INFLUENCE OF TREE AGE, SPECIES AND DISTANCE ON GAME DAMAGE TO PLANTATION FORESTS IN SOUTH WEST OF MOUNT KENYA

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DECLARARTION AND RECOMMENDATION

Declaration

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

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DEDICATION

This thesis is dedicated to my late parents Mr. Ojuang' Odhuong'o and Mrs. Cecilia Atieno Ojuang'.

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ABSTRACT

The impacts of game animals such as elephants *(Loxodonta africana),* buffaloes *(Synerus caffer) and* syke monkeys (*Cercopithecus mitis)* is an impediment to successful forest plantation development particularly in south west of Mount Kenya ecosystem. The specific objectives of the study were to evaluate the influence of age, species and distance from the natural forest on game damage to *Cupressus lusitanica, Pinus patula and Eucalyptus saligna* plantation trees. A cross sectional research design was used. Systematic random sampling was employed to select sample points, plantation sub compartments and 19124 trees used in the study. An observation schedule was used to capture data on tree characteristics and game damage which was expressed as debarking/bark stripping, uprooting and broken tops. Additional data was gathered from records of the Kenya Forest Service and Kenya Wildlife Service the organisations mandated to manage Mt Kenya ecosystem. Frequencies and percentages were used to describe and summarised qualitative data while one-way analysis of variance (ANOVA) was used to explore differences in ages of trees. The results of the ANOVA test revealed that the mean ages of trees in the four stations were not statistically significant. The Chi-Square test indicated that the association between tree age, Chi-Sq = 319.037, DF = 4, P-Value = 0.000, tree species, Chi-Sq = 799.514, DF = 4, P-Value = 0.000, distance of plantation trees from natural forest, Chi-Sq = 1163.419, DF = 4, P-Value = 0.000. and game damage were statistically significant at .05 level. The multinomial logistic regression also indicated that Cox and Snell R^2 = .019 and Nagelkerke R^2 = .022 for tree age, species Cox and Snell R^2 = .051 and Nagelkerke R^2 = .059 while distance of plantation trees from natural forest Cox and Snell R^2 = .067 and Nagelkerke R^2 = .077 were significant at P-Value = 0.000 on game damage. Younger plantations were found to suffer more damage than older plantations and *Cupressus lusitatnica* were the most destroyed tree species while *Eucalyptus saligna* were the least destroyed. Sub compartments which were furthest from the natural forest were destroyed more than closer ones. The findings will assist the Kenya Forest Service establish new plantations and develop policies and practices that enhance management of forest plantations.

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LIST OF ABBREVIATIONS AND ACRONYMS

DBH	Diameter at Breast Height
FAO	Food and Agricultural Organization
FDGO	Forest Department General Order
FPP	Forest Preservation Programme
FPRA	Forest Plantations Resource Accounts
FSGO	Forest Service General Order
FSK	Forest Society of Kenya
GOK	Government of Kenya
IPCC	Inter-governmental Panel on Climate Change
KEFRI	Kenya Forestry Research Institute
KFMP	Kenya Forestry Master Plan
KFS	Kenya Forest Service
KWS	Kenya Wildlife Service
M ha	Million Hectares
MENR	Ministry of Environment and Natural Resources
NEMA	National Environmental Management Authority
NRC	Non-Residential Cultivation
NRM	Natural Resource Management
PELIS	Plantation Establishment and Livelihood Scheme
SAS	Statistical Analysis System
WWF	World Wildlife Fund

CHAPTER ONE
INTRODUCTION

1.1 Background

Forests play a key role in the social and economic development of nations because they are a vital reservoir of biodiversity, habitats for wildlife and source of wood products (Africa Forest Forum [AFF], 2019; Ingram et al., 2016; Thomson et al., 2011). Forests are important in provision of social services like soil and water conservation, tourism industry resources, industrial timber, fuelwood and pulpwood. They also provide utilitarian support for people and communities. For example, some communities depend on forests for their livelihood, and many people in developing countries still rely on forests for medicinal remedies derived from indigenous plants (Food and Agricultural Organization [FAO], 2011). Forests also sequester carbon which would otherwise be released into the atmosphere in the form of carbon dioxide. They thus contribute to mitigation of global warming (Intergovernmental Panel on Climate Change [IPCC], 2007; Laclau, 2003; Nabuurs et al., 2008).

Forests occupy more than 4 billion hectares which corresponds to about 30% of the total world land area (Africa Forest Forum [AFF], 2019). More than half (53.0%) of the global forests are found in Russia, Brazil, Canada, United States of America and China (Chakravarty et al., 2012). Areas under forest have remained fairly stable in North and Central America but expanded in Europe during the past decade (Anon, 2011). The Asian continent, especially India and China registered a net gain in forest area due to their large scale afforestation programmes in the last decades while South America registered loss of forest area during the same period. Africa's forests cover an estimated 674 million hectares or 23% of the continent's land area and account for 16.7% of global forest cover (Chamshama, et al., 2009). The distribution of forests in Africa varies from one sub□region to another, with the extremes in southern of the Sahara Desert having the least forest cover while Central Africa has the densest forest cover (AFF, 2011). Five countries: Congo, Sudan, Angola, Zambia, and Mozambique account for half of this forested area. Kenya is among the countries in Africa with low forest cover with 58 million hectares of forests corresponding to 6.99% of its land mass (Ministry of Environment and Natural Resources [MENR], 2016; Forest Preservation Programme [FPP], 2013). Forests are usually classified as either natural or plantation (Muukkonen, 2009). Natural forests refer to 'natural vegetation' of a given area that has been in existence for thousands of years and supporting a biodiversity of complex ecosystem.

In Kenya, natural forests comprise of indigenous tree species of natural regenerations found mainly within water catchment areas (Peltorinne, 2004). Examples of common tree species in natural forest include; Cedar (*Juniperus procera*), Podos (*Podocarpus latifolia* and *Podocarpus falcutus*) and Rosewood (*Hargenia abyssinica*). The main plantation tree species grown in Kenya are; Cypress (*Cupressus lusitanica*), Pines (*Pinus patula)* and Blue Gum (*Eucalyptus species*) (Kagombe & Gitonga, 2005; Wamugunda, 1987).

Plantation forests are established by planting in the process of afforestation or reafforestation. In Kenya, plantation forestry was started in 1900's and intensified around 1940's (Mugo et al., 2010; Njuguna & Muriithi 1995; Omenda et al*.,* 2000). Adoption of plantation forestry was deemed necessary because of increased demand for wood products by a fast growing construction industry and an ever-increasing human population (Wamugunda, 1992; Wass, 1995). According to Hutchins (as cited in Chamshama & Nwonwu, 2004), plantations were introduced because indigenous trees lacked vigour to enable them extend to margins of forest or form fresh development on the grasslands. The forest plantation programme was started by clearing some of the indigenous forests and replacing with fast growing exotic tree species such as *Cupressus species. Pinus species and Eucalyptus species* (MENR, 1994; Wass, 1995). After the Second World War, the country's development committee recommended planting of cypress and pines on an equal basis (MENR, 1994). These plantations were raised through the *shamba* (taungya) system.

The *shamba* system involved integrating some of the squatters who were cultivators into Forest Department as resident workers and allocating them plots (*shambas*) (Mathu & Ng'ethe, 2011; Mugo et al., 2010). The cultivators were engaged for nine months in a year and allowed to grow crops on the plots as they tendered young trees. They were allowed to take home what was produced in the plots as part of their emoluments. In 1975, some of resident workers were offered permanent employment by the forest department while others stayed on as squatters. The permanent employees rented plots and also came along with their friends and relatives who also engaged in farming activities. The number of cultivators in the forests significantly increased as there were still the squatters who were not engaged as resident workers during the *shamba* system, and friends and relatives of the permanent employees. The squatters become an impediment to effective management of forests as the available forest land under cultivation could not sustain their numbers (Kagombe & Gitonga, 2005). Evicting the squatters could also not be done at the discretion of the forest officers due to political pressure. The politician used their status to campaign for excision of forest land for permanent settlement to gain political mileage over their competitors (Chamshama & Nwonwu, 2004).

The *shamba* system was later re-organized and re-introduced in 1994 as Non-Residential Cultivation (NRC) (Bertram, 2003). After clear fell of plantations cultivation continued without replanting this led to closure of NRC in 2003. This gave birth to Plantation Establishment and Livelihood Scheme (PELIS) in 2004 (Kagombe & Gitonga, 2005). Under the PELIS programme, the cultivators pay rent annually and are allocated half an acre plot which they cultivate for three years before being moved to a new site.

Plantation forests have been exposed to many disturbances which have affected its structure and composition in recent decades. A study conducted in Sweden showed that pests are among the common natural disturbances that damage plantation forest (Katona et al., 2011). Anthropogenic activities such as forest logging, charcoal burning and silvicultural operations also disturb forests (Boucher et al*.,* 2006, 2009). Fires are a menace as they destroy thousands of hectares of plantation forests during dry seasons (FAO, 2007). A study conducted in Kenya by Mathu and Ng'ethe (2011) revealed that changes in climate and natural disturbances such as floods and rain storms affect forests' structure and composition. Diseases are also a major challenge in the development and management of plantation forests. For example, in Kenya, many plantations of *Pinus patula*, *Cupressus lusitanica* and *Eucalyptus species* have been destroyed by aphids and blue gum chalcid (KEFRI, 2009).

The growing of *Cupressus macrocarpa* and *Pinus radiata* were also discontinued due to *Monochaetia unicornis* and *Mycosphaerella pini* (*Dothistroma pini var. keniense*) (FAO, 2007; Mugo et al., 2010). Studies have further shown that plantation forests suffer massive destruction from game animals (Kenya Forest Service [KFS], 2010; Mutiso et al*.,* 2013).

Game animals are major agents of disturbance in plantation forests. The game animals which are known to damage plantation forest trees are elephants *(Loxodonta africana),* buffaloes *(Synerus caffer)* and primates. They destroy trees by trampling, debarking/bark striping, breakages and uprooting. Malik and Karnet (2007) and, Welch and Scott (2008) observed that trees with damaged bark usually suffer from infestation of fungi and decay which consequently decreases financial returns in addition to low timber quality. Studies conducted in Zimbabwe indicated that primates strip the bark of *Pinus patula* trees resulting in mortality, deformities and stunted growth (Gwenzi et al., 2007; Katsvanga et al, 2009a; Ndagurwa, 2012). Maganga and Wright (1991) study conducted in Mount Meru, Tanzania, observed that syke monkeys are pests to both agricultural crops and exotic plantation trees. Researches on game damage to plantation forests carried out in Kenya (Njuguna & Muriithi, 1995; Thomson, 1993a; Wass, 1995) revealed that game animals attack *Pinus patula* and *Cupressus lusitanica* plantations. Elephants are known to gouge trees using their tusks and trunks to peel off the bark leading to drying and subsequent death (Holdo, 2003; Ihwagi, 2009). Buffaloes also damage trees through browsing, bark stripping, and fraying resulting in deformities, retarded growth and death (Mutiso et al., 2013).

Studies have shown that game damage to plantation forests is influenced by several factors. Baubet et al. (2005) established that topography of land and weather influence game damage to plantation forest. They also established that damage on forest regeneration by rodents is heavier during winter season. Yamada and Fujioka (2010) study revealed that damage on trees by bears in the Chichibu Mountains was lower in areas where the topography was steep. They noted that seasonal availability of food plays a crucial role in forests' predisposition to game. Others factors that lead to forest damage include; human settlement, excisions, and water point (Khaleghi, 2017; Nichols et al, 2017). Human activities influence game damage because they disturb the animals' natural habitat and food sources, thus forcing them to seek alternatives in plantations (Ochieng, 1993).

Other studies have also shown that game damage to forest plantations is influenced by tree characteristics (Morgan, 2007; Ssali et al., 2012). Plantation tree characteristics such as open patches within, age, species, distance from natural forest, have also been associated with game damage. A study done on pine plantations in Finland by Heikkila (1990) revealed that moose browsing occurrence was most common in plantations established on fertile soil with the damage highest in those with openings. Kamler et al. (2010) study examined whether species affects game damage and noted significant differences in game damage among tree species. The study further observed that rowan, beech and douglas fir were the most affected while alder, beech, spruce and pine were the least affected. A study conducted by Morgan (2007) in Gabon established that the minerals/nutrients in a tree influence game damage. Trees that are rich in sodium, potassium, calcium, nitrogen and sugars tend to attract browsers. Thomson (1993a) noted that young plantations were more prone to uprooting and breaking by elephants than older ones. While Njuguna and Muriithi (1995) found that older *Pinus patula* plantations were more vulnerable to damage than younger ones. Older trees were more vulnerable because they had high concentration of plant minerals that elephants require.

The Mount Kenya ecosystem comprises of natural and plantation forests (Peltorinne, 2004) and is a water catchment area for river Tana and Ewaso Nyiro. It provides both wood and non-wood forest products and is rich in biodiversity. The ecosystem has attractive sceneries and has great potential for tourism, since 1980s forests within the Mount Kenya region has been degraded due to logging, overgrazing, forest fires and invasive species (KWS, 2010). Other threats to forests include; excisions, encroachment, water abstraction, pests, diseases and game damage (KFS, 2010). According to KFS, damage on plantation forests is mostly caused by elephants, buffaloes and syke monkeys through debarking, fraying, uprooting and trampling. In South West of Mount Kenya, the animals mostly destroy pine, cypress and eucalypts plantations in Gathiuru, Nanyuki, Kabaru, Hombe and Naromoru forest stations.

Game damage on plantation forests in South West Mount Kenya is a threat to the development and management of plantation forests (FAO, 2007; KFS, 2010; KWS, 2010). Studies of Holdo (2003) and Khaleghi (2017) have shown that anthropogenic activities, human settlement, excisions and watering points are factors that influence game damage on plantation trees. Game damage on plantations is also influenced by characteristics of trees like their medicinal value, age, species and distances from the natural forest (Camperio-Ciani et al., 2001). In the current study, the influence of tree age, species and distance on plantation forest in South West of Mount Kenya was investigated in Ragati, Hombe, Kabaru and Gathiuru forest stations.

1.2 Statement of the Problem

Plantation forests play a key role in provision of industrial timber, fuel wood, pulpwood, ecosystem services such as nitrogen and carbon sequestration, soil water conservation and biodiversity protection. Kenya Forest Service has invested and continues to invest heavily in establishing plantation forests in South West of Mount Kenya. Despite this effort, game animals continue to debark, uproot, break down and trample on these plantations. The continued destruction of plantation forests by game results in retarded growth, deformities and death of trees. This leads to premature harvesting of the plantations, loss of forest cover and economic loss to Kenya Forest Service and the country. There is a possibility that game damage to forest plantation in South West of Mount Kenya could have been influenced by tree characteristics. This study examined the influence of age, species and distance from natural forest on game damage in South West of Mount Kenya. There is evidence from the literature that game damage to forests is of critical significance. However, many studies have not focused on influence of age, species and distance of plantation forests from the natural habitats of the game animals. The motivation of this study was to fill the knowledge gap by examining the influence of tree age, species and distance from natural forest on game damage on forest plantations.

1.3 The Broad Objective

To provide information on the influence of game damage on plantation forests of *Cupressus lusitanica, Pinus patula* and *Eucalyptus saligna* in south west of Mount Kenya.

1.4 Specific Objectives

The specific objectives of the study were to:

i. To determine the influence of tree age on effect of game damage to plantation forest trees in south west of Mount Kenya.
ii. To determine the influence of tree species on effect of game damage to plantation forests in south west of Mount Kenya.
iii. To establish the influence of distance from natural forest on effect of game damage to plantation forest trees in south west of Mount Kenya.

1.5 Hypotheses of the Study

The following null hypotheses were tested during the study:

H01: Age has no influence on game damage to forest plantations in south west of Mount Kenya.

