ABUNDANCE AND CONSERVATION STATUS OF *PRUNUS AFRICANA* IN WESTERN MAU FOREST, KENYA

CHEBET GLADYS (B. ED SCIENCE)

I56/CE/21143/2010

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF DEGREE OF MASTER OF SCIENCE (PLANT ECOLOGY) IN THE SCHOOL OF PURE AND APPLIED SCIENCES, KENYATTA UNIVERSITY

MARCH, 2020

DECLARATION

I hereby declare that this thesis is my original work and has not been presented for a degree or other awards in any other university.

Signature …………………… Date 3/03/2020

Gladys Chebet

Department of Plant Sciences

Kenyatta University

We confirm that the work reported in this thesis was carried out by the candidate under our supervision as University supervisors;

SUPERVISORS:

Signature …………………… Date 3/3/2020

Prof. Paul K. Mbugua

Department of Plant Sciences

Kenyatta University

Signature …………………… Date 3/3/2020

Dr. Rebecca N. Karanja

Department of Plant Sciences

Kenyatta University

DEDICATION

To my dear father Mr. **Willy Koskei**, my late mother Mrs. **Anne Koskei**, my loving husband **Mr. Geoffrey Mutai** and my children Laura, Brandon and Clinton. Your inspiration and support kept me going.

ACKNOWLEDGEMENTS

My Sincere and special thanks go to my supervisors, Prof. Paul K. Mbugua and Dr. Rebecca N. Karanja for the professional guidance they offered tirelessly in supervising the project from its inception to its completion.

Special thanks also go to Londiani KEFRI for providing me with equipments which enabled me to undertake my research. Special thanks go to forest guards and field assistants such as Mr. Boaz Ngonga, Mr. Dickson Onono and Mr. William Bii for their assistance and taking me through Western Mau forest during my research.

I am also grateful to my friends at Kenyatta University, especially the staff from Department of Plant Sciences for their support and encouragement throughout my study. Lastly, my heartfelt gratitude and thanks to my family for the patience and perseverance endured during the thesis write up.

To everybody else who contributed either materially or morally in one way or the other towards the achievement made in this study, thanks a lot and may God bless you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABBREVIATIONS

ANOVA	_	Analysis of Variance
BPH	_	Benign Prostatic Hyperplasia
CITES	_	Convention on International Trade in Endangered Species of wild Flora and Fauna
DBH	_	Diameter at Breast Height
DRSRS	_	Department of Remote Sensing and Resources Survey
FAO	_	Food and Agricultural Organisation
GPS	_	Global Positioning System
IUCN	_	International Union for the Conservation of Nature
ICIPE	_	International Centre of Insect Physiology and Ecology
KEFRI	_	Kenya Forest Research Institute
KIFCON	_	Kenya Indigenous Forest Conservation
SPSS	_	Statistical Package for Social Sciences

OPERATIONAL DEFINITION OF TERMS

Endangered plant species - Plants that are in danger of extinction and whose survival is unlikey if the causal factors continue operating.

Vulnerable plant specie - Plants that are believed to move into the endangered category in the near future if the causal factors continue operating.

Rare plant species - Plants with small populations, difficult to find and not at present endangered or vulnerable, but are at risk.

Seedling - Ayoung plant which is less than 1.35m high.

Sapling - Ayoung tree which is larger than a seedling but smaller than a tree. The height is less than 4.5m high.

Tree - It is a perennial woody plant that develops along a single main trunk. The height is greater than 4.5m high.

