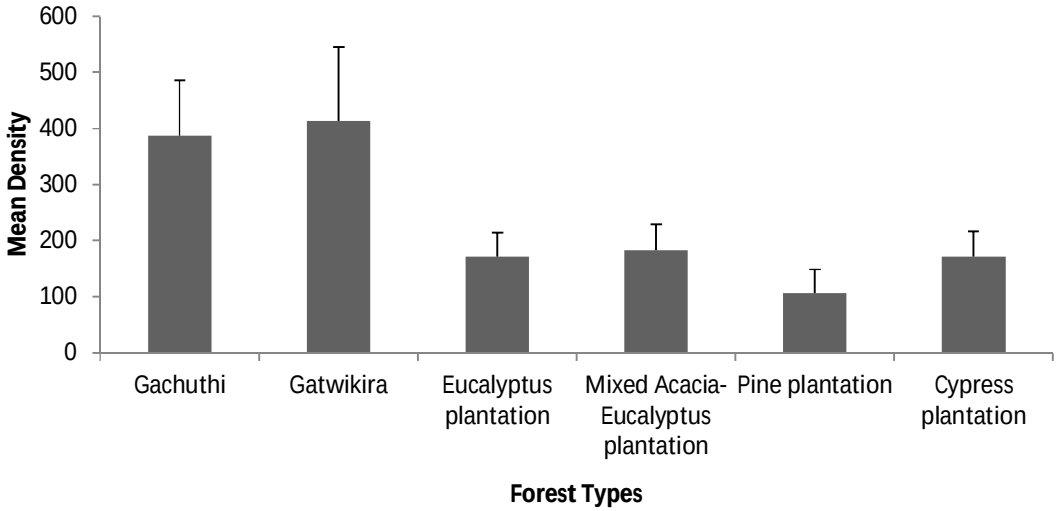

Figure 8: Mean Density (± SE) of seedlings in the different forest types

Species diversity of seedlings in the different forest types ranged from 1.34-2.10. Comparison of species diversity indices showed that the indigenous forest forests differed significantly from the plantation forests (Table 7).

Table 7: Results of *t*-tests comparing species diversity of seedlings in the different forest types (two-tailed *t*-test, p=0.05)

	***t*-test**					
	Gachuthi	Gatwikira	Eucalyptus plantation	Mixed Acacia-Eucalyptus plantation	Pine plantation	Cypress plantation
Gachuthi		8.74**	3.13**	2.23*	4.60***	3.18**
Gatwikira			-2.99**	-4.33***	ns	-2.26**
Eucalyptus plantation				ns	2.74**	ns
Mixed Acacia-Eucalyptus plantation					3.32**	ns
Pine plantation						-2.42*
Cypress plantation						

ns= not significant; ***p*<0.05; **** p <0.01; ***** p <0.001

The Eucalyptus plantation and mixed Acacia-Eucalyptus plantations were the most similar to the indigenous forests at 0.53 respectively, while the Pine plantation had the least similarity to the indigenous forests at 0.16.

Foliar cover and abundance of immature trees showed a significant positive correlation (r = 0.362) in Gachuthi ($t_{0.05\ (2),\ 34}$ = 2.26, p<0.05) and a significant negative correlation (r = -0.414) in the mixed Acacia-Eucalyptus plantation ($t_{0.05\ (2),\ 34}$ = 2.65, p<0.05). The sapling and seedling abundance had no significant correlation to foliar cover (p>0.05) in the different forest types (Table 8).

Table 8: Pearson's correlations (r) between abundance of woody regenerates and percentage foliar cover in the different forest types (two-tailed test, p=0.05)

	Percentage foliar cover	
	r	*P*
	Gachuthi forest	
Immature	0.36	*
Sapling	0.28	ns
Seedling	0.03	ns
	Gatwikira forest	
Immature	-0.23	ns
Sapling	0.29	ns
Seedling	0.19	ns
	Eucalyptus plantation	
Immature	-0.06	ns
Sapling	0.18	ns
Seedling	-0.13	ns
	Mixed Acacia-Eucalyptus plantation	
Immature	-0.41	*
Sapling	0.09	ns
Seedling	-0.01	ns
	Pine plantation	
Immature	0.02	ns
Sapling	-0.02	ns
Seedling	-0.07	ns
	Cypress plantation	
Immature	0.19	ns
Sapling	0.10	ns
Seedling	0.07	ns

ns= not significant; ***p*<0.05; **** p* <0.01; ***** p* <0.001

3.2 Soil Nutrient Content and Fertility

3.2.1 Soil pH, Textural Composition and Soil Nutrient Content

The soils in the different forest types were classified as Clay soils (Table 9) with clay content accounting for the highest mean percentage of the soil structure at a range of 50-62%, followed by the silt content at 22-31% with the sand content accounting for the lowest mean percentage at 16-23% (Figure 9).

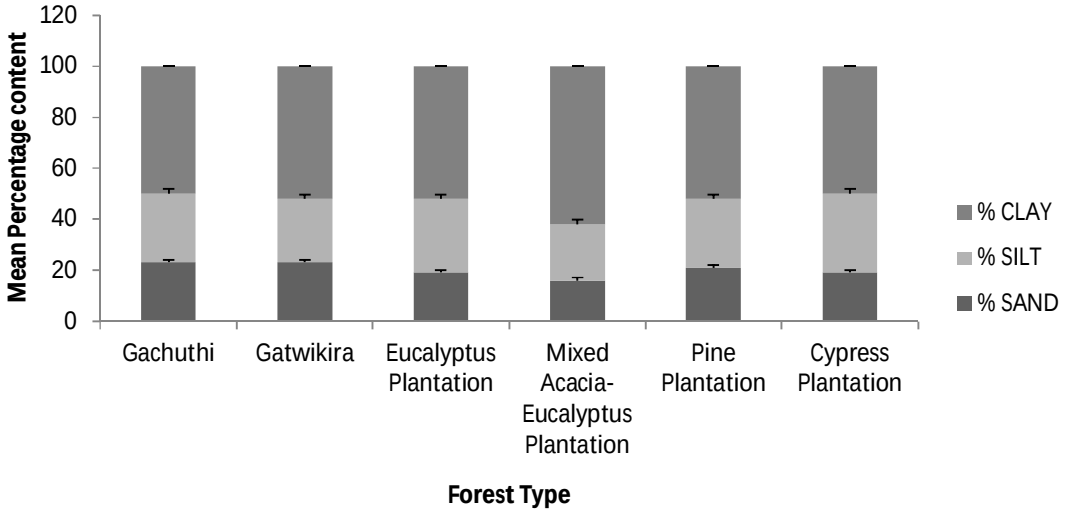

Figure 9: Soil texture composition of the different forest types expressed as mean percentage (± SE) content of Sand, Silt and Clay

The soil pH of the different forests studied ranged from 5.55 - 6.25 and the soils were classified as moderately to slightly acidic. The soils in the Eucalyptus plantation had the highest pH at 6.25 followed by the indigenous forest Gachuthi, while the lowest pH was recorded in the Cypress plantation at 5.55 (Table 9). Results of Kruskal-Wallis determined that soil pH did not vary significantly between the indigenous and plantation forests ($X^2_{0.05,\ 5}$ = 6.00, p>0.05).

Table 9: Soil pH, mineral composition and texture in the different forest types

Habitat	pH	Soil Texture Class	% Total Nitrogen	%Organic Carbon	Phosphorous (ppm)	Potassium (m.e. %)	Calcium (m.e %)	Magnesium (m.e. %)
Gachuthi	6.02	Clay	0.45	4.04	18.00	1.96	16.50	7.59
Gatwikira	5.81	Clay	0.49	4.235	8.50	1.47	14.00	6.42
Eucalyptus Plantation	6.25	Clay	0.28	2.77	25.50	0.60	6.2	4.69
Mixed Acacia-Eucalyptus Plantation	5.66	Clay	0.28	2.845	9.50	1.35	8.40	4.90
Pine Plantation	5.66	Clay	0.33	3.04	13.50	0.95	8.60	2.99
Cypress Plantation	5.55	Clay	0.30	3.165	9.50	1.06	11.35	3.69

The percentage total nitrogen in the soils of the forests studied ranged from 0.28 - 0.49%. The indigenous forests had higher levels of total Nitrogen as compared to the Plantation forests with Gatwikira at 0.49% and lowest in the mixed Acacia-Eucalyptus plantation at 0.28% (Table 9). Nitrogen levels in the soils studied did not vary significantly among the different forest types ($X^2_{0.05, 5} = 7.661$, $p>0.05$).

The levels of percentage organic carbon ranged from 2.77 - 4.23% and were found to be higher in the indigenous forests as compared to the plantation forests. Gatwikira had the highest levels of organic carbon at 4.235% while the lowest was Eucalyptus plantation at 2.77% (Table 9). Organic carbon did not vary significantly among the different forest types ($X^2_{0.05, 5} = 6.54$, $p>0.05$).

The different forests exhibited low Phosphorous levels ranging from 8.50 – 25.50 ppm (parts per million). The Eucalyptus plantation had the highest phosphorous levels at 25.5ppm followed by Gachuthi forest at 18.00 ppm while the lowest phosphorous levels were recorded in Gatwikira at 8.50 ppm (Table 9). However, the phosphorous levels did not vary significantly between the indigenous and plantation forests ($X^2_{0.05, 5} = 9.58$, $p>0.05$)

The exchangeable cations tested for in the soils were Potassium, Calcium and Magnesium. The Potassium levels in the soils ranged from 0.60 – 1.96 m.e.% with Gachuthi and Gatwikira forests exhibiting the highest levels at 1.96 and 1.47 respectively while the lowest potassium levels were found in soils of the Eucalyptus plantation at 0.60 (Table 9). There was no significant difference in potassium levels between the indigenous and plantation forests ($X^2_{0.05,\ 5}$ = 7.04, p>0.05). The Calcium levels in the different forests ranged from 6.20 - 16.5m.e.% and the highest Calcium levels were recorded in Gachuthi and Gatwikira forest at 16.50 and 14.00 respectively while the lowest levels were recorded in soils of the Eucalyptus plantation at 6.20 (Table 9). The calcium levels did not vary significantly among the different forest types ($X^2_{0.05,\ 5}$ = 8.09, p>0.05).