H02: Tree species does not influence game damage on forest plantations in south west of Mount Kenya.

H03: Distance from natural forest does not influence game damage on forest plantations in south west of Mount Kenya.

1.6 Justification

This study is significant because plantation forests play a key role in provision of industrial timber, fuel wood and pulpwood (FSK, 2006; MENR, 2016). They also provide ecosystem services such as nitrogen and carbon sequestration, detoxification, regulation of hydrologic cycle and material cycling of critical elemental substrates (MENR, 2005). The findings of this study may provide plantation forest managers with an insight of the association between tree age, species and distance from natural forest and game damage. This information can assist forest managers identify areas of weakness, formulate policies and develop practices that enhance plantation forest management. The findings of the study may also provide the Kenya Forest Services with an overview of impact of game activities on plantation forests. It may also assist KFS to come up with measures that minimise game damage to plantation trees. The findings can also be used as baseline data by researchers in future. Finally, the study is significant because its findings bridge the gap in literature. Previous studies did not focus on association between tree species, age and distance from natural forest and game damage neither were they conducted in south west Mount Kenya.

1.7 Scope of the Study

This study was carried out in Ragati, Hombe, Kabaru and Gathiuru forest stations in south west of Mount Kenya. The researcher examined the influence of age, species and distance from the natural forest on game damage to *Cupressus lusitanica, Pinus patula* and *Eucalyptus saligna* forest plantations. The forms of game damage examined during the study were; debarking, top breaking and uprooting. Trampling and girdling/fraying were not considered as forms of game damage in this study.

1.8 Limitations of the Study

It was not possible to collect data from all the plantation age categories of *Pinus patula* and *Eucalyptus species* trees. *Pinus patula* trees aged between 11 – 20 years were not sampled since they were not in the study area as they had been wiped out by game animals (Gitonga, 2005; Kagombe & KFS, 2010; KFS, 2014). *Eucalyptus species* plantations aged between 21 and 30 years were also not part of the study sample because eucalypts are managed on an age rotation of 8 to 20 years to produce transmission poles, fuel wood and timber in Technical Order No. 4.4.04 (MENR, 1996). The sampling challenge was considered a limitation because a balanced combination of tree species and age classes could have possibly provided more insight and different outcome.

1.9 Assumptions of the Study

The study assumed that damage to plantation forests were due to game animal activities. It was also assumed that game animal's habitat is the natural forests.

1.10 Definition of Terms

Age Refers to length of time during which a being or thing has existed or length of life. In this study it refers to the duration of plantation trees expressed in years from the time seedlings were planted in the field or plantation established to the time they are harvested.

Broken Top A tree whose uppermost whorls of branches and main stem have broken off the main trunk (Gschwantner et al., 2009). In this study it means trees whose tips/tops have been broken by game animals in the course of their feeding.

Damage The term means causing injury to something**.** In this study it refers to the destruction of forest plantation trees by game animals through debarking, uprooting and breaking their tops

Debarking This is the process of removing the bark from wood. In this study it is the peeling off the bark of plantation trees by game animals for the purpose of feeding.

Distance: This is a numerical measurement of how far apart objects are. In this study it refers to the space between plantation forests and natural forests expressed in kilometres.

Forest: A forest is defined as land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10 percent, or trees being able to reach these thresholds in situ but does not include land that is predominantly under agricultural or urban land use (FAO, 2012). In this study it means forest areas occupied by trees of Indigenous species and plantation trees.

Plantation forest: Refers to stands established by planting or/and seeding in the process of afforestation or reafforestation. They are either induced or indigenous species that meet a minimum area requirement of 0.5 ha tree cover of at least 5 per cent of land cover and total height of the adult tree of at least 5 m (FAO, 2001). In this study it refers to forests of *blue gums, pines and cypress* in south west of Mount Kenya.

Species: Refer to groups of actually or potentially interbreeding natural populations which are reproductively isolated from other such groups (Aldhebiani, 2017).The term refers to forest plantations of *Eucalyptus saligna, Pinus patula* and *Cupressus lusitanica*.

Uprooting: This means to pull out of the ground or to take out. In this study it means the pulling out of plantation trees from the ground by the game animals for the purpose of feeding on their twigs.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this chapter literature on influence of selected tree characteristics on game damage is reviewed. An examination of forests, environmental services provided by forests plantations and damage on plantation forests are discussed. A critique is made on the determinants of game damage on plantation forests with a review of the influence of age, species and distance from the natural forest on game damage. In the last section of the chapter, a conceptual framework which depicts the relationship among the study variables is presented.

2.2 Forests

Forests have contributed significantly towards man's wellbeing over the years. Before the industrial revolution, forests, woodlands, and trees were the source of land for settlement and cultivation, materials for construction, woody biomass for fuel and non timber forest products (Agrawal et al., 2013). Many people in developing countries still rely on forests for pharmaceutical remedies derived from indigenous plants (FAO, 2011). They also play vital roles such as maintenance of water cycle, wildlife habitat, carbon and nitrogen sequestration (FSK, 2006; KEFRI, 2009). Forests and trees support sustainable agriculture, stabilize soils and ameliorate climate, regulate water flows, provide shade and shelter, and are habitats for pollinators and the natural predators of agricultural pests (Ichikawa, 2014). They also provide sources of energy and income, and contribute to the food security to hundreds of millions of people all over the world.

Forests occupy a total land area of more than 4 billion hectares which corresponds to about 30% of the total land area of the world (FAO, 2015). Most (53%) of these forests are in Russia, Brazil, Canada, the United States of America and China (Chakravarty et al., 2012). The areas under forest in North and Central America have remained fairly stable during the past decade while those in Europe have increased. The Asian continent, especially countries like India and China have registered a rise in forest area due to large scale afforestation programmes in the last decade while South America and Oceania have registered decline in forest area during the same period (Anon, 2011).

Africa has a forest area of about 675 million hectares (ha), or about 23 percent of land area, with wooded landscapes (trees outside forests) accounting for another 13 percent, or 350 million hectares (Chamshama et al., 2009). Dryland forest areas in Southern and Eastern Africa and the Sahel constitute the majority of forested landscapes by area. Five countries: DR Congo, Sudan, Angola, Zambia, and Mozambique are the most forest rich nations in Africa. Deforestation and forest degradation have slowed down marginally in Africa over the last decade (World Bank, 2012). However, deforestation and forest degradation are still of concern, especially in densely populated humid West African countries and some countries in Eastern and Southern Africa. The degradation is associated with poverty which drives communities to clearing wooded land for agriculture.

According to a report by FAO (2015) data on the forest resources of Kenya (FRA) indicate that the country's forest cover is 4.4 million hectares, which is about 7.7 percent of the total land area. This report showed that between 2010 and 2015, there was an annual increase of 36 600 hectares in forest cover in Kenya. Most of the forests in Kenya are found along the coast and highlands between 1500 to 2500 meters above sea level, with rainfall of between 1000 to 1750 mm per year (Africa Forest Forum, 2011). The highlands include Mau, Aberdares, Cherenganyi, Mt. Kenya and Mt. Elgon. Mount Kenya is one of the largest forests ecosystems in Kenya with a total forest area of 232,047 hectares (National Environmental Management Act [NEMA], 2011).

Literature shows that there are several ways of classifying forests (Muukkonen, 2009; Peltorinne, 2004). Classifying forest as natural and plantation is one of the most commonly used methods (Carle & Holmgren, 2011). Plantation forests are different from natural ones because they are planted species, often of mono crop and doesn't support a variety of natural biodiversity. The stands are either introduced species or intensively managed indigenous species which are of the same age and are regularly spaced. Planted forests are generally defined according to the extent of human intervention in the forest's establishment and/or management, which depends, to a large extent, on the purpose of growing it (FAO, 2000).

2.2.1 Environmental Services Provided by Forests

Forests provide various products and services and also play an important role in maintaining ecological balance (WWF, 2012). Forests provide an environment for many species of plants and animals thus protects and sustains the diversity of nature. They also provide habitats to different types of organisms. Birds build their nests on tree branches while some animals and birds live in the hollows, insects and other organisms live in various parts of the trees.

Some species of trees have the ability to fix atmospheric nitrogen in the soil thus enriching the soil fertility. Through root decomposition and fallen leaves forests maintain and increase soil nutrients. The leaves layer that fall around the trees prevent runoff and allows the rain drops to slowly percolate into the soil thus helping in ground water recharge (Government of India, 2009). Forest cover also plays an important role in amount of precipitation received within an area as they maintain the hydrological cycles (Chamshama et al., 2009).

Forests play vital role in maintaining healthy watershed as catchment areas for many rivers in the world that transport organic matter from forest downstream thus supporting life of aquatic organisms (KFS, 2014). According to World Bank (2012) forests absorb suspended particles in air thereby reducing pollution and global warming. The trees in the forest clean the air, cool it on hot days, conserve heat at night, and act as excellent sound absorbers. They also clean the environment by muffling noises, buffering strong winds and stopping dust and gases.

2.3 Plantations Forests

Plantation forests are mainly for producing wood related goods and services and contribute to sustainable development goals (FAO, 2010). Plantation forests provide not only wood and fibre products but also ecosystem services such as carbon sequestration, regulation of the hydrological cycle, alleviation of desertification and improvement in connectivity of landscape mosaics for biodiversity conservation (Kanninen, 2010). Forest plantations cover about 140 million (M) hectares globally, representing 4% of the total forest area (FAO, 2015). China (31.4 M) ha has the largest forest plantation area followed by US, Russia and Japan with 17.1 M ha, 17.0 M ha and 10.3 M ha respectively (Garforth & Mayers, 2005)
Forest plantations were established in Kenya in the early 1900s with *Eucalyptus* trees for production of fuel wood for locomotive engines and were planted along the railway lines (MENR, 1994; Mugo et al*.,* 2010). Commercialization of tree plantations started in the early 1920s to meet demand for timber, fuel wood and pulpwood (Kagombe & Gitonga, 2005; Mathu & Ng'ethe, 2011). The commercialised trees were; *Cupressus lusitanica* Miller, *Pinus radiata* D. Don and *Pinus patula* Schlecht. These species were preferred because of their rapid growth and vigor to extend to the forest margins (Hurchins, 1910 as in Mugo et al., 2010). The plantations were raised through the "shamba" system, known internationally as "taungya" which was an agroforestry practice that was used to convert natural forests to plantation forests. Land was set aside for tree planting and issued to cultivators/squatters for

crop cultivation. After a period of two years of crop growing, trees were planted and the cultivators continued to grow their crops for two to three more years until the trees were too tall for agricultural crops. Under this system, cultivators/squatters gained from the agricultural crops while the trees were tendered (KEFRI, 1990; Vanleeuwe et al., 2003). The Shamba system was later converted to Non Residential Cultivation, and lastly PELIS (Kagombe & Gitonga, 2005; KWS, 1999).

Most of the plantation forests in Kenya are found in the Central highlands, Western, Mau and North Rift Conservancies. The forests are located at an altitudes of 1500 to 2500 meters above sea level, with annual rainfall of 1000 to 1750 mm per year (Muchiri & Omenda, 2000; Omenda, et al*.,* 2000). In the past, management of plantation forests was regulated through Technical and General Orders which were issued by the former Forest Department and currently the Kenya Forest Service (Mathu & Ng'ethe, 2011). Technical and General Orders describe the quality of the planting site and are specific to tree species and the purpose of planting the tree crop. For example, plantations of cypress and pine establishments are guided by Technical Order No. 4.4.03 and 4.4.06 (MENR, 1996) respectively. Establishment of plantations by *shamba* system is guided by Technical Order No.48 (MENR, 1996). The orders have provisions for prudent forest management practices such as thinning which enhances diameter growth of trees and pruning. Pruning involves removal of dead and live branches so as to ensure knot free timber.

2.3.1 Environmental Services Offered by Plantation Forests

The functions and services provided by plantation forests are many and diverse. For instance, plantation forests have a productive and protective role. Productive functions are primarily geared towards generation of timber, fuelwood and non-wood forest goods such as fodder, apiculture and oils among others (Thompson et al*.,* 2011). Whereas protective plantations forests are established for conservation, recreation, carbon sequestration, water quality control, soil erosion control and rehabilitation of degraded areas. The recognition by the scientific community that plantation management is being compromised by multiple factors which are associated with climate change is of a major concern today (Ramsfield et al*.,* 2016). One of the major environmental issues today is the increase of the carbon dioxide in the atmosphere and its potential effects on climate. Fossil fuels and cement production are two major sources of atmospheric carbon dioxide (Brown et al., 1989; Myneni et al., 2001). Deforestation and other land use practices in the tropics are also significant source of carbon dioxide (Amichev et al., 2008; Lindner et al., 2008). However, the role of mature and secondary plantation forests as sinks of atmospheric carbon dioxide cannot be over emphasized (Brown, 1986; Laclau, 2003). Uptake of carbon is also associated with reforestation and recovering forest vegetation and soils after abandonment.

The focus of forest-based systems for sequestering carbon has largely been on creating permanent stores of carbon on defined areas of land. In terms of forest management, this focus leads to two outcomes, continuing production of timber if the forest area is sufficiently large to create an effective permanent carbon pool, or a cessation of harvesting if the forest area is too small (Bigsby, 2009). Under the provisions of the Kyoto Protocol, numerous countries worldwide agreed to mitigate global climate change by controlling greenhouse gases. The governments and industries of these nations would reduce greenhouse gases by sequestering atmospheric carbon dioxide, or by reducing carbon dioxide emissions (Wright et al., 2000).

According to Laclau (2003) fast growing forest plantations and secondary forests are highly efficient systems for carbon sequestration. The net sequestration effect can be greater for a sustainable harvested forest producing timber products than a forest that is not harvested (Dowell et al., 2009). The harvesting cycles also play a role in the long-term storage of the carbon, as the sooner the forest is harvested to obtain high value commercial logs, the more carbon is stored in the products if the forest is continuously being re-planted at each harvest. However, carbon sequestration potential of a forest ecosystem depends on initial soil organic carbon content, stand growth rates, the site's biological carrying capacity, stand age, and product utilization (Giese et al., 2003; Thurig et al., 2005; Vavrova et al., 2009). This means therefore, more above ground biomass is converted to carbon from softwoods compared to hardwoods, which may indicate that softwoods are more effective for storing carbon. However, this difference is offset to some extent by the fact that, for the same volume, more carbon is stored in hardwoods, which are usually denser than softwoods. Again high value commercial logs are likely to be processed into products that will remain in service longer than products from lower quality logs, thus further extending the term of carbon storage in wood products. Immediately after harvesting following stand regeneration, new forests will begin finding more permanent solutions for carbon sequestration (IPPC, 2000). Determining the magnitude of carbon storage in forests is an important step towards predicting how regional carbon balance will respond to climate change.

2.3.2 Economic Importance of Plantation Forests in Kenya

Forest plantations in Kenya are established mainly to provide timber, pulp and fuel wood, thus easing pressure on natural forests (MENR, 2016). In Kenya forests occupy 6.99% of the total land area, of these plantation forests occupy 135,000 ha which account for 8% of the total forest cover (KFS, 2016). Mt Kenya Forest Reserve, has 18,994 ha of plantation forests distributed in 16 forest stations which includes, Ragati, Hombe, Kabaru, Gathiuru, Naro Moru and Nanyuki among others (KFS, 2010). Mathu and Ng'ethe (2011) observed that forest plantations in Kenya are ranked high as important national assets with significant economic value, for example, before the 1999 national ban on tree harvesting it was estimated that the forestry sector contributed about Ksh320 million per year to Kenya's Gross Domestic Product (GDP). However preliminary results have indicated that the contribution of the forest sector to the economy is at least three times higher than currently reported in official statistics. According to Kilawe and Habimana (2016), this sector provides raw materials worth at least Kshs6.9 billion per year, which is not captured in national accounts. They assert that the forestry and logging sectors supply round wood to the manufacturing sector with a value addition of Kshs21.6 billion. While direct use values in terms of timber, fuelwood and poles were estimated at Kshs3.64 billion in the year 2017 (KFS, 2018). According to KFS (2010), there are an estimated 18,000 hectares of plantations around Mt. Kenya, which are valued at approximately Kshs18 billion. Forest Plantations Resource Accounting [FPRA] (2018) indicated that before the moratorium on log harvesting in 2018, plantation forests were valued to be Kshs61 billion and contributed Kshs3.6 billion to the GDP in the year 2017 (FPRA, 2018).