ABSTRACT

Prunus africana (Hook. f) Kalkman, 1965 (formerly *Pygeum africanum* Hook.f) is a geographically widespread tree restricted to highland forest of main land Africa and outlying islands. The species is commercially important for its bark, which is used in the treatment of prostate gland disorders. It also produces high quality timber used locally for building poles and furniture as well as fuel wood. The high demand for the bark has led to notable destruction of the species in natural forests, leading to concerns on the long term sustainability of harvesting and the conservation of the species. Despite the fact that Mau forest is a protected area, the region experiences illegal exploitation with *P. africana* being one of the main targets. The tree is of great demand for its strong timber and highly medicinal bark making its population to be under threat. As a result *P. africana* is listed as vulnerable species under Appendix II of CITES. In this study, information on *P. africana* was obtained mainly from literature survey while population data was obtained by sampling methods. The study was conducted in Western Mau forest (longitude E35^{0}27.05' to E35^{0}39.42' and latitude 0^{0}10'46''S to 0^{0}17'42''S) which is found in the South Rift region, Kericho county. Transects were laid across four blocks in Western Mau forest and diameter at breast height (dbh) and height of mature trees measured. The level and causes of disturbances were collected using questionaires and through observation and recorded for each of the plots. Saplings were counted and recorded in subplots and seedlings counted in micro plots. Densities of seedlings, saplings and mature *P. africana* trees were examined across the Western blocks of Mau forest. A socio-economic survey was further conducted to determine community perceptions on the status of the tree under study. The data generated were analyzed using both descriptive and inferential statistics. Data on height and dbh were summarized as mean ± SE and variations tested using one way ANOVA. Socio-economic data were mainly analyzed in form of proportions and variations between sites tested using chi-square statisctics.Data was presented in histograms, tables and graphs. Inferential statistics revealed significant variation in the density of saplings ($p<0.05$). Majority of the mature trees were of height between 20m and 40m though this height varied significantly between the blocks. As concerns dbh, most of the trees ranged between 40cm and 50cm with a signigficant variation between the blocks. The seedling numbers exceeded saplings and trees, suggesting potential for regeneration and population increase even though the population is not increasing. Observations showed that human activities, herbivory and diseases pose serious threats to *P. africana* tree. The local community was of the opinion that the main anthropogenic activities affecting the tree are unsustainable de-barking, logging, and animal grazing. It was recommended that awareness creation be organized regularly for all stakeholders on sustainable de-barking and logging be greatly regulated to save this tree of great value to mankind. The local community and more so those who rely on the tree for herbal medicine should be encouraged to grow the tree in their homestead gardens to reduce the pressure on wild trees thereby enhancing its conservation.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Forests are one of the man's greatest natural resourcesand are sources of numerous raw materials, such as medicinal extracts,timber and fuel wood (Moser and Hansen, 2006).They are also important in the exchange of matter between the geosphere and atmosphere, as habitats of numerous faunal and floral species and a key player in environmental protection (FAO, 2015). Many indigenous communities living in forests or adjacent to them have evolved cultures intertwined with these ecosystems and are known for their rich ethnobotanical knowledge (Chazdon, 2008). Under normal circumstances, species in natural forest display a complex, stable and self sustaining relationship that is a result of many years of evolution (Pan *et al*., 2013). Therefore, conservation of individual species, particularly those threatened is required in order to protect the roles and functions of these reserves.

In East Africa, the distribution of forest ecosystems and tree species is largely determined by the climate, altitude, latitude, edaphic and historical factors (Gray and Bond, 2015). However, human activities, especially in the past two centuries, have emerged as the most important factor affecting the distribution of forests and tree species (Davidson *et al*., 2005). Human exploitation of forest resources has been unprecedented and is reducing their spatial distribution through selective harvesting and deforestation to pave way for settlements, farming and exotic plantations (MacDicken, 2015).

The African cherry (*Prunus africana*) is a widespread tree in montane habitats of Africa, providing multiple uses for the peoples throughout its range. About 50 years ago, bark extracts were found to be effective in the treatment of prostate cancer *(Benign Prostatic Hyperplasia)* and therefore of high economic value (Ochwang'i *et al*., 2014). The bark extract is manufactured into various herbal products.Currently, *P. africana* bark is entirely collected from the wild, although attempts at cultivation are underway in Kenya (Jimu, 2011).Prior to the discovery in 1966 as an effective herbal remedy, *P. africana* was a relatively common montane species. The treehas been the subject of several studies addressing several ecological and socio-economic aspects (Stewart, 2001; Stewart, 2003; Davidson *et al*., 2005; Wittemyer*et al*., 2008; Stewart, 2009; Jimu, 2011).In Kenya, the tree has several local names depending on the region found and tribes. Some of these local names in Kenya include Muiri (Kikuyu), Muritsa (Luhya), Mweria (Meru),Tenduet (Nandi/Kipsigis), and Kanukwa (Tugen) among others.

Prunus africana is geographically widespread forest tree, restricted to African highland forests, generally above 1000m in altitude (Hall, 2000). It extends along an escarpment /rift mountains and volcanoes, from latitude 33^0 40'S in South Africa to latitude 11^o 55'N, near the Gulf of Aden. There are extensions west into central Africa and disjunct populations in Western Africa and islands of Comoros and Madagascar (Hall, 2000). The distribution appears to be associated with climatic conditions (especially temperature and forest regimes) rather than elevations. *P. africana* has been reported in many African countries such as Angola, Democratic Republic of Congo (DRC), Ethiopia, Kenya, Malawi, Mozambique, South Africa, Swaziland, Sudan, Tanzania, Uganda, Zambia and Zimbabwe. Islands where the species occur are Bioko, Grand Comore, Madagascar and Sao Tome (Hall, 2000). This species occurs mainly at altitudes above 1500m in Kenya

(Navarro-Cerrillo *et al*., 2008). It occurs in moist evergreen forests, riverine, often in remnants or on forest margins between 1350-2750 m above sea level (Navarro-Cerrillo *et al*., 2008). It is common in Mt. Kenya, Aberdares, Kakamega, and Cherangani forests. It also occurs in Timboroa, Nandi, Tugen hills and western part of Mau forest (Nguta, 2012).