The soils in the different forest types had high levels of Magnesium ranging from 2.99 - 7.59 m.e. %. The indigenous forests Gachuthi and Gatwikira exhibited the highest magnesium levels at 7.59 and 6.42 respectively while the lowest levels of magnesium were recorded in the Pine plantation at 2.99 (Table 9). However, the levels of magnesium in the soils did not vary significantly among the different forest types ($X^2_{0.05,\ 5}$ = 9.77, p>0.05).

Results of Pearson's correlation analysis showed significant correlations between abundance of woody regenerates and soil pH, nitrates and organic carbon (Table 10). The abundance of immature trees and soil nitrates showed significant negative correlation (r= -0.38) in Gachuthi ($t_{0.05\ (2),\ 34}$ = 2.39, p<0.05). The soil pH and sapling abundance showed significant negative correlation (r= -0.64) in Gachuthi ($t_{0.05\ (2),\ 34}$ = 4.86, p<0.05) and positive correlation (r= 0.39) in the Pine plantation ($t_{0.05\ (2),\ 34}$ = 2.47, p<0.05). Soil nitrates and sapling abundance showed significant negative correlation (r= -0.68) in Gachuthi ($t_{0.05\ (2),\ 34}$ = 5.41, p<0.05) and positive correlation (r= 0.39) in the Pine plantation ($t_{0.05\ (2),\ 34}$ = 2.47, p<0.05). Soil organic carbon and sapling abundance showed significant negative correlation (r= -0.63) in Gachuthi ($t_{0.05\ (2),\ 34}$ = 4.73, p<0.05) and positive correlation (r= 0.41) in the Pine plantation ($t_{0.05\ (2),\ 34}$ =

2.62, $p<0.05$). The soil pH and seedling abundance showed significant negative correlation ($r= -0.35$) in the Cypress plantation ($t_{0.05\ (2),\ 34} = 2.18$, $p<0.05$).

Table 10: Pearson's correlations (*r*) between abundance of woody regenerates, soil pH, nitrates and organic carbon in the different forest types (two-tailed *t*-test, $p=0.05$)

	Soil pH		**Soil Nitrates**		**Organic Carbon**	
	r	*P*	*r*	*P*	*r*	*P*
			Gachuthi forest			
Immature	-0.23	ns	-0.38	*	-0.21	ns
Sapling	-0.64	**	-0.68	**	-0.63	**
Seedling	0.16	ns	-0.2	ns	0.18	ns
			Gatwikira forest			
Immature	-0.05	ns	0.13	ns	0.12	ns
Sapling	0.03	ns	-0.06	ns	-0.04	ns
Seedling	0.24	ns	0.14	ns	0.16	ns
			Eucalyptus plantation			
Immature	0.03	ns	-0.02	ns	0.00	ns
Sapling	-0.07	ns	0.07	ns	0.135	ns
Seedling	0.24	ns	-0.23	ns	-0.26	ns
			Mixed Acacia-Eucalyptus plantation			
Immature	0.19	ns	0.14	ns	0.15	ns
Sapling	0.13	ns	0.09	ns	0.13	ns
Seedling	0.19	ns	0.18	ns	0.15	ns
			Pine plantation			
Immature	-0.21	ns	-0.18	ns	-0.19	ns
Sapling	0.39	*	0.39	*	0.41	*
Seedling	0.31	ns	0.34	ns	0.32	ns
			Cypress plantation			
Immature	-0.134	ns	-0.09	ns	-0.10	ns
Sapling	-0.09	ns	0.04	ns	0.05	ns
Seedling	0.35	*	0.29	ns	0.32	ns

ns= not significant; ***p*<0.05; **** p* <0.01; ***** p* <0.001

3.2.2 Soil Seed Bank and Seedling Emergence

The mean abundance of seeds in the soils of the different habitats ranged from 83 to 2099 seeds per kilogram. The Mixed Acacia-Eucalyptus plantation had the highest mean

abundance of seeds at 2,099±106 (SE) seeds/kg while the Pine plantation had the lowest mean abundance at 150±12 (SE) seeds/kg (Figure 10).

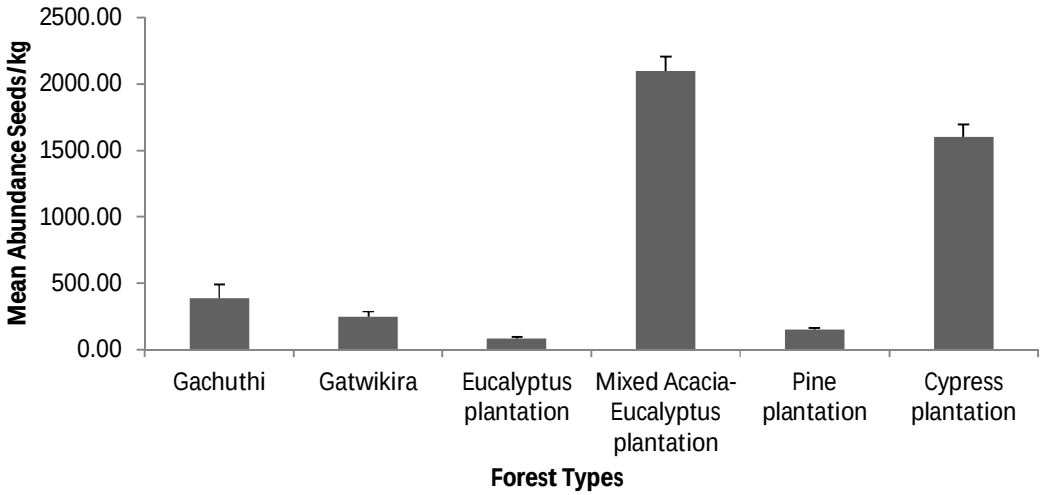

Figure 10: Mean Seed Abundance (±SE) in the soils of the different forest types

Emergent seedling abundance in the soil samples of the different forest types studied ranged from 1-23 seedlings with the Cypress plantation recording the highest number of emergent seedlings at 17 followed by the Mixed Acacia-Eucalyptus plantation at 11. Indigenous forests recorded the lowest emergent seedling numbers at 3 and 7 for Gatwikira and Gachuthi respectively (Figure 11).

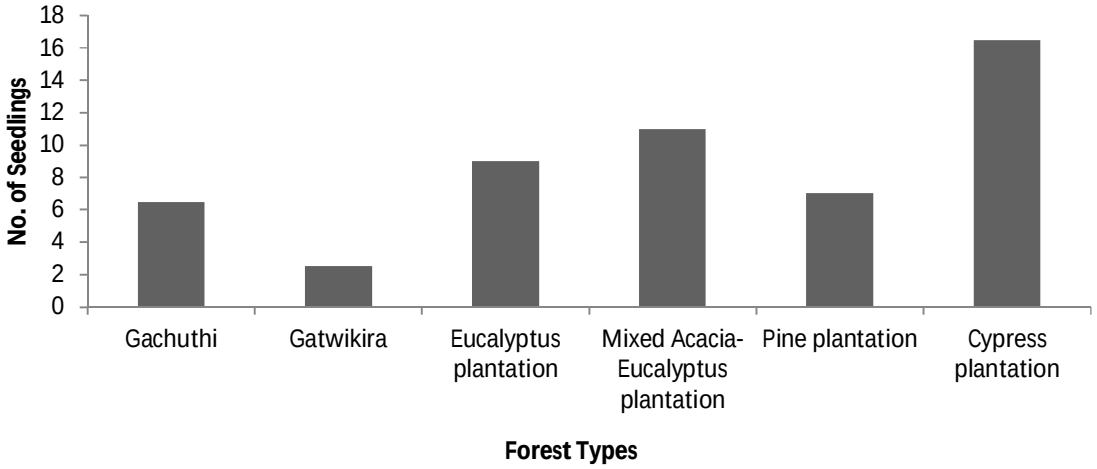

Figure 11: Emergent seedling abundance in the soils of the different forest types

Further observation of the emergent seedlings showed that the soil seed banks were dominated by herbaceous plants and shrubs with few indigenous woody species. Of the 13 species of emergent seedlings identified, only 3 were woody species and the remaining 10 were of herbaceous species. The herbaceous species included *Eragrostris superba* that comprised 18% of the emergent seedlings, *Galinsoga parviflora* (6%), *Commelina benghalensis* (5%), *Chenopodium* sp. (5%), *Oxalis* sp. (5%) and *Lippia javanica* (5%). The woody species found were *Leucas grandis* which comprised 14% of the emergent seedlings, *Abutilon mauritianum* at 5% and *Solanum incanum* at 1%. In the indigenous forest blocks, the highest abundance in Gachuthi was of *Abutilon mauritianum* and *Oxalis* sp. at 4 and 3 seedlings respectively while in Gatwikira, *Chenopodium* sp. had the highest abundance at 3 seedlings. The plantation forests had high abundance of non-indigenous herbaceous species where the Eucalyptus stand had *Leucas grandis* with 7 seedlings, the Mixed Acacia-Eucalyptus plantation *Eragrostis superba* with 12 seedlings, the Pine plantation by *C. benghalensis* with 5 seedlings and the Cypress plantation by *Leucas grandis* and *L. javanica* with 7 seedlings each.