2.4 Damage on Plantation Forests

Plantation forests all over the world have faced a myriad of management challenges over the years which include; encroachment, excisions, anthropogenic activities including charcoal burning, livestock grazing and game damage among others. The main drivers of forest degradation are; poverty, breakdown in forest law enforcement, governance, and population pressure in the adjacent forest areas and including natural factors such as fires, land slide and drought (Vanleeuwe et al., 2003). For example, according to Government of Kenya [GOK] (2004), 67000 hectares of forest land were excised under unclear circumstances between 2000 and 2003 for development of settlements and Nyayo Tea Zone.

Cypress forest plantations have been known to be affected by fungal diseases, Cypress canker, caused by a parasitic fungus *Monochaetia unicornis*. The fungus causes lesions on the stem of the cypress trees, especially *Cupressus macrocarpa***,** it has also been known to attack *Cupressus lusitanica*. The prevalence of the disease lead to stoppage of planting of *Cupressus macrocarpa* in Kenya despite it being a more superior species in terms of growth and quality timber (Mathu & Ng'ethe, 2011) *Dothistroma pini* is another fungal disease known to weaken the trees and sometimes kill them at a younger age between five to fifteen years. After this (5-15) age, the trees which survive sometimes recover and sprout again. This fungus was responsible for the termination of planting of *Pinus radiata* in Kenya in 1961 (FAO, 2007).

Plantation forests are also damaged by fungi such as *Armillaria mellea* in both *Cupressus lusitanica* and pine plantations (Burleigh et al., 2014; KWS, 2010). Insect pests such as wooly aphid are also a menace to trees, especially the pines. The insect attacks young twigs and needles, weakening the trees and eventually killing them. *Oemida gahani* is another insect species that enters the heart of *Cupressus lusitanica* trees through pruning scars, causing oozing of the sap, thus degrading the quality of the timber (Mathu & Ng'ethe, 2011). *Cryphonectria cancer* and *Cryphonectria cubansis* have been known to attack *Eucalyptus species* including *Eucalyptus gradis* and *Eucalyptus saligna* (KFS, 2009).

Forests plantations are also prone to fires during the dry seasons, which is among the biggest forest health problems. In Kenya, the main sources of fires are from honey hunters, *shamba* clearing, arsonists, illegal grazers and charcoal burning among others (KWS, 2010). Damage to young cypress and pine plantations is caused by rodents (MENR, 1996). In the early years of establishment (four to five years) the bark of cypress and pines are usually smooth and attractive to rodents from ground level upwards. The rodents gnaw the bark to the xylem and circling the tree completely leading to death. The palatable portion of the bark recedes upwards as the tree grows older but the palatability of cypress bark persists indefinitely in the higher portions of the tree (Graham, 1950 as in MENR, 1996).

2.5 Game Damage on Forest Plantations

Studies have shown that game play a significant role in damage on plantation forests. Mutiso et al. (2013) noted that the sykes monkey damage cypress and pines by eating their barks at considerable heights. They cause severe damage to pines by peeling off their barks. Similarly, elephants and buffaloes are persistent problem in forest plantations, either they feed on the succulent bark of the trees, break down or trample on the trees (MENR, 1996; Wass, 1995). The exposure of xylem may however, result in the entry of a Cerambycid, *Oemida gahani,* which by making galleries within the living tree, may render the trunk useless (Mathu & Ng'ethe, 2011).

Damage on plantations forests by game animals is through debarking, top breaking or uprooting. For example, elephants are known to seriously damage or kill trees by removing parts of the canopy by debarking and breaking the stems (Birkett & Stevens-Wood, 2005; Holdo, 2003). Stem breakages by the game disrupt mechanical structure and transport pathways linking the elevated and lower parts of the tree (Vasiliauskas, 2001). Stem damage is also known to reduce mean tree lifetimes (Schoonenberg et al., 2003). Debarking of the tree stems on the other hand impairs growth, reduces the commercial value of the timber and sometimes results in their mortality (Gwenzi et al*.,* 2007). Bark-stripping results in mortality, deformation and stunted growth leading to large economic losses (Katsvanga et al., 2006).
Plantation forest trees also get damaged through fraying (Motta, 1996; Motta & Nola, 1996). Fraying involves the loss of outer bark cambial cells which are either removed or exposed. Fraying sometimes leads to death of trees due to complete girdling (Cermak & Strejcek, 2007; Motta & Nola, 1996). Ndagurwa, (2012) noted that complete girdling is lethal to a tree, whereas partial girdling reduces growth and provides pathways for insect and fungi infestation, and may lead to tree death. Browsers also contribute to damage on plantations as they are known to eat terminal shoots and the side shoots as well as the buds of young plants (Cermak & Mrkva, 2006).

In Europe for example, small ungulates such as red deer (*cervus elaphus L.),* moose (*Alces alces L.)* and grey squirrel (*Sciurus carolinensis*) among others are known to destroy forest plantations. Arhipova et al. (2015) and Gill et al. (2000) found that *Pinus contorta* plantations are susceptible to bark stripping by moose (*Alces alces L.*) Ungulates browsers are also known to strongly influence the structure, composition, growth and succession of forest stands (Motta, 2003). Gacic et al. (2012) in a study conducted in Serbia noted high incidences of bark removal of beech and hornbeam by red deer. While Saint-Andrieux et al. (2009) also observed bark stripping to forest plantations as a major problem in many countries.

In African large herbivorous mammals such as elephants, buffaloes, giraffes, and antelopes, are known to damage trees via browsing, uprooting, and trampling (Birkett & Stephen-Wood, 2005; Dublin *et al*., 1990; Mwalyosi, 1990). Game damage in plantation forests caused by elephants *(Loxodonta africana),* buffaloes *(Synerus caffer)* and syke monkeys (*Cercopithecus mitis)* has been reported across Africa (Sheila & Salim, 2004; Wass, 1995). In Zimbabwe for example, plantation forest industry is threatened by Chacma baboons *(Papio ursinus)* which strip barks of pine trees (Katsvanga et al., 2006) while in Tanzania bark stripping by blue monkeys and elephants have been reported in pine and cypress plantations in Mt. Meru and the slopes of Mt. Kilimanjaro (Afolayan, 1975; Maganga & Wright, 1991). Elephant also destroy trees as they engage in social displays (Guy, 1976; Ssali et al., 2012). In Kenya elephants and buffaloes are known to destroy Pine, Cypress and Eucalypts plantations through debarking, uprooting and trampling (KFS, 2010). The damage has been reported in Gathiuru, Nanyuki, Kabaru, Hombe, Naromoru, Ontulili and Mucheene forest stations among others.

2.5.1 Factors that Influence Game Damage on Forest Plantations

Several factors have been cited to influence game damage to plantation forests. According to Khaleghi (2017) and Nichols et al*.* (2017), game damage on plantation forests is influenced by anthropogenic activities such as fires; charcoal burning and logging others include human settlement, excisions, and water points. Fires are a menace to forests as they destroy thousands of hectares of plantation forests during dry seasons (FAO, 2007). Usually after fires, the succulent grass and vegetation that sprouts attracts game animals in the forest area. Forest logging influences game damage as it creates abundant secondary vegetation that attracts elephants (Barnes, 1999; Lahm, 1996). Natural and artificially maintained water sources attract game animals during drought. Ihwagi et al. (2009) in their study found out that riverine plots had higher number of heavily debarked trees than those which were far away.

Confining game animals to protected areas such as game parks and reserves also affect co-plantations (Guldmond & van-Aarde, 2007). Under such conditions, their foraging and feeding habits reduce tree densities and transform forests and intact woodlands into mixed woodlands and even grasslands (Trollope et al., 1998).

2.6 Tree Characteristics and Game Damage on Forest Plantations

Tree characteristics include; proximity to the natural forest and game parks, age and species. A study done on pine plantations in Finland by Heikkila (1990) revealed that moose browsing occurrence was most common in plantations established on fertile soil with the damage highest in those with openings. Muriithi and Njuguna (1995) also associated game damage of plantation forests to tree characteristics such as open patches within, age, species and distance from natural forest. Thomson (1993) and Morgan (2007) noted that environmental factors such as tree species and variations in their mineral/nutrient content affect use of trees by game animals.

2.6.1 Age and Game Damage on Forest Plantations

Age has been cited by scholars as one the tree characteristics that influence game damage on plantation trees. Malick and Karnet (2007) in a study carried out in Czech Republic found that trees are more vulnerable when young because they have minerals that the game animals require. While Cermak et al. (2004) found that bark stripping occurs with the subsequent penetration of rot in the majority of trees when their age ranged between 15 and 30 years. The rate of the rot spread decreases with the increasing period of infection. Stems cleaned of lower branches show smooth barks which are vulnerable to stripping (Cermak & Strejcek, 2007). The Proportion of trees with stem rot decreased with the age of the stand (Cermak et al., 2004). Thomson (1993) noted that young plantations were more prone to uprooting and breaking by elephants than older ones. While Njuguna and Muriithi (1995) in a study conducted in Mt Kenya and Aberdares found that older *Pinus patula* plantations were more vulnerable to bark stripping than younger ones.

2.6.2 Species and Game Damage on Forest Plantations

Literature reveals game damage on plantation forests is influenced by species. Kamler et al. (2010) in their study examined whether species affects game damage. They noted a significant difference in game damage among tree species. Rowan, beech and douglas fir were affected most while alder, spruce and pine the least. Only minor damage appears in beech plantations. They also observed that tree species which are rich in sodium, potassium, calcium, nitrogen and sugar are more attractive to browsers.

Elephants are known to break trees in search of food and have preferences for species such as marula (Gadd, 2002). The elephants forage in specific patches within an area and on particular species within those patches. Holdo (2003) also noted selective suppression of tree species by elephants and other game animals. Studies conducted in Zimbabwe reported that baboons have a tendency of stripping the barks of *Pinus patula* (Gwenzi et al., 2007; Katsvanga et al*.,* 2006; Katsvanga et al., 2009). Bark stripping by primates is not unique only to pine trees; it has been reported elsewhere on other species (Camperio-Ciani et al*.,* 2001; Huffman, 2007). In a study carried out in Sokoine University by Maganga and Wright (1991) to determine the extent of tree bark stripping caused by blue monkeys *(Cercopithecus mitis)* established that cypress *(Cupressus lusitanica)* was more debarked than pine (*Pinus patula).* Afolayan (1975) and Njuguna and Muriithi (1995) also established that *Pinus patula* suffered more damage among the three exotic tree species of *Cupressus lusitanica* and *Eucalyptus saligna*. The studies reviewed above have confirmed that tree species influence game damage on plantations.

2.6.3 Distance from Natural Forest and Game Damage on Forest Plantations

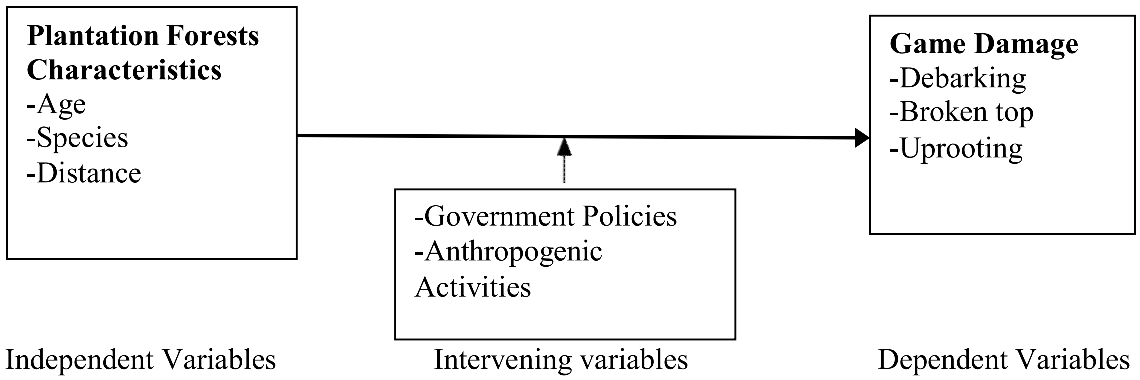
A study conducted by Andren and Angelstam (1993) demonstrated that moose damage was not related to distance from the forest edge. While a study by Thomson (1993a) on economic analysis of damage caused by wildlife on forest plantations along the Western side of Mount Kenya, found out that plantations furthest from the natural forest suffer greatest damage per hectare. The results of Njuguna and Muriithi (1995) study contradicts those of Thomson. They noted that sub- compartments (plantations) which were adjacent to the indigenous forests were more damaged than those neighbouring farms. They attributed this to the fact that game animals felt more secure in their natural habitat especially during day time when there are human activities in the plantation areas. Ssali et al. (2012) observed a higher incidence of elephant damage on plots nearer to the forest edge in Bwindi Impenetrable National Park, Uganda. Similarly, Jerina et al*.* (2008) observed that trees which were nearer to the forest edge were more damaged reaching a maximum at about 600-800 metres from the forest edge.

2.7 Conceptual Framework

In this study the researcher examined the influence of selected tree characteristics on game damage to plantation forests. The selected tree characteristics variables were age, species and distance from natural forest, and game damage. The relationships among the variables are depicted in Figure 1.

Figure 1

Conceptual Framework on Influence of Tree Age, Species and Distance on Game Damage to Plantation Forest.



Plantation forests characteristics as expressed by age, species and distance are the independent variables while damages caused by game animals are expressed in terms of debarking, broken top and uprooting are the dependent variables. The figure shows that government policies and anthropogenic activities are the intervening variables. The figure further shows that under ideal conditions, game damage is influenced only by plantation tree characteristics. However, under dynamic conditions, the association between the constructs is moderated by government policies and anthropogenic activities. The effects of the intervening variable were minimised through sampling by only involving forest stations from one region (S.W. Mt Kenya Forests) which operate under the same policy guidelines within one ecosystem (County Government) and national government. The effects of the intervening variables were further minimized through randomization. Best and Khan (2006) recommended randomization as one of the best methods of minimizing the effects of intervening variables as it ensures that any association between variables is not attributed to chance.

CHAPTER THREE
METHODOLOGY

3.1 Introduction

In this chapter the methods and procedures that were used to collect and analyse data to address the objectives of the study are described. Location of the study, research design, target population, sample size and sampling procedures are outlined. Instrumentation, data collection and analysis are addressed.

3.2 Location of study

This study was conducted in South West of Mt. Kenya forests. South western Mt. Kenya is located on the equator and is 180km north of Nairobi and lies between longitude 37^{o}20' E and latitude of 0^{o} 15'S (KFS, 2010). South west of Mt Kenya forests stations include; Ragati, Hombe, Kabaru, Naro Moru, Gathiuru and Nanyuki (Kahurura) with both natural and plantation forests.

3.2.1 Climate, Geology and Soils

South west of Mt Kenya forest is characterized by diurnal temperature range that is as high as 20^{o} C in January to February (KFS, 2010). The region has two rainy seasons; March to June and October to November with dry months being in January and February (KWS, 2010). The amount of rainfall in the region ranges from 1200mm on the West to 2300mm on the south-eastern slopes which are exposed to wind from the Indian Ocean (Akotsi & Gachanja, 2004).
South west of Mt. Kenya geological features are strongly influenced by valcanicity which consists of basic and intermediate rocks including phonolites, trachytes, basalts, kenytes and syenites. Pyroclastic rocks and volcanic ash originating from various secondary eruptions, these rocks have extensively eroded over time.