Trees are a part of our heritage and should be saved from extinction. Most trees occur in areas where human influence is diminishing their habitat (Musila *et al*., 2009).Over the past several decades, African cherry populations have been declining in many forests due to unsustainable bark exploitation for international medicinal plants trade (Hall, 2000; Betti, 2008). Following the discovery in1966 that an extract from *P. africana* bark effectivelytreats prostate gland hypertrophy and benign prostatichyperplasia, pharmaceutical companies began hiringAfricans to collect *P. africana* bark for export to Europe(Fashing, 2004; Orwa *et al*., 2009). Since that time, the amount of *P. africana* barkstripped from African forests has increased exponentially, with a greater than 17-fold increase during the period 1980–1999 alone (Orwa *et al*., 2009). Unfortunately, much of this exploitation has been irresponsible with entire treesbeing girdled of their bark and left to die or, in othercases, felled to facilitate easier access to their bark (Orwa *et al*., 2009). This massive increase in the intensity of *P. africana* bark harvesting over a relatively short period prompted CITES to categorize the species as Appendix II and IUCN to list it asVulnerable (IUCN, 2002). Despite the protection afforded by these designations, *P. africana* remainsAfrica's most intensively exported medicinal plant speciesby volume (Cunningham *et al*., 2002).Several studies and surveys have provided evidence ofthe adverse effects large-scale bark harvesting has on *P. africana* populations (Cunningham *et al.,* 2002; Orwa *et al*., 2009).

Prunus africana is a tall (6-30m high), light-demanding evergreen tree patchily distributed in montaneforests, forest remnants or forest margins. In the tropics, *P. africana* is found between 1200-3000 m above sea level, but further south, where cooler latitudes compensate for altitude, it occurs atlower elevations. At the extreme southern end of its range, at theBloukrans River, Cape Province, South Africa, it therefore occurs close to sea level. As a light-demanding tree species that reproduces primarily from seed, *P. africana* is generally single stemmed, developing multi-stems when saplings are browsed. Although young trees re-sprout, forexample if browsed by forest antelopes or goats, large trees have weak re-sprouting capability. The fruits are bitter tasting drupes less than 10mm in diameter and are eaten by a wide range of animals. Seeds are recalcitrant and germinate best when fresh, losing viability quickly so that few seeds older than 6 months are viable. Ripe fruits germinate well in partial sunlight after a short drying period in an airy, shaded place. The seeds are dispersed by birds and non-human primates.

Despite the fact that *P. africana* leaves contain higher levels ofcyanogenic glycosides compared to most other African montane tree species, their leaves are one of the mostpreferred food sources for red Columbus monkeys (Chapman and Chapman, 2002) and black and white Columbus monkeys (Fashing, 2004). Die-off of *P. africana* trees is causing serious concern aboutColumbus monkey conservation in Kakamega forest, Kenya (Fashing and Mwangi, 2004).

Although it is a light demanding tree species which under good conditions can grow to 14 m high and 37cm diameter at breast height in 18 years, *P. africana* is a long-lived tree species with very heavy, dense wood. At 12% moisture content, the wood weighs 1090kg/m3 (Gachie, 2002). Fruit production starts when trees are around 15 years old and increases with tree age, with high fruitproduction years alternating with low fruit production years (Stewart, 2001). As a shade-intolerant tree species, natural forest disturbance coupled with fruit dispersal into canopy gaps or onforest margins are important to landscape level population biology of *P. africana.* This also accountsfor the scattered distribution of this species in African forests. The annual mortality of adult-sized *P. africana* trees in natural populations was considered to be 1.5% per year (Stewart, 2001). Based on the study of tree growthand mortality in African mortality rates of trees with diameters at breast height (dbh) greater than 10 cmaveraged 0.71% per year (Betti, 2008). The mortality of the larger dbhin commercially harvested wild populations can be more than 50 times higher than natural mortality rates.