CHAPTER FOUR: DISCUSSION, CONCLUSION AND RECOMMENDATIONS

Discussion

An important aspect of forest conservation is the establishment of plantation forests to increase forest cover and to facilitate the regeneration of indigenous woody species. The purpose of this study was to determine the ability of different types of exotic tree plantations to facilitate indigenous woody species regeneration. The focus of the study was on the regeneration of indigenous woody species in different plantation forests and this differs from other studies that focus on herbaceous vegetation regeneration in plantation forests such as studies carried out in the Ethiopian Highlands (Michelsen *et al.*, 1996). The habitats studied in Muguga forest station included both indigenous and plantation forests located within the same forest station and were under the influence of similar climatic conditions to limit variability that could possibly influence regeneration.

The results of this study show that there were significant differences in species composition between the indigenous and plantation forests with the indigenous forests exhibiting significantly higher species diversity. In this study, the Gachuthi indigenous forest had significantly low percentage foliar cover and higher soil nitrates content as compared to the plantation forests. The significantly lower foliar cover and higher soil nitrates seemed to favour the survival of seedlings to the immature age class. The plantation forests had low similarity to the indigenous forests in terms of understory species composition. The salient findings of the study show that the regeneration of indigenous woody species within Muguga forest station differed significantly between the indigenous and plantation forests as well as among the different types of tree plantations. The different types of plantation forests varied in their ability to facilitate woody species regeneration and while regeneration in the understory of the plantations differed from that of the indigenous forest, the plantations still

allowed for the regeneration of indigenous woody species in the understory to a lesser extent. This implies that the plantations could act as initial steps in the secondary succession of the degraded sites back to natural forests by allowing the indigenous forest species to colonise the site (Kuusipalo *et al.*, 1995).

The composition of mature tree species of the different plantations also influenced understory regeneration. The mixed Acacia-Eucalyptus plantation was most similar in understory woody species composition to the indigenous forest and had the highest density of understory regenerates as compared to the pure plantation stands. In studies conducted with species of pure and mixed plantations in Costa Rica, tree regeneration was found to be more successful under the forest plantations that in abandoned pastures (Montagnini *et al.*, 1999). Other studies conducted by Carnevale and Montagnini (2002) in mixed and pure plantations in Costa Rica found that tree regeneration was more diverse under the mixed plantations in comparison to pure plantation stands.

A total of 60 woody species were found in the understory of the indigenous and plantation forests of which 8 were non-indigenous woody species that were predominantly found in the plantation forests. The composition of understory woody species in the indigenous forests was comprised mainly of dominant canopy species while in the plantation forests representation of indigenous canopy species was poor.

In the study, the composition of understory woody species among the immature trees, saplings and seedlings in the plantation forests was dominated by species that are known to be shrub or small trees in their life forms while in the indigenous forests, the understory comprised predominantly of upper canopy tree species. The understory composition of the indigenous forests Gachuthi and Gatwikira was, in general, dominated by *Vepris simplicifolia*, an upper and middle canopy species, while in the plantation forests, the understory composition was predominantly of shrub life forms and other lower canopy

species. These observations correlate with studies carried out on plantation forests that found that the predominant woody species in the understory were shrubs or small trees and few upper canopy trees were represented (Senbeta and Teketay, 2001).

In the plantation forests, a large number of the woody species found among the understory regenerates were woody species that were not native to the indigenous forests. This could mean that despite regeneration occurring within the understories of the plantation forests, the probability of the establishment of a secondary forest comprising of indigenous woody species would be limited. These results concur with those found in studies carried out in the Ethiopian highlands by that showed that despite the fact that the number of species within the plantation forests did not differ significantly from those of the indigenous forest, most of the species found within the plantations were weed species not native to the indigenous forest (Michelsen *et al.*, 1996).

The mean densities of regenerates were higher in the indigenous forests as compared to the plantation forests. Studies carried out in other regions have also found that density of woody species was higher in natural forests as compared to plantations (Senbeta and Teketay, 2001). The densities of regenerates differed significantly amongst the different age classes in the different forest types, with the highest proportion of regenerates in the seedling population. The density of seedlings represented the highest proportion of regenerates accounting for 85% while the densities of the immature trees and saplings each accounted for 7% of the understory woody species. The woody species showed a preference for the development of a persistent seedling bank as the source of regenerates, with a large number of seedlings to increase survival. Studies carried out by in the Afromontane forests of Ethiopia, found that woody species do not accumulate seeds in the soil but instead have persistent seedling bank (Teketay and Granstrom, 1995). This could be because the woody species tend to produce

recalcitrant seeds that germinate quickly and do not persist in the soil as well as being a means of avoiding predation.

Similarity in species composition of the plantations to the indigenous forests could determine if in future, the plantations would eventually undergo secondary succession to be replaced by indigenous woody species that closely resemble the floristic composition of the indigenous forest. The results of the study showed that the Pine plantation exhibited the least similarity in species composition to the indigenous forest block across all age-classes i.e. immature, saplings and seedlings at an average similarity of 0.21 while the Mixed Acacia-Eucalyptus plantation was the most similar to the indigenous forests at 0.46. The similarity indices determine if the composition of a future secondary forest that replaces the plantation forest will be similar to the indigenous forest.

While the plantations had high densities of mature tree species, they conversely had low species diversity as compared to the indigenous forests. The species diversity in the overstory had an influence on the species diversity of the understory regenerates with the indigenous forests exhibiting higher species diversity among the understory woody species as compared to the plantation forests. Among the plantation forests, the Pine and Cypress plantations exhibited the lowest species diversity as compared to the Eucalyptus plantation and the Mixed Acacia-Eucalyptus plantation. This can possibly be attributed to the lack of viable seed sources from the canopy species as well as limited seed dispersal into these plantation forests. However, other studies carried out by in the Pine (*Pinus caribaea* and *P. patula*) and Cypress (*Cupressus lusitanica*) plantations in Kibale, Uganda found that the Pine and Cypress plantations can have high species diversity and richness of indigenous trees which was attributed to the presence of frugivores that transported seeds into the plantations contributing to the high species richness (Chapman and Chapman, 1996).

The reforestation of degraded tropical forest ecosystems can be difficult as most of the sites have been depleted of soil nutrients through intensive agricultural practices, soil compaction and competition with grasses and other light-demanding species (Parrotta, 1993). The establishment of fast growing exotic tree plantations has been found to provide some assistance in the regeneration of the indigenous forest (Parrotta, 1992). The results of studies conducted by Hofstede *et al.* (2002) support suggestions that some exotic tree plantations established on degraded sites can be used for soil improvement and to facilitate secondary forest succession to a limited degree.

The different species of exotic tree plantations showed variability in the densities of understory woody species and this could be due to various factors with different tree species influencing the understory in different ways and thus affecting woody species regeneration. The Pine and Cypress plantations were observed to have higher litter content, as compared to the other plantations, which formed a dense litter layer and decomposed slowly. These findings relate to those of other studies carried out that also found that Pine plantations had thicker litter layers than other plantations (Hofstede *et al.*, 2002). The thick layer of leaf litter can inhibit seedling establishment by burying seeds such that light penetration is hindered. Seeds require certain levels of light penetration into the soil to break dormancy and the thick layers of litter could possibly prevent that. This relates to other studies that found there was a significant negative correlation between understory species richness and litter depth and that litter depth and seedling densities were negatively correlated (Parrotta, 1995). The higher leaf litter density correlated to lower seedling densities resulting in the inhibition of woody species regeneration. Over time, depth of leaf litter increases especially if decomposition is slow further inhibiting seedling establishment (Senbeta and Teketay, 2001) such that over time there was an increase in litter depth in slow-decomposing litter.

The Eucalyptus plantation had low woody species density and this could be attributed to possible allellopathic effects caused by tannins produced by the plants. These allellochemicals are deposited into the soil through leaf litter and water runoff from the trees and inhibit seedling establishment and growth. Studies carried out by Espinosa-Garcia (2008) in plantations in Mexico, have shown that *Eucalyptus* species produced allellopathic chemicals that accumulated in soils and could inhibit germination and early growth (Espinosa-Garcia *et al.*, 2008). In the Eucalyptus plantation it was observed that little understory woody vegetation grew close to the trunks of Eucalyptus trees lending credence to this theory. Pine species have also been linked to possible allellopathic effects on indigenous forest species. In some studies, conifer forests were found to cause dieback of indigenous tree species in natural forests that were downslope of the plantation forests (Struhsaker *et al.*, 1989) and it was suggested that these plantations be grown at a distance from the indigenous forests. This would defeat the purpose of using the Pine plantations to facilitate indigenous forest regeneration.

Allellopathic chemicals in the plantation species could also inhibit microbial activity and prevent litter decomposition and soil nutrient. These allellopathic chemicals could also inhibit *mycorrhizal* action in the soil, preventing nitrogen fixation in the soil as well as nutrient uptake by plants. The possible allellopathic effects by Eucalyptus and Pine species could hinder the regeneration of indigenous woody species and make them unsuitable in facilitating the regeneration and secondary succession by the indigenous forests.

The overstory species in the plantations also exhibited little regeneration of their propagules in the understory and it was noted that the Pine and Cypress species had no understory regenerates while the other plantation species had low densities. These observations correlate with results of other studies that have found that the *Pinus patula* species as well as *Cupressus lusitanica* species have difficulty naturally regenerating (Albrecht, 1993; ICRAF,

1992). The natural regeneration of *Pinus patula* is not common as the seedlings do not produce deep enough root systems to enable them to survive the first dry season. The inability of these species to regenerate on their own could possibly result in loss of the plantation forest cover in future where no human interventions are applied. This would be detrimental to future secondary forest succession by indigenous woody species as forest cover is essential in suppressing growth of light-demanding species and facilitating woody species establishment.