Soils in south western Mt. Kenya are influenced by altitude. The upper parts of the mountain have shallow soils and consist of stony dark loams with high organic matter and low bulk density. The types of soils in the area are; Leptosols, Regosols and Greysols, the soils in the lower parts of the mountain consist of Histosols and Nitisols which are deep well drained with angular blocky structure and more than 30 % clay content, Cambisols and Andosols are rich in organic matter with considerable amount of clay.

3.2.2 Biodiversity, Hydrology and Land Use

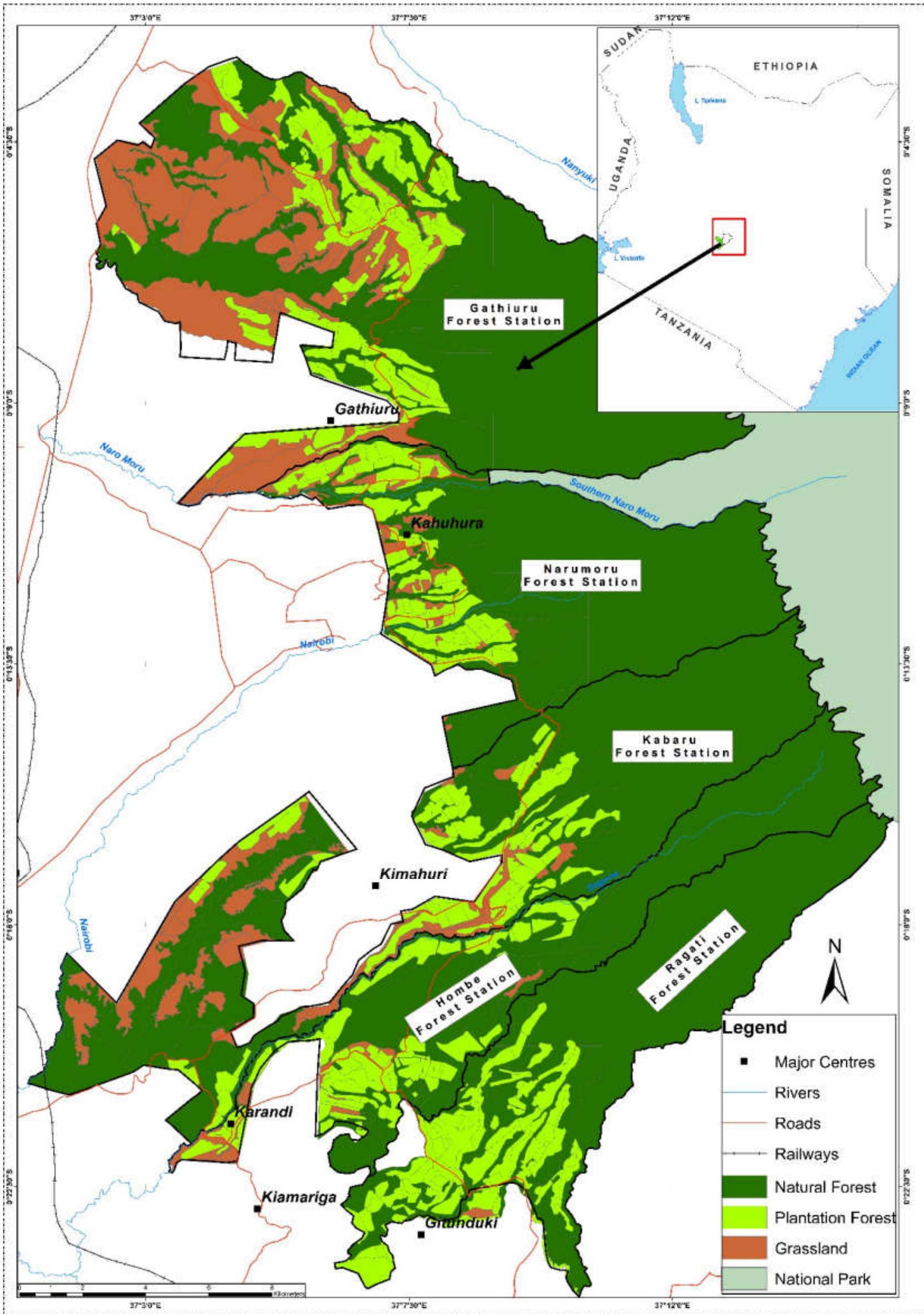
Mt Kenya ecosystem has attractive sceneries and has great potential for tourism development, and is endowed with unique geomorphologic features, cultural and historical sites which are of great attraction to tourists (KWS, 2010). Mount Kenya forest is also gazetted as National Park which falls within the natural forest. The natural forest is rich in flora and fauna and hosts large populations of animal species which include the African elephant (*Loxodonta africana*), buffaloes *(Synerus caffer),* Black rhinoceros (*Diceros bicornis,* White rhinoceros *(Ceratotherium simum simum)* and Grevy's zebra *(Equus grevyi).* It also has several primates, the most common being the black and white Colobus (*Colobus guereza*), Sykes monkey (*Cercopithecus mitis*) and Olive baboon (*Papio anubis*). These primates are widely spread within the Mt Kenya ecosystem (KWS, 2010). The south west of Mt. Kenya comprises of both natural and plantation forests. The natural forest is surrounded by plantation forests which in turn are buffered by Nyayo tea zones. The major tree species in the natural forest are; Cedar (*Juniperus procera*), wild olive (*Olea europaea*), East Africana Rosewood (*Hagenia abyssinica*), Camphor (*Ocotea usambarensis*), *Olea capensis* and *Vitex keniensis* among others. The main plantation tree species planted are; *Pinus patula, Eucalyptus saligna* and *Cupressus lusitanica* (KWS, 1999).

The area is a major economic and ecological importance due to its value as a catchment area. South west Mt. Kenya forest is a source to many rivers and streams which include; Tana, Ewaso Nyiro, Ragati, Sagana, Naro Moru, Burguret, Likii and Sirimon among others (KFS, 2015).

Agriculture is the main economic activity in the areas adjacent to the forest reserve. The main cash crops grown are: tea, coffee, pyrethrum and wheat (Africa Forest Forum, 2011). Subsistence crops such as potatoes, maize, beans and vegetables are also grown. Livestock rearing and agro-forestry are also practiced within the area with many farmers planting *Gravellia robusta, Eucalyptus species Cupressus lusitanica and pinus patula* among others. Various agro-forestry practices have been adopted which include tree woodlots, cropland, homestead and boundary planting. The study location was chosen because of its proximity to Mt. Kenya National Park and high incidences of game damage on plantation forests (Wass, 1995). Figure 2 gives the location of the study area.

Figure 2

Forest Stations within south west of Mt. Kenya



3.3 Research Design

In this study the researcher adopted cross sectional research design. The design was deemed appropriate because data was collected at one point in time. In addition, the researcher examined the influence of tree age, species and distance on game damage without any manipulation of variables.

3.4 Target Population

The target population were all trees in forest plantations in South West of Mount Kenya. The accessible population were cypress, pines and blue gum trees in Ragati, Hombe, Kabaru and Gathiuru forest stations. These forest stations were chosen because they border Mount Kenya National Park which is a habitat to game animals and a sanctuary to elephants and buffalos (KWS, 2010). In addition, the forests records high incidences of game damage on plantations. The three tree species were selected because they are the major commercial plantation tree species grown in Kenya (KFS, 2010).

3.5 Sample Size and Sampling Procedures

The sub compartment was taken as the sampling unit of the study as it is homogeneous in age, species and is subjected to the same silvicultural treatments. A total of 29 sub compartments were selected for the assessment of game damage. The number of sub compartments (29) was determined using the recommendations for determining a sample of a finite population proposed by Kathuri and Pals (1993). The number of plots on each sub compartments from the four stations sampled was determined using proportionate sampling techniques. There were eight sub compartments in Hombe station, eight in Gathiuru, and four in Kabaru while the remaining ten were in Ragati.

At the station level, purposive sampling procedures were used to select the sub compartments (7 in Hombe, 8 in Gathiuru, 4 in Kabaru, 10 in Ragati) which were included in the study. The power of purposive sampling lies in its ability to help researchers select objects/informants' best placed to provide information central to issues being studied (Kombo & Tromp, 2006). The technique enabled the researcher to select those sub compartments that had the characteristics (species, age and distance) required for study. Information on area of the selected sub compartment was extracted from the compartment register. The sub compartment map was traced from plantation maps in a scale of 1:10,000 and a grid sheet used to lay plots proportionate to the area as guided by Technical Note No.116 (Veldhoen, 1969). The most regular corner on the ground was identified and utilized as the point of commencement. Hand held Global Positioning System (GPS) equipment was used to measure the distance from the point of commencement to the nearest first plot. The subsequent plots were selected using systematic sampling techniques. A distance of 150 metres (m) was maintained between plots which spanned on a North – South direction while 125 m distance was maintained on plots in East – West direction. This process was repeated in all the sub compartments in all the four forest stations. A total of 242 plots were generated given that the numbers were proportionate to the area of the sub compartments (appendix b). Each of the plots was circular in shape, measured 0.05 ha in size and had a radius of 12.62m, in conformity with the Technical Note No.116 (Veldhoen, 1969). At the plot level, the centre was marked and the nearest tree to the North recorded as tree number 1. All the trees in the plot were sampled. The 242 plots which were sampled in the study had a total of 19124 trees.

Table 1:

Distribution of the Sampled Trees by Station

Forest Stations	Sub Compartments	Number of trees in sub compartments	Plots	Trees Sampled
Gathiuru	8	92501	64	6201
Hombe	7	49378	43	2011
Kabaru	4	83080	45	4544
Ragati	10	99115	90	6368
Total	**29**	**324074**	**242**	**19124**

3.6 Instrumentation

Game damage forms were used to collection data in this study. The tool was used to generate data on forest station, sub compartment, number of trees in a sub compartment, tree age, species and distance from the natural forest. It was also used to generate data on types of game damage and debarking levels. The instrument was constructed using open and close ended items. The close-ended items were included in the instrument because they are easy to fill, takes little time to complete, keeps the respondent' focused on the subject and are fairly easy to tabulate and analyse (Frankfort & Nachmias, 2009).

3.6.1 Validity of Instruments

The researcher used Game Damage Form to collect data. The instrument was validated by 5 experts (3 Egerton University lecturers and 2 experts from KFS). The experts examined the face and content validity of the instrument in terms of coverage of the theme under investigation, language and whether the tools adequately addressed the study objectives. The recommendations of the experts were used to improve the instrument by reframing the items that were not clear and deleting those which were irrelevant and ambiguous before it was used in the field.

3.7 Data Collection

Data was collected from a total of 29 sub-compartments in Ragati (10), Hombe (8), Kabaru (4) and Gathiuru (8) forest stations and entered in the game damage form. Data on distance was gathered by measuring the distance between the selected sub compartments and the natural forest using the GPS Germine e-Trex 10 equipment. The trees in the plots were examined for bark stripping, uprooting and broken tops and their conditions recorded in the game damage form. Trees that were debarked were examined further and the degree of bark stripping expressed as a percentage of the circumference using a four-point scale (1–25%, 26–50%, 51-75% and 76–100%) adapted from Walker's (1976). After collecting data from all the plots, the filled Game Damage Forms were grouped by station and kept awaiting analysis.

3.8 Data Analysis

The data gathered was cleaned by checking for errors and inconsistencies corrected. The data was then coded and a data entry file developed using the Statistical Analysis System (SAS) computer package. The coded data was then keyed into the data file and analysed with the aid of SAS. Qualitative data was described and summarised using frequencies and percentages. Differences in age of trees were determined using ANOVA. The test was selected because it is ideal for comparing differences of more than two sub-groups of a variable that is measured at interval or ratio scale (Field, 2017). The influences of tree age, species and distance on game damage to plantation forests were determined using the chi-square test for independence and multinomial logistic regression. The Chi-Square was used because it is ideal for establishing the association between constructs that are measured at ordinal or nominal scale (Tabachnick & Fidell, 2007). While multinomial logistic regression was selected because the variables were polytomous categorical data and its ability to explain variations in the dependent variable caused by the factors. According to Madhu et al. (2013) multinomial logistic regression is recommended for exploring relationships between polytomous categorical constructs.

The study also ascertained that the assumptions underlying use of ANOVA and regression tests were not violated. These assumptions include; equality of variance, normality, linearity between the independent and dependent variables, multicollinearity and homoscedasticity. According to Cronk (2012) violation of these assumptions negatively affect the results. Diagnostic test was done to ensure that these assumptions were not violated before conducting the ANOVA and regression procedures. Levene's test was used to check homogeneity of variances, normality was tested using the Kolgomorov Smirnov procedure while linearity between the explanatory variables and the outcome was checked using Pearsons Correlations. Presence of multicollinearity was examined using Tolerance and Variance Inflation Factor (TVIF) statistics while homoscedasticity was detected using the standardized residual scatter plots.

The factors; ages, species and distance from the natural forest categories were transformed into dummy variables before conducting the regression tests. The transformation was deemed necessary because the factors were measured at nominal scale yet regression assumes variables are at ratio or interval scale. Oyeka and Nwankwo (2014) assert that regression assumes that variables are at ratio or interval scale. They recommend use of dummy variables when constructs are at nominal or ordinal scale for regression to correctly test association between constructs. The 1 to 10 years' age group, cypress and 4 km and above were chosen as the baselines (constants) during the regression analysis because they were the most frequent categories. Hayes and Preacher (2014) suggest use of the most frequent category as the baseline variable. During analysis, two dummies (representing 2 variable categories) of each independent variable were regressed on game damage. According to Skrivanek (2009), the recommended number of dummies of a polytomous variable is m – 1 (m is the number of conditions it can take). All the statistical tests were conducted at .05 level of confidence. The statistical procedures used during the study are summarized in Table 2.

Table 2

A summary of the Statistics used in Data Analysis

Hypothesis	Independent variable	Dependent variable	Statistics
HO1: Age does not significantly influence game damage to plantations trees in South West of Mt. Kenya forest.	Age	Game damage	Frequencies, percentages, ANOVA, Chi-Square, multinomial logistic regression
HO2: Species does not significantly influence game damage to plantations trees in South West of Mt. Kenya forest.	Species	Game damage	Frequencies, percentages, Chi-Square, multinomial logistic regression
HO3: Distance from natural forest does not significantly influence game damage to plantations trees in South West of Mt. Kenya forest	Distance from natural forest	Game damage	Frequencies, percentages, Chi-Square, multinomial logistic regression

3.9 Ethical Considerations

Ethics in research refers to application of moral principles in planning a study, data collection and analysis, dissemination and use of the results (Mugenda, 2011). The researcher attempted to adhere to ethical standards set by seeking permission to conduct it from NACOSTI and other relevant National and County government bodies before collecting data. The forest station managers were formally contacted through the Head of Conservancy and the Ecosystem Conservator. The purpose of the study was explained to the forest managers and were requested to facilitate data collection in their forests. The Forest Rangers who provided security during data collection were accorded dignity and respect, in addition, all information provided by the forest personnel was treated with utmost confidentiality. The researcher also acknowledged all the sources cited in the thesis by listing the authors in the reference and did not alter data gathered in the field or modify results to suit his opinion.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction

The results and discussions of the study are presented in this chapter. They are organised in four themes; characteristics of the sampled plantation trees, influence of age, species and distance from the natural forest on game damage.

4.2 Characteristics of Sampled Trees

The characteristics examined were forest stations and sub-compartments from which the trees were drawn.