P. africana is a fast growing species and the seeds germinate easily, however the seeds need to be planted within six weeks of collection (Mligo *et al*., 2009). The possible keystone function of *P. africana* within forests in maintaining their integrity is therefore a key consideration. However, although the fruit of *P. africana* is eaten by a number of threatened birds and other animal species (Fashing and Mwangi, 2004) none of these appear to be critically dependent on *P. africana* but appear to be generalist frugivores that may feed off a number of fruits. Moreover, the density of mature *P. africana* trees in forests is generally low (Kireger, 2003), suggesting that the quantity of fruit produced is limited and unlikely to compose a large part of the diet of birds and other mammal species.

Human anthropogenic destruction of forests and natural habitat fragmentation of a small size forest population cover has increased and has now become a significant threat to maintenance of biodiversity in many terrestrial ecosystems (Clasen*et al*., 2015). The most important striking changes in the ecosystems have been observed to be as a result of mans' interference through clearance, fire and grazing.The processes affect large areas of the montane forest belt by degradation of the forest leading to loss of biodiversity and genetic diversity (Lienert, 2004).

In Cameroon,the bark was initially harvested in a sustainable manner under the control of an exporting company. However, the licensing of local contractors with the intention of stimulating the industry broke the monopoly control of the exporting company which led to over exploitation of the tree (Rembold *et al*., 2013). Instead of stripping two opposing quadrants of bark from standing trees (which allows bark regeneration), trees were felled and all the bark removed. In the past 10 years the annual harvest of *P.africana* bark has risen to approximately 3500 tons,most of which comes from destructive felling of trees (Sedano *et al*., 2016).

Destruction of *P.africana* in natural forest has raised concerns regarding the long term sustainability of harvesting and conservation of the species.Consequently *P. africana* is listed as threatened species under Appendix II of the Convention on International Trade in Endangered Species of wild fauna and flora (CITES). Appendix II status means that although trade is not banned,it must be strictly regulated under a licensing regime. *P. africana* is also listed as a vulnerable species with a risk of extinction in the conservation Database of the World Conservation Monitoring Center (Nguta, 2012), where it is classified as “VUALCD”. FAO has also classified it as one of the 18 top priority species for action in Africa (Nguta, 2012). Although species for sustainable use exist in the areas where exploitation is highest,regulations are often not enforced due to a lack of resources and potential will (Apollonio *et al*., 2017). Natural regeneration of *P.africana* is episodic,because of irregular seeding and the lighting requirements of seedlings,which cannot develop under dark forest floor conditions (Jaenicke *et al*., 2000). This coupled with insurance harvesting of the species decimates populations in natural forests. Incorporation of *P.africana* into agro forestry system appears to be one of the few ways of ensuring its survival and the sustainability of bark production for the pharmaceutical industry (Ryan *et al*., 2012; Chidumayo and Gumbo, 2013; Zulu and Richardson, 2013). Such plantings will benefit the farmer from the sale of bark and timber and reduce the pressure exerted on natural forest stands. The tree grows well in open and may therefore be intercropped with food crops (Orwa *et al*., 2009).

In Kenya the forest department is known to have established plantations of the species within Kenya highlands as early as 1913 for timber production (Navarro-Cerrillo *et al*., 2008).The planting of *P. africana* by farmers in Kenya is also increasing as they have already realized the value of the species.With the assistance of a number of donors, the International Center for Research in Agro forestry (ICRAF) has started the domestication of the species (Nguta, 2012).The main important issue to be addressed in the domestication programme of *P. africana* is the lack of planting material. Erratic flowering and seeding in *P. africana* coupled with the fact that the approximate time for first flowering and fruiting is 15 -20 years,compounds the unavailability of sustainable planting material. Moreover the seed of *P. africana* is recalcitrant (Jaenicke *et al*., 2000). However, some progress in the area of propagation techniques including seed storage and vegetation propagation has been reported (Jaenicke *et al*., 2000).

1.2 Statement of the Problem and Justification

Although Western Mau forest is protected by law, illegal exploitation of forest resources continues (IUCN, 2002), further degrading this habitat. It is estimated that there has been annual global forest loss of 0.2% between the years 1990 and 2000 comprising of 94000 km^2in the 10 year period. Most of this loss was observed in Africa (53000 km^2) whereas in Kenya the annual loss was quantified at 0.5% annual forest loss, which is 930 km^2 forest cover over the 10 year period (FAO,2003). Even though the rate of loss of forest cover in Kenya may appear to be small, it is worth noting that the Kenyan forest cover was 30% of national area in the year 2000 (Kelatwang and Garzugli,2006).This kind of annual loss would thereforehave a significant negative effect on the ecology of forests.In Western Mau forest in Rift valley,there has been anthropogenic activities such as conversion of forests for agriculture land and extractive use of forest products resulting into deforestation. Consequently, only small fragments of intact forest remains. Extractive use of forest products targets several species with *P. africana*.being one of those under facing the pressure.