In general the density of the mature trees had a positive correlation to foliar cover however this correlation was not significant. The plantation forests had higher foliar cover than the indigenous forests with the plantation canopy cover ranging from moderately closed to closed canopy while the indigenous forests ranged from open to moderately closed canopies. The higher foliar cover influences canopy cover and light intensity and penetration in the understory which subsequently has an influence on regeneration of indigenous woody species. The foliar cover reduces light penetration in the understory and could suppress the establishment of light demanding vegetation such as grasses and other herbaceous vegetation while facilitating the establishment of woody species (Parrotta *et al.*, 1997). Studies have shown that in plantations where light intensity was higher in one plantation as compared to another of a similar age, the plantation with higher light intensity had a greater amount of grass species (Kuusipalo *et al.*, 1995). Poor shading and vigorous competition by grass may have inhibited the germination and survival of the indigenous plant seedlings.

The Pine and Cypress plantations were observed to be further away from the indigenous forests as compared to the other plantations which were located adjacent to the indigenous forests. Similarity in understory species composition and density was lower in the Pine and Cypress plantations as compared to the Eucalyptus plantation and Mixed Acacia-Eucalyptus plantation and this could be attributed to the distance and isolation of these plantations from

the seed source. Other studies have found that isolated plantations had lower native woody species richness and stem density as compared to plantations adjacent to the natural forest (Zanne and Chapman 2001). In studies carried out by Hooper *et al.* (2005), the density of naturally regenerating trees and shrubs correlated positively with proximity to the indigenous/remnant vegetation and species richness declined significantly with increasing distance from the indigenous forest. The distance of the plantations from the indigenous forest could limit the spread of woody species from the indigenous forest to the plantations and depending on the size of seeds and their method of dispersal, the seeds of various woody species vary in the distance in which they can be propagated. Studies have found that most indigenous woody species that dispersed into plantations had seed sources within 100m although some of the bird and mammal-dispersed seed were transported over 200m (Parrotta, 1993). Therefore, establishment of plantation forests with the intention of facilitating indigenous forest regeneration should take into consideration the need for close proximity to the indigenous forest to allow for seed dispersal.

The limited regeneration under the Eucalyptus stand and the mixed Acacia-Eucalyptus stand can possibly be attributed to regular coppicing and clearing of the sites. These disturbances could prevent the establishment of indigenous woody vegetation by exposing the understory through the removal to the canopy vegetation cover. The exposed sites are then subject to extreme variations in temperature and moisture and competition with other light-demanding species, resulting in the suppression of woody species regeneration.

The plantations had simple vertical stratification with a majority of the trees studied concentrated within a single stratum unlike the indigenous forests where mature trees were distributed among the different canopy layers i.e. upper canopy, middle canopy and lower canopy. This is because the trees within the plantations had similar growth rates, thus most of the trees were concentrated within a single canopy layer as compared to the indigenous

forests where different species have different growth rates and tree heights. In the indigenous forests, the complexity of the vertical stratification of mature trees influenced regeneration of woody species with the indigenous forests exhibiting higher density of immature trees, saplings and seedling in the understory (Parrotta *et al.*, 1997). Studies have also shown that the complex vertical structure of indigenous forests means high rainfall interception reducing surface runoff and leaching (Tang *et al.*, 2007).

The Indigenous forest blocks had, on average, higher concentrations of nutrients especially of secondary macronutrients as compared to the Plantation forests. This could be construed to mean that the indigenous forests were more fertile compared to exotic tree plantations. The nutrient requirements of the exotic tree species can also be considered to have a detrimental effect on regeneration. The nutrient requirements of the fast-growing Eucalypts were generally higher than those of indigenous species and this can lead to competition for nutrients with the understory woody species resulting in lower woody densities and the inhibition of regeneration (Tang *et al.*, 2007). Demand for soil nutrients by trees usually peaks at the establishment phase. The fast-growing tree plantation species could possibly exhaust soil nutrients during the establishment phase as the trees are of the same age and growing at the same rate; this could deplete soil nutrient levels faster than the ecosystem is capable of replenishing them.

Comparison of soil attributes found that, in general, the Eucalyptus plantation had the lowest concentration of soil nutrients especially the secondary macronutrients as compared to the other plantation forests. Studies have shown that Eucalyptus plantations deplete the soil of nutrients where a decline in soil nutrient and organic matter was noted when the Eucalyptus plantations were established; this decline increased with increase in age especially in plantations less than ten years old (Bargali *et al.*, 1993). Other studies conducted in plantations in south western China by Tang *et al.* (2007) found that the soils under

Eucalyptus plantations were impoverished and showed deterioration of its chemical characteristics as compared to the secondary and climax forests in the same area.

Soil texture in all the habitats was classified as Clay soil. This means that the soils are finely textured and studies have shown that they tend to hold more water than coarser textured soils but the movement of water within these soils is slow due to the high surface tension (Brady, 1984). These soils can also be described as very fertile but difficult to work on and it is difficult for plant roots to penetrate. The clay soils have fine particles that provide a large surface area for the adsorption of nutrients and microbial activity which increases the availability of nutrients to plants. The breakdown of litter by microbial activity makes available the nutrients which supplement those lost or absorbed by the trees.

Soil pH for the habitats studied was classified as moderate to slightly acidic (pH 5.0-6.5) which in studies carried out has been found to be common in tropical regions where rainfall is substantial. The soil pH interacts with nutrient availability affecting the form of nutrients available in the soil and therefore uptake by plants. The optimal range for nutrient availability is usually pH 6.0 to 7.0 (Kanyanjua *et al.*, 2002) thus the pH found in the soils of the study site could possibly limit the uptake of nutrients by plants. Soil pH can also be affected by decomposition and microbial activity where inhibited litter decomposition results in accumulation of humic acid which in turn lowers the soil pH. Slow litter decomposition in Pine and Cypress plantations can therefore be a possible cause of the low soil pH.

The percentage organic carbon in the different habitats ranged from 2.11% to 4.38%. The soils of the plantation forests were classified as having low organic carbon content (2-4%) while the indigenous forests were classified as having medium organic carbon content (4-10%). Soils with higher organic carbon content are considered more fertile (Landon, 1991), thus the indigenous forests could be considered to be more fertile than those of the plantation forests. The organic carbon levels can also be attributed to the type of tree species that made

up the plantation. Organic carbon levels are related to organic matter and thus the amount of leaf litter deposited in the soil. It was observed that the Eucalyptus plantation and Mixed Acacia-Eucalyptus plantation had little leaf litter and this could have resulted in little organic matter in the soil.

Total percentage nitrogen ranged from 0.2% to 0.55% and the soils were classified as having moderate nitrogen content (0.2-0.5%) that is adequate for plant growth (Landon, 1991). The indigenous forests also had higher nitrogen levels as compared to the plantation forests. The Eucalyptus plantation and Mixed Acacia-Eucalyptus plantation had the lowest concentrations of organic carbon and nitrogen. This could be attributed to the high nutrient demands required by Eucalyptus as well as slow litter decomposition and slow mineralisation of Nitrogen that makes it unavailable for plant uptake.

The occurrence of more organic matter content in the indigenous forests could be attributed to a number of factors including the diversity of vegetation cover. Similarly, the availability of more total nitrogen is a result of the presence of more organic matter in the natural forest and due to rapid mineralisation of litter in the top soil of the indigenous forest. This faster mineralisation could also be due to the diversity of the litter substrate under the natural forest contributed by the various species which occur together. The litter quality is also affected by the canopy species present as the litter is a source of nutrients through the decomposition of organic matter. Studies have found that although Pine plantations produced more litter than the indigenous forests, the litter had lower nutrient concentrations as compared to the indigenous forest litter (Lugo, 1992).

The concentrations of exchangeable cations in the soils of the different forest types were found to range from medium to high, at concentrations conducive to plant growth. Potassium levels ranged from 0.60 to 1.96m.e.% and were classified as having high potassium content (0.6-2.0 m.e.%). Calcium content ranged from 6.20 to 16.50 m.e.% and classified as medium

(5-10 m.e.%) and high (>10m.e.%) calcium content. Magnesium ranged from 2.99 to 7.59m.e.% and were classified as high (>1.5 m.e.%) magnesium content. Exchangeable cations such as Potassium, Calcium and Magnesium are weakly bound to the soil and can leach out of the surface soil easily especially at low pH. These minerals adhere by electrical attraction to the negatively charged surfaces of clay particles (Brady, 1984). Clay in soil prevents the leaching of mineral nutrients during heavy rain or irrigation because of the large surface area for binding minerals (Brady and Weil, 2002). The soils in Muguga were characterised as Clay soils and this could further explain the generally high concentrations of these exchangeable cations in the soils of the different forest types.

A large number of the seeds found in the seed screening tests were small in size. These results concur with studies that speculate that species that produce small seeds tend to also produce them in large numbers so as to increase the survival chances of seeds.

The seedling emergence showed that the plantation forests had, on average, higher numbers of emergent seedlings as compared to the indigenous forest. However, it was noted that a vast majority of the emergent seedlings were herbs, forbs and grasses and very few were woody species. These results concur with other studies that indicated that herbaceous seeds tend to dominate the soil seed bank with few woody species accumulating long-lived seeds in the soil seed bank (Teketay and Granström, 1995). Other studies have also shown that the seed bank had higher proportions of herbaceous vegetation as compared to the above-ground flora that was dominated by woody species (Senbeta and Teketay 2001). This could be due to herbaceous species producing smaller seeds in large numbers as compared to woody species. These results also support the theory that woody species invest their recruitment in the seedling bank as compared to herbaceous vegetation whose investment is mainly in the seed bank (Teketay and Granström, 1995).