Table 3

Distribution of the Sampled Trees by Forest Stations

Forest Stations	Sub Compartments	Number of Trees in Sub Compartments	Plots	Trees Sampled
Gathiuru	8	92501	71	6201
Hombe	7	49378	38	2011
Kabaru	4	83080	49	4544
Ragati	10	99115	84	6368
Total	**29**	**324074**	**242**	**19124**

The results in Table 3 reveal that a third (33.3%) of the sampled trees were from Ragati Forest Station while slightly over a quarter were from Gathiuru (26.7%) and Hombe (26.7%) respectively. Kabaru Forest Station provided the lowest (13.3%) number of trees. The sample was representative of the population as all the forest stations in the study area were included in the study.

The sampled trees were examined and their condition categorised as damaged and undamaged. A summary of their condition is given in Table 4.

Table 4

Condition of the Sampled Trees

Condition	Stems	Percentage
Undamaged	2104	10.9
Damaged	17020	89.1

From Table 4 the results show that about nine tenth (89.1%) of the sampled trees were damaged while only a few (11.0%) were undamaged, implying that plantation trees are vulnerable to damage. These findings support those of a study conducted in Latvia by Arhipova et al. (2015) that recorded widespread damage on plantation forests. The damage was associated with red deer (*Cervus elaphus L.)* and moose (*Alces alces L.*). While Malik and Karnet (2007) observed that damage to standing trees by ungulates was one of the most serious problems in Czech forests. In Kenya, Mathu and Ng'ethe (2011) noted that big game such as elephants, buffaloes and syke monkeys (*Cercopithecus mitis)* were a persistent problem in forest plantations as they push over the trees or feed on their succulent barks.

4.3 Influence of Age on Game Damage to Plantation Forest Trees.

The first objective of the study was to establish the influence of age on game damage to plantation forest trees. A hypothesis was drawn from the objective and the Chi-Square and multinomial logistic regression used to test it. The ages of damaged trees ranged from 6 to 30 years. The mean age of the trees was determined as shown in Table 5.

Table 5

Mean Age of the Sampled Trees by Forest Stations

Forest station	N	Mean age	SD
Ragati	4714	14.33	9.47
Hombe	3986	15.00	8.42
Kabaru	3230	15.83	8.47
Gathiuru	5090	13.14	5.84
Overall	**17029**	**14.52**	**7.86**

The results in Table 5 indicate that the mean age of trees in Kabaru (M = 15.8, SD = 8.47) forest station was highest while that of Gathiuru (M = 14.52, SD = 7.86) was lowest. The overall mean age of the sample was 14.52 (SD = 7.86) years. Further examination of the results in Table 5 reveals that the mean ages of the stations were comparable. This was confirmed by conducting the ANOVA test (Table 6).

Table 6

Comparison of Tree Ages by Station

Scale	Sum of Squares	df	Mean Square	F-ratio	P-value
Within Groups	25.551	3	8.519	.125	.945
Between Groups	1705.690	17017	68.228		
Total	**1731.241**	**17020**			

Table 6 shows that the difference in mean tree age among the four forest stations were not statistically significant, F (3, 17017) = 8.517, p>.05). This is an indication that the trees were similar with regard to age. The ages of the damaged trees were converted into ranges; 1-10 years, 11-20 years and 21- 30 years. The ranges were then summarized using frequencies and percentages (Table 7).

Table 7

Ages of the Tree Sample

Age in years	Frequency	Percentage
1 – 10	7700	45.2
11 – 20	5985	35.2
21 – 30	3335	19.6

Most (45.2%) of the sampled trees were in the 1-10 years' age bracket and slightly over a third (35.2%) of the trees were in the 11-20 years' age bracket while about one fifth (19.6%) were in the 21-30 years' age bracket. The results further indicate that the number of stems declined with age. This trend may be attributed to thinning operations usually carried out in forest plantations as they grow to maturity Technical Order No.4.4.03 and 4.4.06 (MENR, 1996). The decline in numbers with age may also be due to attacks on the trees by pests, animals and diseases which at times lead to deaths. The damaged trees were examined and their conditions categorised as debarked, broken top and uprooted as summarised in Table 8.

Table 8

Types of Damage on Plantation Forest Trees

Damage	Frequency	Percentage
Debarked	8234	48.4
Broken Top	3835	22.5
Uprooted	4951	29.1

Table 8 results indicate that nearly half (48.4%) of the trees were debarked, almost a third (29.1%) were uprooted and slightly over a fifth (22.5%) had broken tops. Debarking was the most prevalent type of damage while broken top was the least prevalent. The results are in harmony with those of a study conducted in Serbia by Gacic et al. (2012) which noted high incidences of removal of beech and hornbeam barks by red deer *(cervus elaphus L.)*. The results also support those of Saint-Andrieux et al. (2009) who observed that damage to forest plantation stand is a problem in many countries, with bark stripping being the most prevalent. They attributed the prevalence of bark stripping to the nutritional and medicinal needs of the game. According to Hutchings et al. (2006), bark stripping improves the digestion of game animals and protects them from parasites. The results also support the findings of a study carried out by Tweheyo et al. (2013) which noted debarking was the most prevalent mode of game damage in Kibale National Park. Similarly, a study by Mutiso et al. (2013) in Mt. Kenya and Aberdares ecosystems found out that debarking was the most prevalent type of damage on pines, cypress and eucalyptus plantations carried out by elephants, buffaloes, monkeys and porcupines.

Further analysis was conducted to explore the levels of debarking given that it was the most prevalent type of game damage. Debarking was measured around the tree bole and expressed as a percentage; 25 and below, 26-50, 51-75 and 76-100 and above adapted from Walker's (1976). A summary of the levels of debarking are given in Table 9.

Table 9

Debarking Levels of the Sampled Trees

Debarking Levels	Frequency	Percentage
1 -25%	3770	45.8
26 – 50%	1870	22.7
51 – 75%	1486	18.0
76 – 100%	909	11.0

The results in Table 9 indicate that the most prevalent (45.8%) level of debarking was 1-25% while the least (11.0%) was 76-100% and above level. They also indicate that there was a steady decrease in prevalence of debarking as the level increases and are consistent with those of a study done by Gadd (2002) in South Africa on game feeding behaviour. This study noted that when elephants enter a plantation they gouge trees and taste their barks, if edible, they proceed to peel bigger strips, if not they are abandoned. This may explain the reason why 1- 25% debarking level was common. The results contradict those of a study conducted by Mounford (1997) in Lady Park Wood, United Kingdom who observed that the above 50% level of bark stripping was the most prevalent when the circumference of the tree bole is taken into consideration. It should however be noted that Mounford's study only examined damage on beech trees by the grey American squirrel *(Sciurus carolinensis)*.

Debarking was further explored by examining it with respect to age of the trees. The distribution of the level of debarking by age is presented in Table 10.

Table 10

Distribution of Debarked Trees by Age

Debarking Levels	Percentage		
	1 – 10 years n = 3616	11 – 20 years n = 2704	21 – 30 years n = 1715
1 - 25%	49.5	44.7	44.9
26 – 50%	24.9	21.1	23.3
51 – 75%	15.1	20.1	23.2
76 – 100%	10.5	14.1	8.6

At the age 1 – 10 years, 25% and below (49.5%) bark stripping level was the most prevalent while the 76% and above level (10.5%) was the least prevalent. In the age category of 11 –

20, 25% and below debarking level (44.7%) was still the most prevalent while 76-100% level was the least (14.1) prevalent. The same results were observed among the 21 to 30years age category. An examination of the results indicates that prevalence of debarking steadily decreases as the level increases in all the age groups. This can be attributed to the feeding behaviour of game animals of stripping and tasting tree barks, and feeding on those which are palatable (Gadd, 2002). The distribution of debarking levels by age groups follows a natural pattern where the lower categories are many and the higher ones are few. The broken top type of damaged was explored after examining debarking with respect to age. The distribution of the sampled trees with broken tops by age is given in Table 11.

Table 11

Distribution of Trees with Broken Tops by Age

Age in years	Frequency	Percentage
1 – 10	1947	50.8
11 – 20	979	25.5
21 – 30	909	23.7

The results in Table 11 show that slightly over a half (50.8%) of the trees with broken tops were aged 1-10 years while about a quarter (25.5%) of them were in the 11-20 years' age bracket and 21-30 year's age range were the minority (23.7%). The results further show that as the age increases, the numbers of broken tops decrease indicating that trees are more susceptible to top breakages when they are still young.

The interaction between age and uprooting was also examined during the study. Data on uprooted trees was analysed and summarised by age using frequencies and percentages as recorded in Table 12.

Table 12

Distribution of Uprooted Trees by Age

Age in years	Frequency	Percentage
1 – 10	2137	43.2
11 – 20	2103	42.5
21 – 30	711	14.4

In Table 12 the results revealed that uprooting was highest (43.2%) among trees aged between 1–10 years while lowest (14.4%) among those aged 21-30 years. They also revealed that the number of trees uprooted decline with age. This means that uprooting is highest when trees are young and lowest when they are old.

The influence of age on game damage to plantation forest trees was established using the Chi-square test for independence. This was determined by cross tabulating tree ages (Table 7) with game damage (Table 8). The counts of the cross tabulation are given in Appendix D. Appendix D indicates that the frequency of categories of age and those of game damage on trees were not similar. This is an indication that the two variables are related. According to Pallant (2005), when the proportions of categories of two variables are statistically different, then they are related. Although the results in Appendix D suggest that age and game damage were related, it was not possible to establish whether the association was significant. This necessitated further analysis using the Chi-Square. The Chi-Square test results damage are presented in Table 13.

Table 13

Cross Tabulation between Tree Age and Game Damage

Scale	Value	df	p-value
Pearson Chi-Square	319.037	4	.000*
N	17020		

*Significant at α = ≤ .05 level

The results revealed that association between tree age and game damage was significant at .05 level, Chi-Sq = 319.037, DF = 4, P-Value = 0. 000. This means that age of a tree influences its damage by game animals. These results do not support the first hypothesis which state that age of trees do not influence their damage by game animals. The hypothesis was thus rejected.

The association between age and game damage was further explored using the multinomial logistic regression. The association was determined by regressing age on game damage. Age categories were converted into dummy variables before running the regression procedure. The 1 to 10 years' age was the base line group during the tests and presence of a relationship between the variables was based on the statistical significance of the chi-square in model fitting information (Table 14).

Table 14

Age and Game Damage Multinomial Logistic Regression Model Fitting Output

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	p-value
Intercept Only	381.153			
Final	52.042	329.111	4	.000

Table 14 reveals presence of a statistically significant relationship between age and game damage, Chi-Sq = 329.111, DF = 4, P-Value = 0.000. The overall strength of relationship between the variables was established using the Cox and Snell R Square and the Nagelkerke R square values. The values indicate the amount of variation in the dependent variable explained by the predictors. The Cox and Snell R Square and Nagelkerke R square values were .019 and .022 respectively implies that between 1.9% and 2.2% of variability in game damage is explained by tree age. The effect of each category of the dependent variable on the outcome was derived from the parameter estimates (Table 15).

Table 15

Age and Game Damage Multinomial Logistic Regression Parameter Estimates

Condition of tree		B	Std. Error	Wald	df	P-Value	Exp (B)
Debarked	Intercept	.526	.027	371.581	1	.000	
	11 to 20 years	-.204	.040	26.493	1	.000	.816
	21 to 30 years	.355	.052	45.973	1	.000	1.426
	1 to 10 years	0					
Broken top	Intercept	-.093	.031	8.833	1	.003	
	11 to 20 years	-.671	.050	181.915	1	.000	.511
	21 to 30 years	.339	.059	32.905	1	.000	1.403
	1 to 10 years	0					

The results in Table 15 indicate that the coefficients of debarking-11 to 20 years (B = -204, p = .000) and broken top-11 to 20 years (B = -.671, p =.000) were negative and statistically significant. This is an indication that young trees are more prone to game damage. The other category pairs had positive and significant relationships. The significant relationship between the categories of the dependent variable and those of the independent variables implies that age influences game damage.

Chi-Square and multinomial logistic regression results showed that age of trees significantly influence game damage. They are in harmony with those of Faber and Thorson (1996) who noted that young trees are more prone to debarking because their barks are thin and easily digestible. The barks of young trees are easy to peel and are rich in nutrients which are necessary for animal nutrition (Malick & Karnet, 2007). This makes them susceptible to debarking by game animals. A study conducted in Scotland by Gill et al. (2000) found that *Pinus contorta* is the most susceptible to bark stripping by moose (*Alces alces L.*) at the age of 5-16 years. Similar studies by Arhipova et al. (2015) found that most *Pinus contorta* trees were damaged when relatively young at the age of 7- 20 years.

Lavsund (1987) study conducted in northern Sweden also established that age influences game damage. Evidence from this study showed that older pine trees above thirty years were frequently bark stripped during winter. The researcher attributed this to the fact that pines remain palatable to game animals for a much longer period. Likewise, a study conducted in Western Scotland by Welch and Scott (2017) noted that trees are most vulnerable to damage from the age of 8 to 47. A study carried out in Central Serbia by Gacic et al. (2012) also noted that damage to trees intensifies during winter and autumn, and is influenced by age. The results from this research concurs with that of Afoloyan (1975) conducted in Tanzania who found out that damage by breaking was higher in younger trees than in old ones. The scholar attributed this to the fact that young trees have not developed strong boles while older ones have stronger boles, are taller and are firm on the ground. Mutiso et al. (2013) study in Mt. Kenya and Aberdares ecosystems observed that young plantation trees were more prone to game damaged than old ones.

The results in Table 15 indicate that age influenced game damage. Several reasons have been advanced by scholars to explain this phenomenon. According to Ssali et al. (2012) elephant damage to plantation trees are on a stem to stem basis and is influenced by stem size, species and location. The scholars noted that smaller boles are vulnerable and can easily be pushed over by the elephants to bring foliage within reach during browsing. Similarly, when trees are young, they are relatively short and not steady on the ground, and are vulnerable to broken tops and uprooting by elephants during feeding. This may explain why trees with broken tops decrease with increase in age (Table 11). Similarly, uprooted trees decrease with increase in plantation tree age (Table 12). The decrease in uprooting in category 21-30 years may be due to the fact that older trees are steadier, taller, and more firm on the ground and not easily uprooted.

Game damage is a phenomenon which is common in plantations all over the world and is mostly manifested through bark stripping/debarking, fraying, uprooting, breaking tree tops and trampling among others. Many countries in Europe have reported bark stripping caused by red deer (*Cervus elaphus*), moose (*Alces alces L.*) and grey squirrel (*Sciurus carolinensis*) among others (Andersone-Lilley et al., 2010; Arhipova et al., 2015; Gacic et al., 2012). In Africa destruction of plantations is mostly caused by game animals such as elephants (*Loxodanta africana*), buffaloes (*Synerus caffer*), syke monkeys (*Cercopithecus mitis*) and baboons *(Papio ursinus*) among others (Katsvanga et al*.,* 2009; Tweheyo et al., 2013). In south west of Mt. Kenya game animals are known to debark, uproot, break tree tops and trample on young trees of *Cupressus lusitanica, Pinus patula* and *Eucalyptus saligna* (KWS, 2010; Mutiso et al., 2013). The results in Table 16 and literature indicate that game damage is influenced by age among other factors. It is thus important that managers take into consideration the age factor when developing plantation forest management policies and guidelines.

4.4 Influence of Tree Species on Game Damage in Forest Plantations

The second objective of the study was to find out the influence of tree species on game damage to forest plantation trees. A hypothesis was drawn from the objective and tested using the Chi-Square test for independence. Data on species of the plantation trees was gathered using the tree species data sheet. The researcher considered three tree species namely; *Cupressus lusitanica, Pinus patula* and *Eucalyptus saligna* as summarised in Table 16.