Information on the ecology, population structure and distribution of *P. africana* in Western Mau, Kenya is lacking. Researchers have concentrated on other aspects of the forest hence research on this heavily exploited and threatened species needs to be carried out. Periodic data collection on the status of endangered species such as *P. africana* is very critical as an effective way of monitoring forest reserves. *P. africana* is used globally as a medicinal tree and therefore traded in both local and global markets making it endangered across its range as a result of unsustainable harvesting. In the Western Mau forest however, the driver is not known. This study focuses on ecological survey of *P. africana* in Western Mau forest, Kenya. It also seeks to identify causes of scarcity and ways that can be done to conserve the species.

1.3 Hypotheses

i. There is no difference in population structure, abundance, and distribution of *P. africana* in Western Mau forest.

ii. Human activities do not have significant negative influence on the population structure of *P. africana* tree.

iii. Herbivores and plant diseases do not pose serious threat to seedling conservation of *P. africana*.

1.4 Objectives

1.4.1 General Objective

The overall objective of this study is to examine the status of selected attributes of the threatened medicinal *P. africana* tree in Western Mau forest, Kenya.

1.4.2 Specific Objectives:

i. To determine the population structure and abundance of *P. africana* in Western Mau Forest.

ii. To assess the uses of *P. africana* and community perception on its value and status across Western Mau Forest.

iii. To determine the influence of human activitieson the population structure and abundance of *P. africana* in Western Mau Forest.

iv. To assess the influence of herbivory and diseases on the population structure and abundance of *P. africana* in Western Mau Forest.

CHAPTER TWO: LITERATURE REVIEW

2.1 Population Structure and Distribution

Prunus africana is an African tree and exhibits different population structure and distribution pattern between different African countries. Until the late 1960s, the tree was known only for its timber, as fuel and as a traditional medicine (Stewart, 2001). Cameroon has the longest history of bark harvest, and most studies of the harvest are from here,particularly from Mount Cameroon.The dire state of the remaining populations of *P. africana* in Cameroon appears to be due to complex and inter-related social and economic factors. For example, until the late 1980s, hundreds of square kilometers surrounding Mount Oku in the North West province were completely forested. Today only10,000 ha of montane forest remain. The same case applies in Madagascar (Stewart, 2001).

In South Africa, *P. africana* has a limited distribution and small harvest occurs in the Eastern and Transkei Mist-belt forest located in the eastern montane regions generally between the cities of Umtata and Peitermaritzburg. The tree can be described as scarce in Rwanda which is corroborated by lack of harvest from the country (Ingram *et al*., 2009). In Kenya, cultivation trials have been conducted, but large scale plantations are not yet in production (Kuijper, 2011). Mature trees are also exploited for their timber. Following harvest of mature trees for local and export timber products, Farwig *et al*. (2007) examined the Kakamega forest in Western Kenya and found few saplings and young trees, suggesting poor recruitments resulting from the removal of mature trees, poor germination or herbivory on seedlings.

2.2 Uses of *Prunus africana*.

2.2.1 Medicinal Use

Benign prostatic hyperplasia (BPH) is a non malignant enlargement of the prostate gland that affects most men over the age of 40 years leading toinability to empty the bladder, pain when passing urine and post urinary dribbling (Betti, 2008). BPH is diagnosed by the presence of prostatic enlargement and lower urinary tract blockage. The etiology of BPH is still unknown but it appears to be an age dependent alteration of the androgen balance associated with reduction of testosterone dihydrotestosterone (DHT) by the enzyme 5-alpha –reductase (Hall,2000).

Treatments of BPH include surgery, balloon dilation, hyperthermia, phytotherapy and pharmaceuticals containing anti androgens and 5-alpha reductase inhibitors (Nguta, 2012). Castration was previously used as a cure of BPH but this practice though effective, is expensive, causes impotence and urinary inconsistency not to mention a 1-3% post operative mortality rate (Hall, 2000). Therefore, medical therapy and phytotherapy using *Serenoa repens* extract, *curcubita pepo* seed and *P.africana* are popular alternatives (Betti, 2008).

Prunus africana bark extract has been found to contain several lipid soluble substances such as fatty acids (C_{12}-C_{24}),phytosterols (free and conjugated sitosterols, composterol), pentacyclic terpenoids and aliphatic alcohols (ndetracosaanol and n-decosano) and the extract varies among different *P.africana* provenances (Stewart, 2003).