Conclusion

The study has demonstrated that different species of exotic tree plantations showed variability in their influence on understory woody species regeneration. In comparison to the indigenous forests, the exotic tree plantations had limited effectiveness in facilitating regeneration of indigenous woody vegetation. The mixed Acacia-Eucalyptus plantation was found to be the most effective in facilitating woody species regeneration as compared to the other plantations. However, further expansion of this study to include plantations of indigenous tree species could provide clearer information on the most suitable tree species for plantation forest establishment.

By limiting variability in climate by comparing plantations within the same region, the influence of the species could be more clearly noted. The different species of plantation forest varied in woody species composition, diversity and soil attributes showing that the overstory species affected regeneration. The various factors that influence regeneration such as canopy cover, litter accumulation and quality, vertical complexity, allellopathic influence and nutrient utilisation can be linked to the species of tree plantation. This makes the species integral in successful regeneration efforts. The selection of suitable species for use in plantations would enhance conservation efforts as well as providing alternative sources of forest resources.

The nutrient requirements of overstory species should be taken into consideration when selecting plantation species in order to prevent depletion of nutrients in the soil and reduce competition with understory species for these resources. The importance of fostering viable seedling banks of indigenous woody species is paramount to the success of indigenous forest regeneration. The woody species tend to invest the majority of their recruits in the seedling bank instead of in the soil seed bank. The soil seed bank of the studied sites was dominated

by herbaceous vegetation rather than woody species; this is the inverse of the understory vegetation which was dominated by woody vegetation.

The importance of the indigenous forests as seed sources is also shown in the study. In order to utilise the fragmented natural forests as a seed source, forest plantations should be established contiguous to natural forest stands. Proximity of plantations to these indigenous forests has been shown to enhance the floristic diversity in plantations and could perhaps enhance the viability of the woody species populations in the natural forests. The link between indigenous forests and plantations implies that the conservation of the indigenous forest stands that are the only indigenous woody species refuges left in many parts of Kenya should be given high priority and importance.

Recommendations

The findings of this study provide recommendations for the use of mixed Acacia-Eucalyptus plantations as a means of facilitating the regeneration of indigenous woody species as well as the soil fertility improvement advantages provided by the Acacia species. However other indigenous species should also be explored as alternatives for the establishment of plantations.

The plantations studied were mainly monocultures and it is suggested that use of multi-species plantations that contain indigenous species could possibly improve the regeneration of indigenous forest species. The inclusion of mixed-species plantations as well as plantations of indigenous tree species into further studies on regeneration could aid in determining the most suitable reforestation method that would provide greater ecological gains and improve productivity.

The use of enrichment planting to expand the area covered by the indigenous forest should also be explored. This method of planting indigenous woody species in degraded forest sites has been noted within selected areas in the Muguga forest station to increase indigenous

forest cover. Studies to determine the effectiveness of enrichment planting in enhancing woody species regeneration and diversity would provide increased understanding and enhance conservation benefits.

This study could be improved through the inclusion of a comparison with a secondary forest in order to determine the understory regeneration status and soil fertility in comparison to indigenous forests and plantations. Studies that include comparisons with plantations of indigenous woody species would also provide valuable information on the effectiveness of indigenous versus exotic tree plantations.

Plantations can play an important role in restoring the productivity, ecosystem stability, and biodiversity of degraded tropical lands as well as providing economically and socially valued forest products and services. Through careful selection of plantation species, the negative effects of the plantations can be offset while facilitating indigenous forest regeneration.

REFERENCES

Albrecht, J. (ed.) 1993. *Tree Seed Handbook of Kenya*. GTZ Forestry Seed Centre, Muguga, Kenya. German Development Cooperation, Nairobi, Kenya

Alem, Shiferaw. and Woldemariam, T. (2009). A comparative assessment on regeneration status of indigenous woody plants in *Eucalyptus grandis* plantation and adjacent natural forest. *Journal of Forestry Research* 20 (1): 31-36. DOI 10.1007/s11676-009-0006-2.

Avery, T.E. and Burkary, H.E. (1994). *Forest Measurements*. McGraw-Hill, New York.

Bargali, S.S., Singh, R.P. and Joshi, M. (1993): Changes in Soil Characteristics in Eucalypt Plantations Replacing Natural Broad-leaved Forests. *Journal of Vegetation Science* 4 (1): 25-28.

Black, C. A. (ed.). (1965). *Method of Soil Analysis, Part 2, Chemical and Microbiological Properties*. American Society of Agronomy Inc. Madison, Wisconsin USA.

Boucher, D., Elias, P., Lininger, K., May-Tobin, C., Roquemore, S. and Saxon, E. (2011). *The root of the problem: what's driving deforestation today?* Tropical Forest and Climate Initiative; Union of Concerned Scientists - Citizens and Scientists for Environmental Solutions. UCS Publications, Massachusetts, USA.

Bouyoucos, G.H. (1951). A Recalibration of the Hydrometer for Making Analysis of Soils. *Agronomy Journal* 43: 434-438.

Brady, N.C. (1984). *The Nature and Properties of Soils*. MacMillan Publishing Company Inc. New York.

Brady, N.C. and Weil, R.R. (1999). *The Nature and Properties of Soils*. Twelfth Edition. Prentice Hall. Upper Saddle River, NJ.

Brady, N.C. and Weil, R.R. (2002). *Elements of the nature and properties of soils*. Second Edition. Prentice-Hall, Inc., Upper Saddle River, New Jersey.

Brockerhoff, E.G., Jactel H., Parrotta, J.A., Quine, C.P. and Sayer, J. (2008). Plantation Forests and Biodiversity: Oxymoron or Opportunity. *Biodiversity Conservation* 17: 925-951.

Brower, J., Zar, J. and von Ende, C.N. (1990). *Field and Laboratory Methods for General Ecology*. Third edition. W. C. Brown Publishers, USA.

Carnevale, J.N., and Montagnini, F. (2002). Facilitating regeneration of secondary forests with the use of mixed and pure plantations of indigenous tree species. *Forest Ecology and Management* 163: 217-227.

Chapman, C.A. and Chapman, L.J. (1996). Exotic Tree Plantations and the Regeneration of Natural Forests in Kibale National Park, Uganda. *Biological Conservation* 76: 253-257.

Day, P.R. (1953). Experimental Confirmation of Hydrometer Theory. *Soil Science* 75: 181-186.

Espinosa-Garcia, F.J., Martinez-Hernandez, E. and Quiroz-Flores, A. (2008). Allelopathic Potential of *Eucalyptus* spp Plantations on Germination and early growth of annual crops. *Allelopathy Journal* 21 (1): 25-37.

Evans, J. (1992). *Plantation Forestry in the Tropics*. Second Edition. Clarendon Press, UK.

Food and Agriculture Organisation (1992). *Mixed and Pure Forest Plantations in the Tropics and Subtropics*. F.A.O. Forestry Paper 103, Rome, Italy. F.A.O. (Food and Agriculture Organization).

FAO (2001). *Global Forest Resources Assessment 2000*. FAO Forestry Paper 140, Food and Agriculture Organisation, Rome.

FAO (2010). *Global Forest Resources Assessment 2010: Country Report - Kenya*. FAO. Rome, Italy. Retrieved from http://www.fao.org/forestry/20360-0381a9322cbc456bb05cfc9b6a7141cdf.pdf

Gachathi, F. and Macharia, E. (2009). *Tree inventory and checklist of Muguga natural forests: Gatwikira and Gachuthi*. Kenya Forestry Research Institute. (Unpublished)

Giri, T. (2007). *Manual on Deforestation, Degradation and Fragmentation using Remote Sensing and GIS*. MAR-SFM Working paper 5. FAO. Rome, Italy.

Hall, R. (ed.). (2013). *REDD+ and the Underlying Causes of Deforestation and Forest Degradation*. Global Forest Coalition, Asuncion, Paraguay.

Harrington, R.A. and Ewel, J.J. (1997). Invasibility of tree plantations by indigenous and non-indigenous plant species in Hawaii. *Forest Ecology and Management* 99:153-162.

Hofstede, R.G.M., Groenendijk, J.P., Coppus, R., Fehse, J.C. and Sevink, J. (2002). Impact of Pine Plantations on Soils and Vegetation in the Ecuadorian High Andes. *Mountain Research and Development* 22 (2): 159-167.

Hooper, E., Legendre, P. and Condit, R. (2005). Barriers to Forest Regeneration of Deforested and Abandoned Land in Panama. *Journal of Applied Ecology* 42 (6): 1165-1174.

Hubbell, S.P. and Foster, R.B. (1986). Canopy gaps and the dynamics of a neotropical forest. In *Plant ecology*. Crawley, MJ. (ed.), 496pp, Blackwell Scientific Publications, Oxford, 77-96.

ICRAF (1992). *A Selection of Useful Trees and Shrubs for Kenya*: Notes on their Identification, Propagation and Management for Use by Farming and Pastoral Communities. ICRAF. Nairobi, Kenya.

IFS (1989). *Trees for development in Sub-Saharan Africa: proceedings of a regional seminar held by the International Foundation for Science (IFS), ICRAF House, Nairobi, Kenya, February 20-25, 1989.* Stockholm.