Table 16

Distribution of the Plantation Forest Tree by Species

Species	Frequency	Percentage
Cypress	13250	77.8
Pine	1700	10.0
Blue gum	2070	12.2

The results in Table 16 indicate that *Cupressus lusitanica* were the highest (77.8%) while *Pinus patula* was the lowest (10.0%). These results are in harmony with those of a study conducted by Mathu and Ng'ethe (2011) which showed that cypress accounted for 54% of plantation forest in Kenya while pine and eucalyptus covered 24% and 14% respectively. Similar results were observed by (KFS, 2013) in Gathiuru forest station where *Cupressus lusitanica* accounted for 77%, *Pinus patula* 22% and *Eucalyptus saligna* 11% of plantation forest.

Further analysis was conducted during the study by examining debarking of the plantation trees by species. Frequencies and percentages were used to describe and summarise the levels of debarking by species (Table 17).

Table 17

Distribution of Debarking Levels by Species

Debarking Levels	Percentage		
	Cypress n = 6262	**Pine n = 878**	**Blue gum n = 895**
1 -25%	49.1	36.9	41.8
26 – 50%	24.3	17.1	22.5
51 – 75%	17.3	28.9	16.9
76 – 100%	9.4	17.1	18.9

In Table 17, cypress species, 1-25% level of debarking was the most prevalent (49.1%) while the 76% and above level (9.4%) was the least prevalent. The results also indicate that debarking level for the pine species of 1 – 25% (36.9%) was the most prevalent while 26 – 50% (17.1%) and 76% and above (17.1%) were the least. Table 17 results further reveal that the most prevalent debarking level for blue gum was 1 – 25% (41.8%) while the 51 – 75% level was the least (16.9%) prevalent. An examination of the levels of debarking by species shows that their frequency distributions are not comparable. This suggests that certain tree species (cypress) are more attractive to game animals.

The results indicate that *Cupressus lusitanica* was the most debarked tree species by the game animals. This concurs with the results of a study by Mutiso et al. (2013) which recorded more debarking on Cypress plantations than other species. This study (2008) observed that cypress plantations were fallback sources of food to monkeys in time of scarcity or in absence of more preferred tree species. However, the results contradict those of Kagombe and Gitonga (2005) who noted that pine trees were most vulnerable to game damage. The damage to pines was so rampant that at some point, the Forest Department abandoned planting them (KFS, 2015a; KFS, 2014).

Additional analysis was performed on uprooted tree data by examining it with respect to species. The results of the analysis are in Table 18.

Table 18

Distribution of Uprooted Trees by Species

Species	Frequency	Percentage n = 4951
Cypress	4407	89.0
Pine	397	8.0
Blue gum	147	3.0

The results in Table 18 revealed that most (89.0%) of the trees uprooted were *Cupressus lusitanica* while blue gum was the least (3.0%). The results indicate that *Cupressus lusitanica* is most vulnerable to uprooting while *Eucalyptus saligna is* the least vulnerable species. KFS (2009) attributed this to the fact that *Eucalyptus saligna* has stronger and deeper tap rooting system than the other two tree species of *Pinus patula* and *Cupressus lusitanica* which have fibrous rooting system. These results are similar to those of Mutiso et al. (2013) who found that cypress trees were more prone to uprooting compared to other tree species.
Data on trees with broken tops was analysed further as a way of establishing whether species influence vulnerability of trees to this type of game damage (Table 19).

Table 19

Distribution of Trees with Broken Tops by Species

Species	Frequency	Percentage
Cypress	2581	67.3
Pine	425	11.1
Blue gum	829	21.6

Results in Table 19 reveal that about two thirds (67.3%) of the trees with broken tops were *Cupressus lusitanica* while *Pinus patul*a accounted only to about one tenth (11.1%). The results indicate that cypress and eucalypts are the most susceptible to top breaking. This suggests that species influence tree top breaking and that *Cupressus lusitanica* had the highest number of broken tops. These results differ with those of Njuguna and Muriithi (1995) who found out that *Pinus patula* suffered more broken tops than *Cupressus lusitanica* and *Eucalyptus saligna* trees. The few *Pinus patula* trees with broken tops may be attributed to their low numbers in the study area (KFS, 2015a) compared to *Cupressus lusitanica* and *Eucalyptus saligna*.

The influence of species on game damage was determined using the Chi-Square test for independence. Data on species was cross tabulated with that of game damage. The cross tabulation counts are presented on Appendix D. These results reveal that the proportion of species categories and those of game damage on trees were not comparable. These results suggest that the two constructs are related but it was not possible to establish whether the relationship between the two variables was significant by examining the results, hence the need for further analysis.

The influence of tree species on game damage was established using the Chi-Square test. The results of the test are presented in Table 20.

Table 20

Chi-Square Test Results Relating Tree Species and Game Damage

Scale	Value	df	p-value
Pearson Chi-Square	799.514	4	.000
N	17020		

The Chi-Square test results show that the association between tree species and game damage was significant at the .05 level, Chi-Sq = 799.514, DF = 4, P-Value = 0.000. This is an indication that species influences game damage. On the basis of these observations, the second hypothesis which states that tree species do not influence game damage was rejected. The relationship between tree species and game damage was analysed further using the multinomial regression. The model fitting outputs (Table 21) were used to indicate whether the relationship between tree species and game damage was significant or not.

Table 21

Species and Game Damage Multinomial Regression Model fitting outputs

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	p-value
Intercept Only	946.803			
Final	48.975	897.828	4	.000

The results presented in Table 21 indicate that the relationship between tree species and game damage was statistically significant, Chi-Sq = 897.828, DF = 4, P-Value = 0.000. The Cox and Snell R Square and Nagelkerke R square values were .051 and .059 respectively. This implies that between 5.1% and 5.9 % of the variability in game damage is explained by tree species. The effect of each category of the independent variable on the outcome was then derived from the parameter estimates (Table 22).

Table 22

Species and Game Damage Multinomial Regression Parameter Estimates

Condition of the tree		B	Std. Error	Wald	df	P-value	Exp (B)
	Intercept	.351	.020	319.229	1	.000	
Debarked	Pine	.442	.064	48.393	1	.000	1.556
	Blue gum	1.656	.090	338.360	1	.000	5.238
	Cypress	0					
	Intercept	-.535	.025	465.923	1	.000	
Broken top	Pine	.603	.074	66.315	1	.000	1.828
	Blue gum	2.265	.093	594.820	1	.000	9.629
	Cypress	0					

Table 22 shows that the coefficient of pairs; debarked-pine (B = .442, p = .000), debarked-blue gum (B = 1.656, p =.000), broken top-pine (B = .603, p = .000) and broken top-blue gums (B = 2.265, p =.000) were all positive and statistically significant. This means that the trees species categories influence game damage.

The Multinomial logistic regression and Chi-Square test results indicate that tree species significantly influence game damage. The results support those of a study conducted in

Poland by Zysk-Gorczyn et al. (2016). The scholars observed that bear populations showed a preference for conifer species because of the high sugar levels in freshly-developing vascular tissues. The results also support those of a study conducted in Czech Republic by Malik and Karnet (2007). The duo performed chemical analyses of barks of damaged and undamaged trees and found that damaged pine forest stands were richer in substances such as nitrogen, potassium, phosphorous and elements, which are important for animal nutrition and medicinal needs. Kamler et al. (2010) study noted significant differences in rodent damage by tree species. They observed that rowan, beech and douglas fir were the most affected species while alder; spruce and pine least affected. They further observed minor damage on beech plantations and deduced that tree species influence damage on trees.

The results in Table 22 are in harmony with those of Saint-Andrieux *et al.* (2009) who demonstrated that red deer had preference for beech trees during summer as the tree species is rich in carbohydrates and iron. The results concur with those of a study conducted in Serbia by Gacic et al. (2012) which established that the relationship between tree damage and species was statistically significant. These results are also in harmony with those of Katsvanga et al. (2009b) who noted high incidences of bark stripping of pine trees in plantations of Eastern highlands of Zimbabwe by chacma baboons. Mutiso et al. (2013) recorded that cypress had the highest damage prevalence in Mt Kenya and Aberdare ecosystems. According to KFS (2015b) *Cupressus lusitanica* plantations form the bulk of commercial trees in Kenya that if left to game animals may be a threat to timber industry.

Game animals have also been known to change their preference to some tree species. For example, in a study conducted by Zysk-Gorczynska et al. (2016) in Poland on tree damage by brown bears (*Ursus arctos*) revealed changes in preference from larch, pine and spruce to fir. An earlier study by Njuguna and Muriithi (1995) reported *Pinus patula* to be the most preferred species in south western Mt. Kenya. Thomson (1993a) also found that *Pinus patula* was the most preferred species in that region, however, the animals turned to other tree species when there was a shortage of the preferred ones. Afolayan (1975) recorded high debarking of *Pinus patula* plantations than *Cupressus lusitanica* plantations in Tanzania by elephants. Similarly, a study by Maganga and Wright (1991) in Mt. Meru Tanzania also reported that *Pinus patula* plantations were more debarked than Cypress plantations by blue monkeys *(Cercopithecus mitis)*.

The results in Table 22 support those of a study by Jarnemo et al. (2014) conducted in Norway which revealed that red deer damage to spruce forests was insignificant when they have alternative forage. The results are also in harmony with those of Zysk-Gorczynska et al. (2016) which established that game animals prefer conifers and fir among other tree species in Bieszczady Mountains.

4.5 Influence of Distance from Natural Forest on Game Damage to Plantation Forest Trees

The third objective of the study was to establish the influence of distance on game damage to plantation forest trees. Data on distance of the plantation trees from the natural forest was gathered using the distance data sheet. The distances were categorised as; 1 kilometre and below, 2 to 3 kilometres, and 4 kilometres and above from the natural forest. The data on distances was summarized using frequencies and percentages as shown in Table 23.

Table 23

Distribution of Sampled Plantation Trees by Distance from the Natural Forest

Distance	Frequency	Percentage
1 Kilometre and below	4463	26.2
2 – 3 Kilometres	6213	36.5
4 Kilometres and above	6344	37.3

Table 23 shows that most (37.3%) of the sampled trees were 4 kilometres and above from the natural forest while fewer (26.2%) were from a distance of 1 kilometre and below. The results also show that number of the trees increase with distance from the natural forest. The level of debarking was explored further by examining it with respect to distance from the natural forest. The distribution of levels of debarking by distance is summarised in Table 24.

Table 24

Distribution of Debarked Levels by Distance

Debarking Levels	Percentage		
	1KM and below n = 2614	2 – 3 KM n = 3237	4 KM and above n = 2184
1 -25%	50.1	52.2	35.3
26 – 50%	27.7	20.0	22.8
51 – 75%	14.6	18.6	23.0
76 – 100%	7.6	9.2	18.9

Table 24 results show that 25% and below (50.1%) level of debarking was the most prevalent at a distance of 1 Kilometre and below while 76% and above (7.6%) was the least frequent. At a distance of 2 – 3 kilometres, the most prevalent level of debarking was 25% and below (52.2%) while the least was 76% and above (9.2%). The same results were observed at a distance of 4 kilometres and above. Further examination of the results show that at distances of 1 kilometre and below, and 2 – 3 kilometres, the frequency of debarking decreases with increase in level of debarking. That trend was not observed at distances of 4 kilometres and above. The results on debarking levels indicate that it varies with distance and suggest that it is affected by distance from the natural forest.

After examining the broken tops type of damage by species, further analysis was carried out by examining trees with broken tops by distance from the natural forest. The results of the analysis are presented in Table 25.

Table 25

Distribution of Trees with Broken Tops by Distance from Natural Forest

Distance	Frequency	Percentage
1km and below	1146	29.9
2 – 3 km	1233	32.1
4 km and above	1456	38.0

Results in Table 25 indicate that majority (38.0%) of the trees with broken tops were 4 km and above from the natural forests while minority (29.9%) were at a distance of 1 kilometre and below. The results also indicate that the number of trees with broken tops steadily increases with distance from the natural forest pointing to the fact that trees located farthest from the natural forest are most susceptible to top breaking.

Trees which were uprooted were further examined with respect to distances from the natural forests and is given in Table 26.

Table 26

Distribution of Uprooted Trees by Distance from Natural Forest

Distance	Frequency	Percentage
1km and below	703	14.2
2 – 3 km	1544	31.2
4 km and above	2704	54.6

Results in Table 26 reveal that uprooting is highest (54.6%) at 4 km and above from the natural forest and lowest (14.2%) at 1 kilometre and below. The results further reveal that uprooting steadily increases with distance. This means that the further a forest plantation trees are from the natural forest, the more vulnerable they are to uprooting.

After examining data on tree plantations' distances from the natural forest, its influence on game damage was determined. The association between the two constructs was established by cross tabulating the tree plantations distances (Table 23) and game damage (Table 8). The expected and observed counts of the cross tabulation are in Appendix F.

The results in Appendix D indicate that the frequency of categories of distance from the natural forest across categories of game damage is not comparable. For example, at distances of 4 kilometres and above, the observed counts across game damage are 2614 for debarked, 1146 for broken top and 703 for uprooted. The results suggest that the two variables are related since the counts are not comparable. The Chi-Square test for independence was conducted to establish whether the association between distance of tree plantations from the natural forest and game damage was significant. The results of the test are presented in Table 27.

Table 27

Chi-Square Test Results between the Distribution of Plantation Trees by Distance from Natural Forest and Game Damage

Scale	Value	df	p-value
Pearson Chi-Square	1163.419	4	.000
N	17020		

The results in Table 27 show that the association between distance of plantation trees from natural forest and game damage was significant at .05 level, Chi-Sq = 1163.419, DF = 4, P-Value = 0.000. This means that distance of plantation trees from natural forest influence game damage, implying that game animals tend to damage trees furthest from the natural forest. The third hypothesis which states that there is no significant relationship between distance from natural forest and game damage was thus rejected.

Further analysis on the relationship between distance from the natural forest and game damage was conducted using the multinomial logistic regression. The model fitting table (Table 28) presents the relationship between the two constructs.

Table 28

Distance from Natural Forests and Game Damage Regression Output Model Fitting

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	p-value
Intercept Only	1241.987			
Final	52.079	1189.908	4	.000

The results in Table 28 indicate that relationship between distance from the natural forest and game damage was statistically significant, Chi-Sq = 1189.908, DF = 4, P-Value = 0.000. The Cox and Snell R Square and the Nagelkerke R square values showed that distance from natural forest accounted for between 6.8% and 7.7% variation in game damage. The coefficients of categories of the independent variable were also determined as shown in the parameter estimates in Table 29.

Table 29

Distance from Natural Forests and Game Damage Parameter Estimates of the Regression

Condition of the tree		B	Std. Error	Wald	df	Sig.	Exp (B)
	Intercept	-.214	.029	55.109	1	.000	
Debarked	1 km & below	1.527	.051	885.501	1	.000	4.604
	2 to 3 km	1.014	.042	581.517	1	.000	2.755
	Intercept	-.619	.033	362.670	1	.000	
Broken top	1 km & below	1.108	.058	366.092	1	.000	3.027
	2 to3 km	.394	.050	61.751	1	.000	1.483
Uprooted		0					

The results in Table 29 reveal that the coefficient of pairs; debarked-1 km and below (B = 1.527, p = .000), debarked-2 to 3 km (B = 1.014, p =.000), broken top-1 km and below (B = 1.108, p = .000) and broken top-2 to3 km (B = .394, p =.000) were all positive and statistically significant. This is an indication that the categories of distance from the natural forest influences those of game damage.