The active ingredients and compounds directly involved with the treatment of BPH have not been fully identified (Hall, 2000). The therapeutic effect is therefore thought to be a synthetic action of different compounds counteracting the biochemical and functional changes of the BPH. According to Hall (2000), pharmacologically active compounds that can interfere with BPH development include phytosterols, pentacyclic tripenes and ferulic esters of long chain fatty acids. It has been suggested that phytosterols may be inhibitors of prostgladin synthesis in the prostatic tissue and contribute in counteracting the inflammation common with BPH. Pentacyclic tripenes inhibit the action of glucosyl transferase, thereby reducing the inflammation while ferulic esters appear to lower cholesterol in blood and increase the secretion of adrenal androgens (Hall, 2000)

The pharmaceutical uses of *P. africana* bark extract were identified in the 1960s and later patented in 1974. However, Mbai (FAO, 2003) reports about the Barkweri people of Cameroon as having used the species in treatment of “old man’s” disease for many years, while the Natal tribes in South Africa are said to have related the palliative effect of the bark on bladder pains to the European settlers in 1700 (Hall, 2000).

2.2.2 *Prunus africana* Bark Trade

Internationally, Cameroon is the leading producer of *P. africana* which is mostly harvested from Mount Cameroon and the Bamenda highlands (Dawson*et al*., 2000). In Cameroon, harvesting is done by villagers employed by special permit holders. After harvesting, the bark is tied in bundles and transported to the factory of the sole exporter (Plantecam) in Mutengene, South Western Cameroon (Stewart, 2001; Ingram *et al*., 2015), where processing to produce an extract normally takes place. Also, Madagascar produces quite significant amount of *P. africana* bark, that is processed by exporting Company Socie`te` pour de Development Industrielle des Plantes de Madagascar (SODIP) in Southern Madagascar (Ingram *et al*., 2015). In Kenya, *P. africana* is quite spread in the highlands and harvesting is currently taking place mainly in forest areas being cleared by the government for other purposes such as agricultural production and settlement. These areas include Mau, Aberdare, Kakamega, Mount Kenya, Karura and Ngong forests (Ingram *et al*., 2015).

Within the Mau forest, there is no reported large bark harvesting at the moment though the case could be different on the ground. There is no information on the potential for an emergence of *P. africana* bark market (Fashing and Mwangi, 2004). *P. africana* has been observed to be a keystone species within forest ecosystems and is major source of food for Colobus monkeys which is the dominant primate in Kakamega forest. Studies have further revealed that *P. africana* is scarce throughout the Mau forest (Fashing and Mwangi, 2004). Increased de-barking will therefore have an influence on the monkeys population. Even though it is documented that *P. africana* bark can regenerate if care is taken not to damage the cambium, however, regeneration from cut young trees have been reported to be low in Cameroon (Dawson *et al*., 2000).

As the world population age, the demand by men for BPH treatment is likely to increase.In addition the increasing trend towards the use of herbal medicine and the expense of synthetic substitute may considerably increase the future world demand for *P. africana* bark (Fashing and Mwangi, 2004). However, in view of the status of *P. africana* bark harvesting in the major producing countries (Cameroon and Madagascar), the future of *P. africana* bark trade looks grim because of the threat of extinction in its natural habitat. Existing reports indicate that the trade is minimal in Kenya but this cannot be confirmed since current information is scanty. Lack of current and organized documented information, coupled with the worlds increasing demand necessitates frequent monitoring of the status. It is therefore important to have documented information on the level and nature of de-barking to avoid further loss of this species.

2.2.3 Deforestation

Due to increased human demand for food and other forest products such as timber and agricultural land as a result of the growing population, deforestation has become a global concern (Achard *et al*., 2007; Vander Werf *et al*., 2009; Hansen *et al*., 2013). The increased demand has resulted in forest destruction and fragmentation. The most detrimental pressures often exist in areas of high biodiversity coupled with lack of infrastructure and anti-deforestation policies (FAO, 2015).

The Western Mau forest is an afromontane forest in the Rift Valley, Kenya. The area is characterized by complex land use history, and is influenced by growth and development within the around it. The main communities living around the forest are Kipsigis and Ogiek. These communities survive mostly by practicing subsistence farming where they keep domestic animals and planting food crops (Ingram *et al*., 2015).