ITTO, (2002). *ITTO Guidelines for the restoration, management and rehabilitation of degraded and secondary tropical forests*. ITTO policy development series No. 13. Collaboration of ITTO-CIFOR-FAO-IUCN-WWF. Yokohama, Japan.

Kanyanjua, S., Ireri M.L., Wambua S and Nandwa S.M. (2002). *Acid Soils in Kenya: Constraints and Remedial Options*. KARI Technical Note No. 11. Kenya Agricultural Research Institute, Kenya.

Kigomo, N Bernard (2001). *State of Forest Genetic Resources in Kenya*. Forest Genetic Resources Working Paper FGR/18E. Forest Resources Division, Food and Agriculture Association. Rome, Italy.

Krebs, C.J. (1989). *Ecological Methodology*. Harper Collins Publishers, New York USA.

Kuusipalo, J., Adjers G, Jafarsidik Y, Otasmo A, Tuomela K, and Vuokko R. (1995). Restoration of natural vegetation in degraded *Imperata cylindrica* grassland: understorey development in forest plantations. *Journal of Vegetation Science* 6 (2): 205-210.

Lamb, D., Erskine P.D. and Parrotta J.A. (2005). Restoration of degraded tropical forest landscapes. *Science*, New Series 310 (5754): 1628-1632.

Lambrechts, C., Woodley B., Church C. and Gachanja M. (2003). *Aerial Survey of the Destruction of the Aberdare Range Forests*. United Nations Environmental Programme (UNEP), Kenya Wildlife Service (KWS) and the Kenya Forests Working Group (KFWG).

Lamprecht, H. (1989). *Silviculture in the Tropics: tropical forest ecosystems and their tree species - possibilities and methods for their long term utilisation*. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ): Eschborn.

Landon, J.R. Ed. (1991). *Booker Tropical Soils Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics*. John Wiley and Sons Inc. New York.

Lemmon, P.E. (1956). A spherical densiometer for estimating forest overstory density. *Forest Science* 2: 314–320.

Lisanework, N. and Michelsen, A. (1993). Allelopathy in agro- forestry systems: the effects of leaf extracts of *Cupressus lusitanica* and three *Eucalyptus* spp. on four Ethiopian crops. *Agroforestry Systems* 21: 63-74.

Lugo, A.E. (1992): Comparison of Tropical Tree Plantations with Secondary Forests of Similar Age. *Ecological Monographs*, 62 (1): 1-41.

Mader, S. Sylvia Ed. (1996): *Biology*. 5th Edition. Wm. C. Brown Publishers. USA. pp 596-597.

Malik, R.S. and Sharma, S.K. (1990). Moisture extraction and crop yield as a function of distance from a row of *Eucalyptus tereticornis*. *Agroforestry Systems*, 12: 187- 195.

Marx, E.S., Hart J. and Stevens R.G. (1996): *Soil Interpretation Guide*. EC 1478; Oregon State University Extension Services. Oregon State University, USA.

Michelsen, A., Lisanework, N., Friis, I. and Holst, N. (1996). Comparisons of understorey vegetation and soil fertility in plantations and adjacent natural forests in the Ethiopian highlands. *Journal of Applied Ecology* 33 (3): 627-642.

Montagnini, F., Gonzalez, E., Porras, C., and Rheingans, R., (1995). Mixed and pure forest plantations in the humid neotropics: a comparison of early growth, pest damage and establishment costs. *Commonwealth Forestry Review* 74: 306-314.

Okabelo, J.R., Gathua, K.W., and Woomer, P.L. (1993). *Laboratory Methods of Soil and Plant Analysis-A Working Manual*. Second Edition. Tropical Soil Biology and Fertility Programme, Nairobi.

Parrotta, J.A. (1992). The Role of Plantation Forests in Rehabilitating Degraded Tropical Ecosystems. *Agriculture, Ecosystems and Environment* 41: 115-133.

Parrotta, J.A. (1993). Secondary Forest Regeneration on Degraded Tropical Lands: The role of Plantations as 'Foster Ecosystems'. In: Leith H and Lohmann M. (Eds.) *Restoration of Tropical Forest Ecosystems*: pp 66-73. Kluwer Academic Publishers, Dordrecht.

Parrotta, J.A. (1995). Influence of Overstory Composition on Understory colonisation by Native species in Plantations on a Degraded Tropical Site. *Journal of Vegetation Science* 6, (5): 627-636.

Parrotta, J.A., Turnbull J.W. and Jones N. (1997). Catalysing Indigenous Forest Regeneration on Degraded Tropical Lands. *Forest Ecology and Management* 99: 1-7.

Senbeta, F. and Teketay, D. (2001). Regeneration of indigenous woody species under the canopies of tree plantations in Central Ethiopia. *Tropical Ecology* 42 (2): 175-185.

Sørensen, J. (1948). A method of establishing groups of equal amplitude in plant sociology based on similarity of species contents and its application to analysis of the vegetation of Danish commons. *Biologiska Skrifter*, Copenhagen. 5: 1-34.

Struhsaker, T.T., Kasenene J.M., Gaither J.C., Larsen N., Musango S. and Bancroft R. (1989). Tree Mortality in the Kibale Forest, Uganda: A case study of dieback in a tropical rainforest adjacent to exotic conifer plantations. *Forest Ecology and Management* 29: 165-185.

Tang, Cindy Q., Hou Xiuli, Gao Kal, Xia Tiyuan, Duan Changqun and Fu Denggao (2007). Man-made versus natural forests in mid-yunnan, southwestern China: plant diversity and initial data on water and soil conservation. *Mountain Research and Development* 27 (3): 242-249.

Teketay, D. (2005). Seed and Regeneration Ecology in Dry Afromontane Forests of Ethiopia I: Seed Production Population Structures. *Tropical Ecology* 46(1): 29-44. International Society for Tropical Ecology.

Teketay, D. and Granström A. (1995). Soil Seed Banks in dry Afromontane Forests of Ethiopia. *Journal of Vegetation Science* 6 (6): 777-786.

Thompson, K., Bakker, J.P. and Bekker, R.M. (1997). *The soil seed bank of northwest Europe – methodology, density and longevity*. Cambridge University Press, New York.

Toky, O.P. and Singh, V. (1993). Litter dynamics in short-rotation high density tree plantations in an arid region of India. *Agriculture, Ecosystems and Environment* 45: 129-145.

Whitmore T.C. (1990). *An Introduction to Tropical Rain Forests*. Oxford University Press. New York, USA.

Zanne, E. A. and Chapman, A. C. (2001): Expediting Reforestation in Tropical Grasslands: Distance and Isolation from Seed Sources in Plantations. *Ecological Applications* 11, (6): 1610-1621.

Zar, H. Jerrold (2010): *Biostatistical Analysis*.Fifth Edition. Pearson Prentice Hall. Pearson Education Inc., New Jersey.

APPENDICES

Appendix 1: Woody Species List for Muguga Forest

SPECIES NAME	SPECIES NAME
Abutilon mauritianum	*Lantana trifolia*
Acacia mearnsii	*Leucas grandis*
Acokanthera oppositifolia	*Maerua triphylla*
Albizia gummifera	*Maytenus senegalensis*
Aspilia mossambicensis	*Maytenus undata*
Calodendrum capense	*Mystroxylon aethiopicum*
Carissa edulis	*Nuxia congesta*
Carissa spinarum	*Ochna holstii*
Cassipourea malosana	*Ocimum gratissimum*
Celtis africana	*Olea europaea africana*
Cestrum aurantiacum	*Olinia rochetiana*
Clausena anisata	*Osyris lanceolata*
Clutia abyssinica	*Pinus patula*
Crotalaria mauensis	*Pittosporum viridiflorum*
Croton macrostachyus	*Psydrax schimperiana*
Croton megalocarpus	*Pterolobium stellatum*
Cupressus lusitanica	*Rhus natalensis*
Cussonia holstii var. holstii	*Ritchiea albersii*
Cyathula polycephala	*Rubus pinnatus*
Dombeya burgessiae	*Schrebera alata*
Dovyalis abyssinica	*Scutia myrtina*
Drypetes gerrardii	*Solanum incanum*
Ehretia cymosa	*Solanum mauritianum*
Ekebergia capensis	*Vepris simplicifolia*
Elaeodendron buchananii	*Vepris trichocarpa*
Erythrococca bongensis	*Toddalia asiatica*
Eucalyptus globulus	*Trimeria grandifolia*
Eucalyptus grandis	*Triumfetta tomentosa*
Euclea divinorum	*Turraea holstii*
Fagaropsis angolensis	*Vangueria madagascariensis*
Grewia similis	*Vernonia lasiopus*
Hibiscus fuscus	*Warburgia ugandensis*
Heteromorpha trifoliata	*Zanthoxylum usambarense*
Juniperus procera	