These results in Tables 27 and 29 indicate that game damage is influenced by distance of plantation from natural forest. Lombardini et al. (2016) noted that wild boar damage to trees was inversely related to distance from natural forests. In a similar study by Jerina et al. (2008) on red deer, bark stripping on spruce showed that damage initially increases with distance to the nearest forest edge and reaches its maximum at about 600-800 metres from the forest edge. These findings are in harmony with the observations of Thomson (1993a) who found out that plantations in south western Mount Kenya which were far from the natural forest were attacked more than those which were closer to the natural forest. According to Thomson plantations which were furthest from the natural forest suffered greatest damage where distances involved are only a few kilometres of up to 5 kilometres. This can be attributed to the feeding behaviour of the game animals, where they rush out in large in numbers to get the best forage from the outer forest edge where it is warmer compared to deep natural forests. The preference is on the vegetation which is still undisturbed and is found in the furthest distances from the natural forest.

However, these results contradict those of Andren and Angelstam (1993) whose study revealed that moose damage was not related to distance to the forest edge. While Njuguna and Muriithi (1995) noted that sub-compartments (plantations) in Mount Kenya and Aberdares which were adjacent to the indigenous forests were more damaged than those neighbouring agricultural farms. The duo argued that game animals feel more secure in their natural habitat especially during day time when there were human activities in plantation forest areas.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Findings

i. The results revealed that the association between tree age and game damage was statistically significant at .05 level, χ^2 (4, N = 17020) = 319.037, $p < .05$ and that younger plantations were more damaged than older plantations.

ii. The association between tree species and game damage was significant at the .05 level, χ^2 (4, N = 17020) = 799.514, $\rho < .05$ and forests plantation of *Cupressus lusitatnica* were the most destroyed tree species in south west of Mount Kenya while *Eucalyptus saligna* were the least destroyed.

iii. That the association between distance of plantation trees from natural forest and game damage was significant at .05 level, χ^2 (4, N = 17020) = 1163.419, $p<.05$, sub compartments which were farthest away from the natural forests were more destroyed than closer sub compartments.

5.2 Conclusions

i. Plantation forests within south west of Mount Kenya are seriously being destroyed by game animals, younger plantations have been seen to suffer more damage than older plantations leading to a conclusion that age has an influence on the destruction of the plantations by the game animals.

ii. Based on the second objective, plantation forests of *Cupressus lusitatnica* were the most destroyed tree species in south west of Mount Kenya while *Eucalyptus saligna* were the least destroyed. It is therefore concluded that tree species has a significant influence on damage to tree plantations by the game animals.

iii. Results from the third objective led to the conclusion that destruction to plantation forest trees were common in sub compartments which were farthest away from the natural forests which are the habitats of the game animals. It is therefore concluded that distance has significant influence on game damage destruction.

5.3 Recommendations

It was observed in this study that age, species and distance from natural forest influence game damage. On the basis of these observations the following recommendations were made:

a. Young plantations should be protected from the game animals possibly by erecting electric fence and / or planting plantation tree species which are not palatable.

b. Introduction of a wide variety of other plantation tree species should be pursued to ease pressure from the three exotic plantation tree species.

c. KFS in consultation with KWS should develop policies and put in place mechanisms that ensure natural forests provide game animals with basic needs like forage, water and salt licks to contain them within their habitat.

5.4 Suggestions for further research

Even though this study provided valuable findings, it also offered insight of issues that remain unanswered and require further investigation.

i. The study was limited to physical damage on plantation forests and hence there is need to conduct studies that cover economic losses and impact on timber grading.

ii. A study to examine nutrient composition of the tree species with a view of finding what makes others more attractive to game.

iii. Anthropogenic activities on the habitat of the game animals need to be investigated further as they influence game behaviour

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APPENDICES

Appendix A: Game Damage Form

Serial No…………………….

Date: ………………………….

1. Forest Station Ragati ( ) Hombe ( ) Kabaru ( ) Gathiuru ( ) 2.
Sub Compartment Number ………………………………………………………
3. Age of the sub compartment 1 – 10 years ( ) 11 – 20 years ( ) 21 – 30 years ( )
4. Species Cypress ( ) Pine ( ) Blue gum ( )
5. Distance from natural forest 1 Kilometre and below ( ) 2 – 3 Kilometres ( )
4 Kilometres and above ( )
6. Number of trees ……………………………………………………….
7. Tree condition

Condition	**Stems**
Undamaged	
Debarked	
Broken top	
Uprooted	

8. Level of Debarking

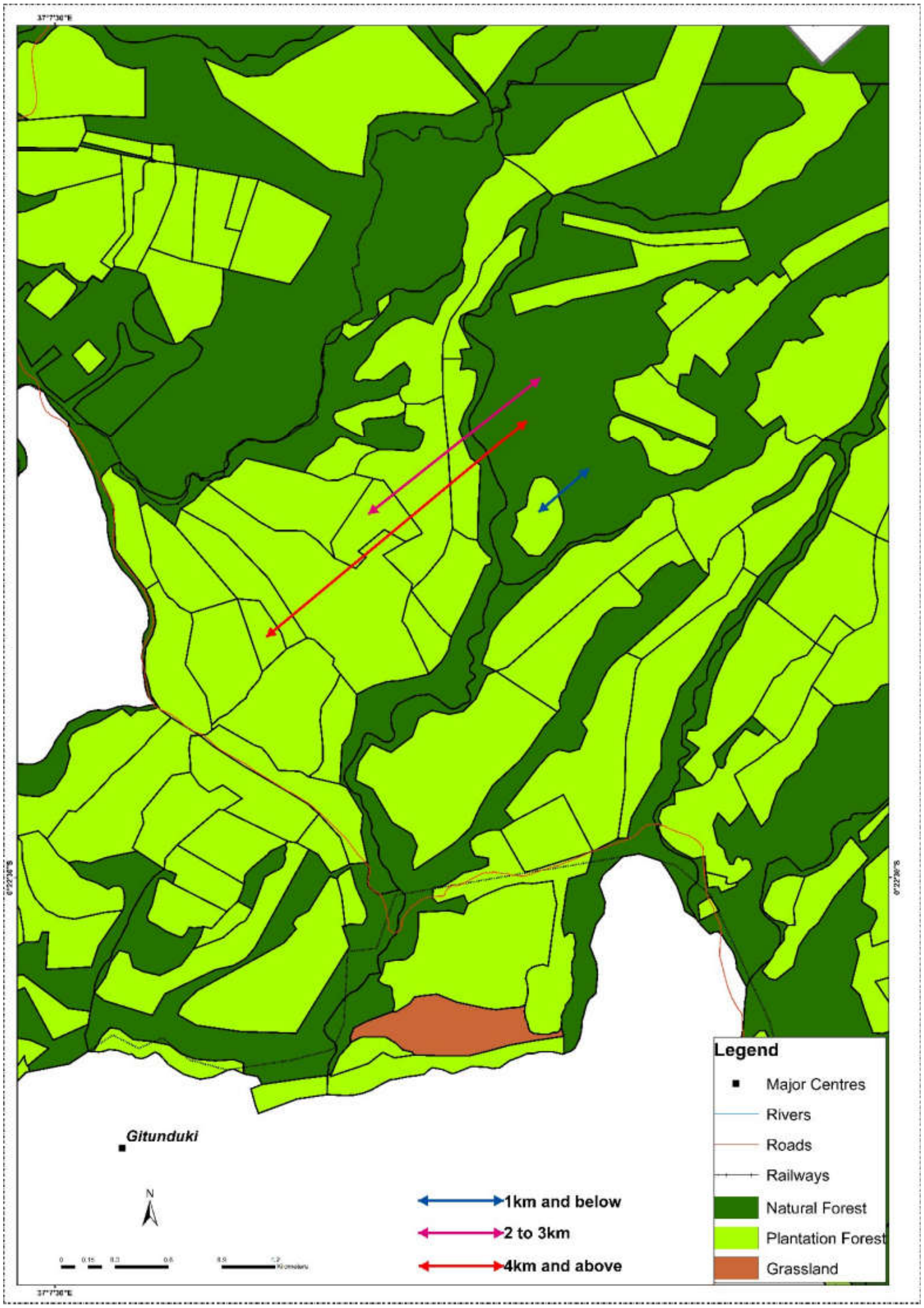
Debarking level	**Number of stems**
1 – 25%	
26 – 50 %	
51 – 75%	
76 % and above	

Appendix B: Sub Compartments Sampled in Forest Stations

Station	Sub compartment	No. of Plots	Species	Age (Yrs)	Area in Ha	SPH	Total No. of trees
Ragati	Ragati Hombe 2N	4	Cup lus	12	9.1	500	4550
Ragati	Ragati Hombe 2K	24	Cup lus	13	47.2	625	29500
Ragati	Ragati Hombe 2J	4	E. sal	11	8	650	5200
Ragati	Ragati Hombe 2D	6	P. patula	30	12.3	425	5228
Ragati	Ragati 2F	17	Cup lus	15	32.1	725	23273
Ragati	Ragati 3Y	4	Cup lus	30	9.6	475	4560
Ragati	Ragati 3L	13	Cup lus	6	24.6	700	17220
Ragati	Ragati 2Q	2	Cup lus	6	1.5	1050	1575
Ragati	Ragati 3K	10	Cup lus	6	17.8	450	8010
Hombe	Hombe 4A	2	P. patula	10	4.5	475	2138
Hombe	Hombe 4C	5	E. sal	9	8.9	500	4450
Hombe	Hombe 4D	2	P. patula	30	4.5	575	2588
Hombe	Hombe 4G	8	Cup lus	23	14.0	425	5950
Hombe	Hombe 4F	4	E. sal	10	7.8	450	3510
Hombe	Hombe 5B	8	Cup lus	8	15.2	900	13680
Hombe	Hombe 5C	9	Cup lus	15	17.5	975	17063
Kabaru	Kabaru 9K	21	Cup lus	27	40.6	850	34510
Kabaru	Kabaru 10L	4	Cup lus	14	7.6	825	6270
Kabaru	Kabaru 9M	5	Cup lus	6	9.7	900	8730
Kabaru	Kabaru 9F	6	P. patula	25	11.4	400	4560
Kabaru	Kabaru 9C	10	Cup lus	9	21	1250	26250
Kabaru	Kabaru 10D	3	E. sal	14	6.9	400	2760
Gathiuru	Gathiuru 2V	8	Cup lus	13	16	1100	17600
Gathiuru	Gathiuru 2F	13	Cup lus	25	23.5	900	21150
Gathiuru	Gathiuru 2C	7	Cup lus	10	13.9	450	6255
Gathiuru	Gathiuru 2M	2	Cup lus	8	3.5	950	3325
Gathiuru	Gathiuru 2P	11	Cup lus	8	21.8	875	19075
Gathiuru	Gathiuru 2H	17	E. sal	14	31.6	225	7110
Gathiuru	Gathiuru 5N	13	Cup lus	14	21.8	825	17985
Total	29	242			451.6		318,846

Source: Self, 2018

Appendix C: Distances of Plantations Sampled from the Natural Forests



Appendix D: Analysed data

Cross tabulation of tree age and game damage

Age in years	Counts	Damage		
		Debarked	Broken top	Uprooted
1 - 10	Observed	3616	1947	2137
	Expected	3725.1	1735	2239.9
11 - 20	Observed	2903	979	2103
	Expected	2895.4	1348.6	1741
21 - 30	Observed	1715	909	711
	Expected	1613.4	751.5	970.1

Cross tabulation of tree species and game damage counts

Species	Counts	Damage		
		Debarked	Broken Top	Uprooted
Cypress	Observed	6262	2581	4407
	Expected	6410.1	2985.5	3854.3
Pine	Observed	878	425	397
	Expected	822.4	383	494.5
Blue gum	Observed	1094	829	147
	Expected	1001.4	466.4	602.1

Cross tabulation of plantation tree distance from natural forest and game damage counts

Distance	Counts	Damage		
		Debarked	Broken top	Uprooted
1 Kilometer and below	Observed	2614	1146	703
	Expected	2159.1	1005.6	1298.3
2 to 3 Kilometers	Observed	3436	1233	1544
	Expected	3005.7	1399.9	1807.3
4 Kilometers and above	Observed	2184	1456	2704
	Expected	3069.1	1429.5	1845.4

		Plots	Percent	Valid Percent	Cumulative Percent
Valid	Gathiuru	8	26.7	26.7	26.7
	Hombe	8	26.7	26.7	53.3
	Kabaru	4	13.3	13.3	66.7
	Ragati	10	33.3	33.3	100.0
	Total	30	100.0	100.0	

Condition of the trees in the sampled plots

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	undamaged	2104	11.0	11.0	11.0
	debarked	8234	43.1	43.1	54.1
	broken top	3835	20.1	20.1	74.1
	uprooted	4951	25.9	25.9	100.0
	Total	19124	100.0	100.0	

Age of trees

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 - 10 years	7700	45.2	45.2	45.2
	11 - 20	5985	35.2	35.2	80.4
	21 - 30 years	3335	19.6	19.6	100.0
	Total	17020	100.0	100.0	

Age of trees by species

Species			Frequency	Percent	Valid Percent	Cumulative Percent
Cypress	Valid	1 - 10 years	6025	45.5	45.5	45.5
		11 - 20	4665	35.2	35.2	80.7
		21 - 30 years	2560	19.3	19.3	100.0
		Total	13250	100.0	100.0	
Pine	Valid	1 - 10 years	925	54.4	54.4	54.4
		21 - 30 years	775	45.6	45.6	100.0
		Total	1700	100.0	100.0	
Blue gum	Valid	1 - 10 years	750	36.2	36.2	36.2
		11 - 20	1320	63.8	63.8	100.0
		Total	2070	100.0	100.0	

Age of trees by distance

Distance from natural forest			Frequency	Percent	Valid Percent
1 Kilometre and below	Valid	1 - 10 years	2575	57.7	57.7
		11 - 20	586	13.1	13.1
		21 - 30 years	1302	29.2	29.2
		Total	4463	100.0	100.0
2 to 3 Kilometres	Valid	1 - 10 years	2175	35.0	35.0
		11 - 20	2805	45.1	45.1
		21 - 30 years	1233	19.8	19.8
		Total	6213	100.0	100.0
4 Kilometres and above	Valid	1 - 10 years	2950	46.5	46.5
		11 - 20	2594	40.9	40.9
		21 - 30 years	800	12.6	12.6
		Total	6344	100.0	100.0

Age of the tree

Distance from natural forest			Cumulative Percent
1 Kilometre and below	Valid	1 - 10 years	57.7
		11 - 20	70.8
		21 - 30 years	100.0
		Total	
2 to 3 Kilometres	Valid	1 - 10 years	35.0
		11 - 20	80.2
		21 - 30 years	100.0
		Total	
4 Kilometres and above	Valid	1 - 10 years	46.5
		11 - 20	87.4
		21 - 30 years	100.0
		Total	

Damage on trees

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	debarked	8234	48.4	48.4	48.4
	broken top	3835	22.5	22.5	70.9
	uprooted	4951	29.1	29.1	100.0
	Total	17020	100.0	100.0	

Level of debarking

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	25% and below	3770	45.8	46.9	46.9
	26 - 50%	1870	22.7	23.3	70.2
	51 - 75%	1486	18.0	18.5	88.7
	76% and above	909	11.0	11.3	100.0
	Total	8035	97.6	100.0	
Missing	System	199	2.4		
Total		8234	100.0		

Level of debarking by age

			Level of debarking			
Age of the tree			Frequency	Percent	Valid Percent	Cumulative Percent
1 - 10 years	Valid	25% and below	1791	49.5	49.5	49.5
		26 - 50%	901	24.9	24.9	74.4
		51 - 75%	545	15.1	15.1	89.5
		76% and above	379	10.5	10.5	100.0
		Total	3616	100.0	100.0	
11 - 20	Valid	25% and below	1209	41.6	44.7	44.7
		26 - 50%	570	19.6	21.1	65.8
		51 - 75%	543	18.7	20.1	85.9
		76% and above	382	13.2	14.1	100.0
		Total	2704	93.1	100.0	
	Missing	System	199	6.9		
	Total		2903	100.0		
21 - 30 years	Valid	25% and below	770	44.9	44.9	44.9
		26 - 50%	399	23.3	23.3	68.2
		51 - 75%	398	23.2	23.2	91.4
		76% and above	148	8.6	8.6	100.0
		Total	1715	100.0	100.0	