As a result of the increasing scarcity, *P. africana* was listed under Appendix II of CITES 2004 (The Convention on Trade in Endangered Species) and further listed as vulnerable by the IUCN, 2002) making it mandatory to declare all imports and exports of *P. africana* in all countries. The exporting countries are also obliged to demonstrate that the *P. africana* was harvested in a" sustainable" manner. The main challenge in enforcing such regulations is the complexity in monitoring the trade since *P. africana* is exported in different forms, such as bark, bark extract, capsules and tonic (Hall, 2000). The situation is worsened by lack of regulatory infrastructure within forests where *P. africana* thrives.

2.2.4 Conservation Strategies

Despite the listing of *P. africana* under CITES, in 1995, and the fact that all member states where its exploitation occurs are signatories to CITES (Ingram *et al*., 2015), the enforcement of the convention has been difficult in Cameroon and Madagascar (FAO, 2015). The destructive harvesting of the species from wild populations continues despite these countries having regulatory and management plans for sustainable bark harvesting (Kuijper, 2011). Control of harvesting has been more effective in the case of Kenya, where monopoly export of *P. africana* bark has limited illegal harvesting of bark.

However, the situation in Kenya is likely to change as the value of the bark becomes more widely known. In addition, the species is endangered in certain parts of Kenya through general forest clearance and because it is felled for timber. Although regulations concerning its exploitation also exist in Kenya, there seems to be no coordination in their enforcement (Hall, 2000). Ingram *et al*. (2015) gave recommendations to improve CITES implementations and thereby assist species conservation which, although challenging, may help.

There are several approaches that can be used in the conservation of such a threatened tree species. The method of choice is location specific and will depend upon the distribution and biology of the species in question, its ecosystem significance and predicted market developments among other factors (Hall, 2000). Considering the reproductive ecology of *P. africana*, *ex-situ* conservation via seed storage is unlimited by the recalcitrant nature of the seed (Jaenicke *etal*., 2000).The species takes a long period to flower and fruit (Dawson*et al*., 2000) and has low density patches and unusual size class distribution in forests (Betti, 2008). These combined with the wide spread exploitation, may limit the use of natural forest as *in situ* conservation stands. However, Dawson *et al*. (2000) suggested the use of protected forests in Cameroon and Madagascar for *in situ* conservation.

The incorporation of *P. africana* in agroforestry systems by small scale farmers is an approach that may help to ensure its survival as well as reduce the pressure on populations (Chapin *et al*., 2000; Musila *et al*., 2009). The successful establishment of *P.*

africana plantations in Kenya indicates that such farm plantings may succeed. In Cameroon and Madagascar, a number of planting initiatives have been undertaken by industry primarily as a condition of license agreements for harvesting, but these have been of limited success (Ingram *et al*., 2015; Apollonio *et al*., 2017). However,through the work of some NGOs such as the Kilum Mountain Forest Project (KMFP), successful on farm establishment of the species has taken place in Cameroon (FAO, 2003) and is currently taking place in Kenya through ICRAF initiatives (Ingram *et al*., 2015). However to enhance the conservation value of *P*. *africana* tree, proper attention should be placed on aspects of population structure and density of *P*. *africana* tree which are some of the aspects covered in this study.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study Area

Mau forest is divided into seven blocks and is the largest remaining near continuous indigenous montane forest in East Africa (Waithiru, 2009). Since its designation as a forest reserve in 1994, Mau forest has lost almost 34000 hectares of primary forest or 9% of the original area. By 1999, the forest covered 360000 hectares and comprised over 25% of Kenya's forest cover. This research was carried out in Western Mau Forest block which is the fifth largest block of Mau Complex in the South Rift region of the Rift Valley Region of Kenya (Figure 3.1). It is located in Kericho County at an altitude of between 2000 and 2600 m above sea level; and between latitude 0^0 10' 46''S to 0^0 17' 42" S and longitude of 35^0 27' 05'' E to 35^0 39' 42" E. It is managed by Kenya Forest Service and covers about 22,712 hectares of indigenous forest. In the Mau forest, tea zones were created by a Presidential decree in 1986 and were also to provide alternative fuel wood plantations. The Mau forest is the catchment area for 12 major rivers and also has streams that drain into Lake Victoria, Sondu, Nyando and Mara and others draining into the Rift Valley lakes notably Njoro and Molo which drain into Lake Nakuru and Lake Baringo respectively. The ecosystem supports key economic sectors in the country that include hydropower generation, tourism, agriculture, livestock and supply of water for domestic and industrial uses.