Appendix 2: Woody Species list and Taxonomical Family Designation

FAMILY	SPECIES NAME	FAMILY	SPECIES NAME
Amaranthaceae	*Cyathula polycephala*	Meliaceae	*Ekebergia capensis*
Anacardiaceae	*Rhus natalensis*		*Turraea holstii*
Apocynaceae	*Acokanthera oppositifolia*	Mimosaceae	*Albizia gummifera*
	Carissa edulis	Myrtaceae	*Eucalyptus globulus*
	Carissa spinarum		*Eucalyptus grandis*
Araliaceae	*Cussonia holstii var. holstii*	Ochnacea	*Ochna holstii*
Boraginaceae	*Ehretia cymosa*	Oleaceae	*Olea europaea africana*
Caesalpiniaceae	*Pterolobium stellatum*		*Schrebera alata*
Canellaceae	*Warburgia ugandensis*	Oliniaceae	*Olinia rochetiana*
Capparaceae	*Maerua triphylla*	Papilionaceae	*Crotalaria mauensis*
	Ritchiea albersii	Pinaceae	*Pinus patula*
Celastraceae	*Elaeodendron buchananii*	Pittosporaceae	*Pittosporum viridiflorum*
	Maytenus senegalensis	Rhamnaceae	*Scutia myrtina*
	Maytenus undata	Rhizophoraceae	*Cassipourea malosana*
	Mystroxylon aethiopicum	Rosaceae	*Rubus pinnatus*
Compositae	*Aspilia mossambicensis*	Rubiaceae	*Psydrax schimperiana*
	Vernonia lasiopus		*Vangueria madagascariensis*
Cuppressaceae	*Cupressus lusitanica*	Rutaceae	*Calodendrum capense*
	Juniperus procera		*Clausena anisata*
Ebenaceae	*Euclea divinorum*		*Fagaropsis angolensis*
Euphorbiaceae	*Clutia abyssinica*		*Vepris simplicifolia*
	Croton macrostachyus		*Vepris trichocarpa*
	Croton megalocarpus		*Toddalia asiatica*
	Drypetes gerrardii		*Zanthoxylum usambarense*
	Erythrococca bongensis	Santalaceae	*Osyris lanceolata*
Fabaceae	*Acacia mearnsii*	Solanaceae	*Cestrum aurantiacum*
Flacourtiaceae	*Dovyalis abyssinica*		*Solanum incanum*
	Trimeria grandifolia		*Solanum mauritianum*
Labiatae	*Ocimum gratissimum*	Sterculiaceae	*Dombeya burgessiae*
Lamiaceae	*Leucas grandis*	Tiliaceae	*Grewia similis*
Loganiaceae	*Nuxia congesta*		*Triumfetta tomentosa*
Malvaceae	*Abutilon mauritianum*	Ulmaceae	*Celtis africana*
	Hibiscus fuscus	Umbelliferae	*Heteromorpha trifoliata*
		Verbenaceae	*Lantana trifolia*

Appendix 3: Mature Woody Species Composition in Muguga Forest

SPECIES	Gachuthi	Gatwikira	Eucalyptus plantation	Mixed Acacia-Eucalyptus plantation	Pine Plantation	Cypress plantation
Acacia mearnsii	-	-	-	103	-	-
Acokanthera oppositifolia	-	2	-	-	-	-
Albizia gummifera	-	4	-	-	-	-
Aspilia mossambicensis	1	-	-	-	-	-
Calodendrum capense	6	6	-	-	-	-
Carissa edulis	1	-	-	-	-	-
Carissa spinarum	2	-	-	-	-	-
Cassipourea malosana	4	1	-	-	-	-
Celtis africana	-	3	-	-	-	-
Clausena anisata	-	10	-	-	-	-
Croton macrostachyus	-	1	-	-	-	-
Croton megalocarpus	-	5	-	-	-	-
Cupressus lusitanica	-	-	-	-	-	200
Cussonia holstii var. holstii	-	1	-	-	-	-
Dovyalis abyssinica	1	-	-	-	-	-
Drypetes gerrardii	-	1	-	-	-	-
Ehretia cymosa	1	5	-	-	-	-
Ekebergia capensis	3	-	-	-	-	-
Elaeodendron buchananii	1	1	-	-	-	-
Erythrococca bongensis	2	5	-	-	-	-
Eucalyptus globulus	-	-	-	2	-	-
Eucalyptus grandis	-	-	267	249	-	-
Euclea divinorum	25	16	-	-	-	-
Fagaropsis angolensis	3	6	-	-	-	-
Grewia similis	1	25	-	-	-	-
Juniperus procera	1	-	-	-	-	-
Maytenus senegalensis	2	-	-	-	-	-
Maytenus undata	-	16	-	-	-	-
Mystroxylon aethiopicum	5	12	-	-	-	-
Nuxia congesta	-	5	-	-	-	-
Ochna holstii	-	7	-	-	-	-
Ocimum gratissimum	-	-	-	-	-	-
Olea europaea africana	2	21	-	-	-	-
Olinia rochetiana	1	2	-	-	-	-
Pinus patula	-	-	-	-	77	-
Pittosporum viridiflorum	21	3	-	-	-	-
Psydrax schimperiana	3	2	-	-	-	-
Pterolobium stellatum	-	4	-	-	-	-

Appendix 3 Continued

SPECIES	Gachuthi	Gatwikira	Eucalyptus plantation	Mixed Acacia-Eucalyptus plantation	Pine Plantation	Cypress plantation
Rhus natalensis	10	15	-	-	-	-
Ritchiea albersii	-	2	-	-	-	-
Schrebera alata	3	1	-	-	-	-
Scutia myrtina	1	15	-	-	-	-
Toddalia asiatica	-	1	-	-	-	-
Trimeria grandifolia	2	-	-	-	-	-
Turraea holstii	2	1	-	-	-	-
Vangueria madagascariensis	8	-	-	-	-	-
Vepris simplicifolia	19	115	-	-	-	-
Vepris trichocarpa	-	27	-	-	-	-
Warbugia ugandensis	-	3	17	-	-	-
Zanthoxylum usambarense	11	23	-	-	-	-

Appendix 4: Woody Species Composition of Immature trees, Saplings and Seedlings in Muguga Forest – Wet Season (October-December)

SPECIES	Gachuthi			Gatwikira			Eucalyptus plantation			Mixed Acacia-Eucalyptus plantation			Pine Plantation			Cypress plantation		
	IMM	SAP	SEED	IMM	SAP	SEED	IMM	SAP	SEED	IMM	SAP	SEED	IMM	SAP	SEED	IMM	SAP	SEED
Abutilon mauritianum		2	1	28	16		8						5			6	1	
Acacia mearnsii										1			1					
Acokanthera oppositifolia				9	2	1												
Albizia gummifera				5	4	1												
Aspilia mossambicensis	1	7																
Calodendrum capense	5	5	5		2	1												
Carissa edulis	4	1	2															
Carissa spinarum	1	6	1					6	1									
Cassipourea malosana	5	2		7														
Celtis africana																		
Cestrum aurantiacum										70	11	19	7			2	1	5
Clausena anisata	42	18	36	45	81	115				3	12	27	6	4	20	3	14	6
Clutia abyssinica		12																
Crotalaria mauensis					1													
Croton macrostachyus				1														
Croton megalocarpus		2	3	1	13	11							1					
Cupressus lusitanica																		
Cussonia holstii var. holstii																		
Cyathula polycephala			1															
Dombeya burgessiae	10	3	2	11	3	5												
Dovyalis abyssinica	1								2								5	2
Drypetes gerrardii																		

Appendix 4 Continued:

Ehretia cymosa				4	4	3	7		2	3	4	2	1			2	1	
Ekebergia capensis																		
Elaeodendron buchananii	1	2	6	3	24	9		2			1	1						
Erythrococca bongensis	17	16	12	14	13	18		2	6	2	134	85				20	43	16
Eucalyptus globulus																		
Eucalyptus grandis							22	23	4									
Euclea divinorum	39	74	100				15	39	29		3	3						
Fagaropsis angolensis																		
Grewia similis	4	8	9					1			7	14						
Heteromorpha trifoliata	1	2	3															
Hibiscus fuscus							7						76	3		3		
Juniperus procera		2	6															
Lantana trifolia			1							1			6		5			
Leucas grandis				43	8					2					3	13		
Maerua triphylla	2							48	42									
Maytenus senegalensis	1	1	1					4	2		3	3						
Maytenus undata											1							
Mystroxylon aethiopicum	8	9	7	2														
Nuxia congesta																		
Ochna holstii					1	1												
Ocimum gratissimum				28						10			28	2				
Olea europaea africana		4	7								2							
Olinia rochetiana	1																	
Osyris lanceolata	1	5	4															
Pinus patula																		
Pittosporum viridiflorum	2	3	2															
Psydrax schimperiana	9	8	2	9		1		1	1			1						

Appendix 4 Continued:

Pterolobium stellatum	1	1	3		53	127					1	1	3				
Rhus natalensis	9	5	1														
Ritchiea albersii				1		2				5	1	2	1			9	4
Rubus pinnatus													25				
Schrebera alata	2	4	8			1			1								
Scutia myrtina	6	1	1	5				1				1					
Solanum incanum					10		5			20			1			1	
Solanum mauritianum				10						8	12		22		2	16	
Toddalia asiatica		3	3			3		2	1								
Trimeria grandifolia	14	3	1	4	1	1	1				10	1			1		3
Triumfetta tomentosa							9						85		33	17	
Turraea holstii	3	2															
Vangueria madagascariensis	9	3		30	14	13		2	4	1	2	3			2		
Vepris simplicifolia	58	74	80	84	14	8					1						
Vepris trichocarpa				2													
Vernonia lasiopus	1						4			9	5	1	60		8	2	12
Warburgia ugandensis	2	2	2	2							1						
Zanthoxylum usambarense	5	2	2	1				10	18		13	3			5	2	3

Appendix 5: Woody Species Composition of Immature trees, Saplings and Seedlings in Muguga Forest – Dry Season (January-March)