Level of debarking by species

Species			Frequency	Percent	Valid Percent	Cumulative Percent
Cypress	Valid	25% and below	3072	49.1	49.1	49.1
		26 - 50%	1519	24.3	24.3	73.3
		51 - 75%	1081	17.3	17.3	90.6
		76% and above	590	9.4	9.4	100.0
		Total	6262	100.0	100.0	
Pine	Valid	25% and below	324	36.9	36.9	36.9
		26 - 50%	150	17.1	17.1	54.0
		51 - 75%	254	28.9	28.9	82.9
		76% and above	150	17.1	17.1	100.0
		Total	878	100.0	100.0	
Blue gum	Valid	25% and below	374	34.2	41.8	41.8
		26 - 50%	201	18.4	22.5	64.2
		51 - 75%	151	13.8	16.9	81.1
		76% and above	169	15.4	18.9	100.0
		Total	895	81.8	100.0	
	Missing	System	199	18.2		
	Total		1094	100.0		

Level of debarking by distance

Distance from natural forest			Frequency	Percent	Valid Percent
1 Kilometre and below	Valid	25% and below	1309	50.1	50.1
		26 - 50%	725	27.7	27.7
		51 - 75%	382	14.6	14.6
		76% and above	198	7.6	7.6
		Total	2614	100.0	100.0
2 to 3 Kilometres	Valid	25% and below	1690	49.2	52.2
		26 - 50%	647	18.8	20.0
		51 - 75%	602	17.5	18.6
		76% and above	298	8.7	9.2
		Total	3237	94.2	100.0
	Missing	System	199	5.8	
	Total		3436	100.0	
4 Kilometres and above	Valid	25% and below	771	35.3	35.3
		26 - 50%	498	22.8	22.8
		51 - 75%	502	23.0	23.0
		76% and above	413	18.9	18.9
		Total	2184	100.0	100.0

Level of debarking

Distance from natural forest			Cumulative Percent
1 kilometre and below	Valid	25% and below	50.1
		26 - 50%	77.8
		51 - 75%	92.4
		76% and above	100.0
		Total	
2 to 3 Kilometres	Valid	25% and below	52.2
		26 - 50%	72.2
		51 - 75%	90.8
		76% and above	100.0
		Total	
	Missing	System	
	Total		
4 Kilometres and above	Valid	25% and below	35.3
		26 - 50%	58.1
		51 - 75%	81.1
		76% and above	100.0
		Total	

Broken tops by age of trees

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 - 10 years	1947	50.8	50.8	50.8
	11 - 20	979	25.5	25.5	76.3
	21 - 30 years	909	23.7	23.7	100.0
	Total	3835	100.0	100.0	

Broken top by species

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Cypress	2581	67.3	67.3	67.3
	Pine	425	11.1	11.1	78.4
	Blue gum	829	21.6	21.6	100.0
	Total	3835	100.0	100.0	

Broken top by distance from natural forest

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 kilometre and below	1146	29.9	29.9	29.9
	2 to 3 kilometres	1233	32.2	32.2	62.0
	4 kilometres and above	1456	38.0	38.0	100.0
	Total	3835	100.0	100.0	

Crosstabs Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Age of the tree * Condition of the tree	17020	100.0%	0	0.0%	17020	100.0%

*Age of the tree * Condition of the tree Cross tabulation*

Count

		Condition of the tree			Total
		debarked	broken top	uprooted	
Age of the tree	1 - 10 years	3616	1947	2137	7700
	11 - 20	2903	979	2103	5985
	21 - 30 years	1715	909	711	3335
Total		8234	3835	4951	17020

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	319.037[a]	4	.000
Likelihood Ratio	329.111	4	.000
Linear-by-Linear Association	18.415	1	.000
N of Valid Cases	17020		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 751.45.

Objective 2: Trees Species sampled

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Cypress	13250	77.8	77.8	77.8
	Pine	1700	10.0	10.0	87.8
	Blue gum	2070	12.2	12.2	100.0
	Total	17020	100.0	100.0	

Sampled tree species by age

Age of the tree			Frequency	Percent	Valid Percent	Cumulative Percent
1 - 10 years	Valid	Cypress	6025	78.2	78.2	78.2
		Pine	925	12.0	12.0	90.3
		Blue gum	750	9.7	9.7	100.0
		Total	7700	100.0	100.0	
11 - 20	Valid	Cypress	4665	77.9	77.9	77.9
		Blue gum	1320	22.1	22.1	100.0
		Total	5985	100.0	100.0	
21 - 30 years	Valid	Cypress	2560	76.8	76.8	76.8
		Pine	775	23.2	23.2	100.0
		Total	3335	100.0	100.0	

Tree species by distance

Distance from natural forest			Frequency	Percent	Valid Percent	Cumulative Percent
1 kilometre and below	Valid	Cypress	3963	88.8	88.8	88.8
		Pine	500	11.2	11.2	100.0
		Total	4463	100.0	100.0	
2 to 3 Kilometres	Valid	Cypress	5086	81.9	81.9	81.9
		Pine	400	6.4	6.4	88.3
		Blue gum	727	11.7	11.7	100.0
		Total	6213	100.0	100.0	
4 kilometres and above	Valid	Cypress	4201	66.2	66.2	66.2
		Pine	800	12.6	12.6	78.8
		Blue gum	1343	21.2	21.2	100.0
		Total	6344	100.0	100.0	

Crosstabs Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Species * Condition of the tree	17020	100.0%	0	0.0%	17020	100.0%

*Species * Condition of the tree Cross tabulation*

			Condition of the tree			Total
			debarked	broken top	uprooted	
Species	Cypress	Count	6262	2581	4407	13250
		Expected Count	6410.1	2985.5	3854.3	13250.0
	Pine	Count	878	425	397	1700
		Expected Count	822.4	383.0	494.5	1700.0
	Blue gum	Count	1094	829	147	2070
		Expected Count	1001.4	466.4	602.1	2070.0
Tota l		Count	8234	3835	4951	17020
		Expected Count	8234.0	3835.0	4951.0	17020.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	799.514[a]	4	.000
Likelihood Ratio	897.828	4	.000
Linear-by-Linear Association	264.988	1	.000
N of Valid Cases	17020		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 383.05.

Objective 3 influence of distance from natural forest on damage

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 kilometre and below	4463	26.2	26.2	26.2
	2 to 3 kilometres	6213	36.5	36.5	62.7
	4 kilometres and above	6344	37.3	37.3	100.0
	Total	17020	100.0	100.0	

Distance from natural forest by species

Species			Frequency	Percent	Valid Percent	Cumulative Percent
Cypress	Valid	1 kilometre and below	3963	29.9	29.9	29.9
		2 to 3 kilometres	5086	38.4	38.4	68.3
		4 kilometres and above	4201	31.7	31.7	100.0
		Total	13250	100.0	100.0	
Pine	Valid	1 kilometre and below	500	29.4	29.4	29.4
		2 to 3 kilometres	400	23.5	23.5	52.9
		4 kilometres and above	800	47.1	47.1	100.0
		Total	1700	100.0	100.0	
Blue gum	Valid	2 to 3 kilometres	727	35.1	35.1	35.1
		4 kilometres and above	1343	64.9	64.9	100.0
		Total	2070	100.0	100.0	

Distance from the forest by age

Age of the tree			Frequency	Percent	Valid Percent	Cumulative Percent
1 - 10 years	Valid	1 kilometre and below	2575	33.4	33.4	33.4
		2 to 3 kilometres	2175	28.2	28.2	61.7
		4 kilometres and above	2950	38.3	38.3	100.0
		Total	7700	100.0	100.0	
11 - 20	Valid	1 kilometre and below	586	9.8	9.8	9.8
		2 to 3 kilometres	2805	46.9	46.9	56.7
		4 kilometres and above	2594	43.3	43.3	100.0
		Total	5985	100.0	100.0	
21 - 30 years	Valid	1 kilometre and below	1302	39.0	39.0	39.0
		2 to 3 kilometres	1233	37.0	37.0	76.0
		4 kilometres and above	800	24.0	24.0	100.0
		Total	3335	100.0	100.0	

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Distance from natural forest * Condition of the tree	17020	100.0%	0	0.0%	17020	100.0%

*Distance from natural forest * Condition of the tree Cross tabulation*

			Condition of the tree	
			debarked	broken top
Distance from natural forest	1 kilometre and below	Count	2614	1146
		Expected Count	2159.1	1005.6
	2 to 3 kilometres	Count	3436	1233
		Expected Count	3005.7	1399.9
	4 kilometres and above	Count	2184	1456
		Expected Count	3069.1	1429.5
Total		Count	8234	3835
		Expected Count	8234.0	3835.0

*Distance from natural forest * Condition of the tree Cross tabulation*

			Condition of the tree	Total
			uprooted	
Distance from natural forest	1 kilometre and below	Count	703	4463
		Expected Count	1298.3	4463.0
	2 to 3 kilometres	Count	1544	6213
		Expected Count	1807.3	6213.0
	4 kilometres and above	Count	2704	6344
		Expected Count	1845.4	6344.0
Total		Count	4951	17020
		Expected Count	4951.0	17020.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1163.419[a]	4	.000
Likelihood Ratio	1189.908	4	.000
Linear-by-Linear Association	998.526	1	.000
N of Valid Cases	17020		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 1005.62.

Trees uprooted by age, species and distance Age of the tree

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 - 10 years	2137	43.2	43.2	43.2
	11 - 20	2103	42.5	42.5	85.6
	21 - 30 years	711	14.4	14.4	100.0
	Total	4951	100.0	100.0	

Species

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Cypress	4407	89.0	89.0	89.0
	Pine	397	8.0	8.0	97.0
	Blue gum	147	3.0	3.0	100.0
	Total	4951	100.0	100.0	

Distance from natural forest

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 Kilometer and below	703	14.2	14.2	14.2
	2 to 3 Kilometers	1544	31.2	31.2	45.4
	4 Kilometers and above	2704	54.6	54.6	100.0
	Total	4951	100.0	100.0	

Objective 2 re-tested Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Age of the tree * Condition of the tree	17020	100.0%	0	0.0%	17020	100.0%

*Age of the tree * Condition of the tree Cross tabulation*

			Condition of the tree			Total
			debarked	broken top	uprooted	
Age of the tree	1 - 10 years	Count	3616	1947	2137	7700
		Expected Count	3725.1	1735.0	2239.9	7700.0
	11 - 20	Count	2903	979	2103	5985
		Expected Count	2895.4	1348.6	1741.0	5985.0
	21 - 30 years	Count	1715	909	711	3335
		Expected Count	1613.4	751.5	970.1	3335.0
Total		Count	8234	3835	4951	17020
		Expected Count	8234.0	3835.0	4951.0	17020.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	319.037[a]	4	.000
Likelihood Ratio	329.111	4	.000
Linear-by-Linear Association	18.415	1	.000
N of Valid Cases	17020		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 751.45.

Appendix E: Permit to Collect Data

KENYA
Forest Service

Kenya Forest Service Hqs
Karura, Off Kiambu Rd
P.O. Box 30513 - 00100
Nairobi, Kenya

Ref: No. FIB/1/15/VOL.II/229

Date: 9th April, 2012

RE: RE: REQUEST FOR PERMISSION TO CARRY OUT RESEARCH ON INFLUENCE OF GAME DAMAGE IN FOREST PLANTATIONS IN RAGATI, HOMBE, KABARU AND GATHIURU IN FOREST STATIONS IN NYERI ECOSYSTEM

Reference is hereby made to your letter on the above subject matter dated 5th of April, 2012.

After consideration on your request you are hereby granted permission to proceed with your research entitled "*Influence of Tree Age, Species and Distance on Game Damage to Plantation Forests in South West of Mount Kenya*". However, you will be expected to meet transport cost and lunches for the Forest Rangers who will be providing security to you during the research period as the forest areas you intent to cover are habitants of wild animals which may be dangerous to human life.

By a copy of this letter the Ecosystem Conservator Nyeri is hereby instructed to make arrangements with the Forest Station Managers to provide you with security on a daily basis starting from 16th of April, 2012 to 11th of May, 2012.

Monica Kalenda

FOR; CHIEF CONSERVATOR OF FORESTS

Trees for better lives

Tel: (254)020-3754904/5/6, (254)020-2014663, (254)020-2020285, Fax: (254)020-2385374
Email: info@kenyaforestservice.org. Web: www.kenyaforestservice.org

Appendix F: Abstract of Published Journal Article

Researchjournali's Journal of Forestry
Vol. 8 | No. 2 October | 2021
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Tree Species As A Correlate Of Game Damage To Plantation Forests In South West Of Mount Kenya

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Professor Elias K. Maranga
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ABSTRACT

Game damage to forest plantations in South West of Mount Kenya is a threat to the development and

ABSTRACT

Game damage to forest plantations in South West of Mount Kenya is a threat to the development and management of forests. Tree species have been reckoned among factors which influence game damage to plantations in many parts of the world. There is little and conclusive information on the impact of game damage on commercial plantations in Kenya. In this paper we have examined the influence of tree species on game damage to plantation forests in south western Mount Kenya. The objective of the study was to generate evidence on the influence of tree species on game damage to plantation forests in a biodiversity conservation area under the purview of the Kenya Forest Service. An operationalized cross sectional research design was used. The sample points, sub compartments and the 19124 trees used in the study were selected using systematic random sampling techniques. Primary data was collected using an observation schedule complemented with secondary data from the Kenya Forest Service and Kenya Wildlife Service. Data was analysed with the aid of Statistical Analysis Systems (SAS). Qualitative procedures were used to describe and summarise data while influence of tree species on game damage was determined using the Chi-Square and multinomial regression. The Chi-Square test indicated that the association between tree species and game damage were statistically significant (X^2 [4, n =17020=799.51, $p\leq .05$). The multinomial logistic regression corroborated the fact that tree species accounted for a significant variation in game damage (R^2 = .051- .059). Forest plantations of Cupressus lusitanica were the most destroyed species in south west of Mount Kenya while Eucalyptus saligna were the least destroyed.

Key words: Forest, game damage, plantation, species, conservation

1. BACKGROUND INFORMATION

Forests contribute significantly towards man's wellbeing and provide a means for servicing human obligations such as supply of clean air as well as provision of ecosystem services. Regulation of microclimate and hydrologic balance, pollination, nutrient cycling, detoxification, provision of carbon sinks through carbon assimilation and nitrogen sequestration are critical ecosystem services. Ecosystem goods of natural forests include wood, timber for construction, and wood biomass for production of fuel energy (Ichikawa, 2014, Agrawal *et al.*, 2013). Forest habitats constitute a natural home for wildlife and provide intangible benefits such aesthetic, spiritual and social values to humans (Forestry Society of Kenya [FSK], 2006; Ingram *et al.*, 2016). Many people in developing countries still rely on forests for pharmaceutical remedies that are derived from indigenous plants (Food and Agriculture Organization [FAO], 2011).

Studies have shown that game animals play a significant role in damage of plantation forests (Ihwagi, 2009; Mutiso, *et al.*, 2013). They damage forest plantations through fraying, trampling, debarking, top breaking or uprooting (Holdo, 2003). Small ungulates such as red deer (*cervus elaphus L.),* moose (*Alces alces L.)* and grey

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squirrel (*Sciurus carolinensis*) among others are known to destroy forest plantations in Europe. Browsers also