SPECIES	Gachuthi			Gatwikira			Eucalyptus plantation			Mixed Acacia-Eucalyptus plantation			Pine Plantation			Cypress plantation		
	IMM	SAP	SEED	IMM	SAP	SEED	IMM	SAP	SEED	IMM	SAP	SEED	IMM	SAP	SEED	IMM	SAP	SEED
Abutilon mauritianum				13			5						5	2	6	22		
Acacia mearnsii																	1	
Acokanthera oppositifolia				2							2							
Albizia gummifera				1	6	2												
Aspilia mossambicensis				5														
Calodendrum capense	4	9	7															
Carissa edulis	30					3		8	3									
Carissa spinarum	11	4	7	2					1									
Cassipourea malosana	5	1	2	5														
Celtis africana	1		3															
Cestrum aurantiacum										9	10	12	6					
Clausena anisata	36	119	116	60	82	105	1		1	4	18	29	3	9	8	4	11	12
Clutia abyssinica																		
Crotalaria mauensis																		
Croton macrostachyus				1														
Croton megalocarpus		5	1	6	1								1					
Cupressus lusitanica																		
Cussonia holstii var. holstii																		
Cyathula polycephala																		
Dombeya burgessiae	3		9	5	4	5												
Dovyalis abyssinica				2				1	1		1	1		1	1		3	4
Drypetes gerrardii	2																	
Ehretia cymosa	1			5			4	2	3	9	2	3	1			2		1

Appendix 5 Continued:

Ekebergia capensis																		
Elaeodendron buchananii	1	3	8	3	16	5		1			1	1					2	
Erythrococca bongensis	21	17	13	19	12	12	2	3	1	4	85	68		1	1	8	43	36
Eucalyptus globulus																		
Eucalyptus grandis							22	9										
Euclea divinorum	67	232	361	1			16	49	44		3	11						
Fagaropsis angolensis																		
Grewia similis	6	58	77	2	1			1	2		19	10						
Heteromorpha trifoliata	1	2	2															
Hibiscus fuscus							7						53	9			3	
Juniperus procera	2		3															
Lantana trifolia										1			4		1	10		
Leucas grandis				19	7					2	1		1	3		3	8	12
Maerua triphylla	3	3	2				2	30	23		8	5						
Maytenus senegalensis	8	8	6	2								1						
Maytenus undata		4	2	1							3	1						
Mystroxylon aethiopicum	5	32	38		4													
Nuxia congesta																		
Ochna holstii																		
Ocimum gratissimum				7						3	4		30					
Olea europaea africana	1	4	1								3	1						
Olinia rochetiana	3	4	3	1														
Osyris lanceolata	2	1																
Pinus patula																		
Pittosporum viridiflorum	13	4	1															
Psydrax schimperiana	9	27	10	4	1	5		2			1	4						
Pterolobium stellatum	1			11	104	174						3						

Appendix 5 Continued:

Rhus natalensis	39	12	13	2															
Ritchiea albersii										1	1								
Rubus pinnatus													11	6	4				
Schrebera alata	3	11	11																
Scutia myrtina	5			4							2								
Solanum incanum				3			5			14	2		5			8	15		
Solanum mauritianum										2	7	2	20	2		2	2	1	
Toddalia asiatica		2	1					3	6	7		1							
Trimeria grandifolia	17	1	2				1		1		2	3					1		
Triumfetta tomentosa	2						9						75	3		57	17		
Turraea holstii																			
Vangueria madagascariensis	11	1	2	23	14	9	1			1	2	5				1			
Vepris simplicifolia	51	125	135	81	10	7													
Vepris trichocarpa			2	3	2														
Vernonia lasiopus							2			4	5		45	6		12	4		
Warburgia ugandensis		3		2	2	1					1								
Zanthoxylum usambarense	3	4	6	1		1		6	11		9	4				1	1		

Appendix 6: Soil Chemical Properties of Muguga Forest

SAMPLE SITE	Sample	SOIL DEPTH	pH	% Total Nitrogen	% Organic Carbon	Phosphorous (ppm)	Potassium (m.e.%)	Calcium (m.e. %)	Magnesium (m.e.%)	Manganese (m.e.%)	Copper (ppm)	Iron (ppm)	Zinc (ppm)	Sodium (m.e.%)
Gachuthi	SU1	0-30 cm	6.45	0.48	4.38	20	2.24	18.1	7.89	1.94	1.04	18.1	48	1.51
	SU2	0-30 cm	5.58	0.43	3.7	16	1.68	14.9	7.29	2.01	1.11	14	46.9	0.91
Gatwikira	SU1	0-30 cm	5.85	0.55	4.37	8	1.56	15.1	6.86	1.74	2.49	45.2	3.28	0.91
	SU2	0-30 cm	5.77	0.43	4.1	9	1.38	12.9	5.98	1.98	1.73	23.2	3.71	0.79
Eucalyptus	SU1	0-30 cm	6.1	0.32	3.15	24	0.29	5.8	4.87	1.74	1.4	64.8	18	0.69
Plantation	SU2	0-30 cm	6.4	0.25	2.4	27	0.9	6.6	4.5	1.8	1.1	60.9	28	0.57
Mixed	SU1	0-30 cm	5.78	0.35	3.58	10	0.69	8.8	4.16	1.76	1.45	31.3	31.2	0.67
Acacia-	SU2	0-30 cm	5.53	0.21	2.11	9	2	8	5.63	1.74	2.04	28.8	27.9	1.09
Eucalyptus														
Plantation														
Pine	SU1	0-30 cm	5.55	0.26	2.28	17	1	6	2.84	2.12	1.88	57.8	33.2	0.59
Plantation	SU2	0-30 cm	5.76	0.4	3.8	10	0.9	11.2	3.13	1.74	0.99	25.1	32.3	0.55
Cypress	SU1	0-30 cm	5.6	0.41	3.92	10	0.94	14.9	4.39	1.92	1.17	22.9	44.2	0.59
Plantation	SU2	0-30 cm	5.5	0.2	2.41	9	1.18	7.8	2.99	1.84	1.47	71.3	29.6	0.67

Appendix 7: Soil Texture Properties of Muguga Forest

SAMPLE SITE	Sample	SOIL DEPTH	% SAND	% SILT	% CLAY	TEXTURE GRADE
Gachuthi	SU1	0-30 cm	30	22	48	C
	SU2	0-30 cm	16	32	52	C
Gatwikira	SU1	0-30 cm	26	24	50	C
	SU2	0-30 cm	20	26	54	C
Eucalyptus Plantation	SU1	0-30 cm	14	24	62	C
	SU2	0-30 cm	24	34	42	C
Mixed Acacia-Eucalyptus Plantation	SU1	0-30 cm	18	24	58	C
	SU2	0-30 cm	14	20	66	C
Pine Plantation	SU1	0-30 cm	20	30	50	C
	SU2	0-30 cm	22	24	54	C
Cypress Plantation	SU1	0-30 cm	14	32	54	C
	SU2	0-30 cm	24	30	46	C

Appendix 8: Soil Seed Bank and Seedling Emergence in Soils of Muguga Forest

SAMPLE SITE	Sample	Original Sample Weight, g	Representative Sample, g	No. of Seeds in Representative Sample	Overall Seed Total	Emergent Seedlings
Gachuthi	SU1	623.62	30	7	146	7
	SU2	522.71	30	16	279	6
Ave.					**212**	**7**
Gatwikira	SU1	449.37	30	9	135	1
	SU2	549.21	30	6	110	4
Ave.					**122**	**3**
Eucalyptus Plantation	SU1	702.82	30	2	47	6
	SU2	906.68	30	3	91	12
Ave.					**69**	**9**
Mixed Acacia-Eucalyptus Plantation	SU1	742.25	30	18	445	8
	SU2	619.94	30	108	2232	14
Ave.					**1339**	**11**
Pine Plantation	SU1	364.42	30	5	61	4
	SU2	541.66	30	4	72	10
Ave.					**66**	**7**
Cypress Plantation	SU1	576.29	30	52	999	23
	SU2	579.02	30	44	849	10
Ave.					**924**	**17**

Appendix 9: Species Composition of Emergent Seedlings in the different forest types

Species	Gachuthi	Gatwikira	Eucalyptus plantation	Mixed Acacia-Eucalyptus plantation	Pine plantation	Cypress plantation
Abutilon mauritianum	4	1	-	-	-	2
Achyranthes aspera	-	1	-	-	-	3
Apium sp.	-	1	-	-	-	-
Centella asiatica	-	-	-	2	2	1
Chenopodium sp.	-	3	-	1	-	2
Commelina benghalensis	-	-	-	2	5	-
Eragrostis superba	1	-	4	12	2	4
Galinsoga parviflora	-	-	-	5	-	4
Leucas grandis	2	-	7	-	2	7
Oplimenus tenuis	-	-	-	-	1	2
Oxalis sp.	3	-	1	-	1	1
Lippia javanica	-	-	-	-	-	7
Solanum incanum	2	-	-	-	-	-
Unidentified species A	1	-	-	-	-	-
Unidentified species B	-	-	1	-	-	-
Unidentified species C	-	-	2	-	-	-
Unidentified species D	-	-	-	-	1	-

Appendix 10: Shannon-Weiner Diversity Indices for the different forest types in Muguga Forest Station

	Gachuthi	Gatwikira	Eucalyptus plantation	Mixed Acacia-Eucalyptus plantation	Pine plantation	Cypress plantation
			Mature Trees			
Taxa S	28	36	1	3	1	1
Individuals	137	389	267	354	77	200
Shannon **H'**	2.738	2.803	0	0.6359	0	0
			Immature			
Taxa S	37	35	13	14	17	14
Individuals	632	645	155	196	588	222
Shannon **H'**	2.791	2.61	2.078	2.004	2.014	1.981
			Saplings			
Taxa S	36	23	16	27	10	17
Individuals	988	530	256	416	46	239
Shannon **H'**	2.35	2.084	1.839	1.987	2.003	2.103
			Seedlings			
Taxa S	37	21	17	22	8	11
Individuals	1156	650	210	332	46	117
Shannon **H'**	2.095	1.513	1.827	1.92	1.344	1.787