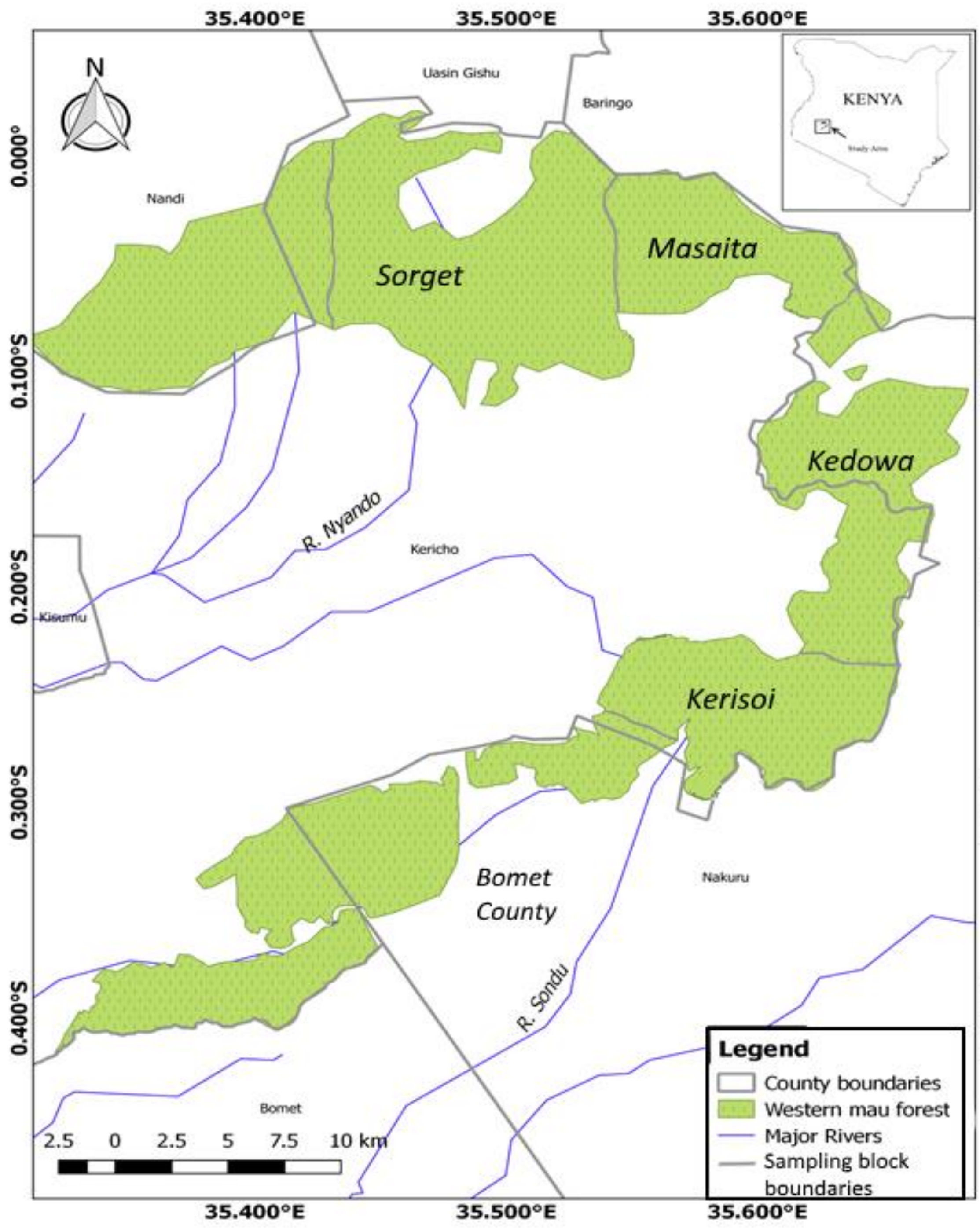

Figure 3. 1: Map of Western Mau Forest and Locations of the Study Blocks.

(Source: GPS Co-ordinates)

The Western blocks of the Mau forest complex which comprise of the West Mau, the South West Mau and Trans-Mara forest blocks harbour at least 61 tree species and 80 climbers and shrubs. The yellow backed duiker, golden cat, Bongo, Giant forest hog, the elephant and the leopard are among the rare fauna found in the Mau forests. There are also 223 butterfly species of which 4 species are rare, 120 bird species of which 2 are regionally endemic (Ingram *et al*., 2015). Special features like Mt. Blakett and Mt. Londiani are also present. West Mau forest which is 67,828.59 hectares is composed of 8 forest blocks; Makutano (5474.09 ha), Tendeno(6723.80ha), Kerisoi 7366.80ha), Kericho (25101.9ha), Kedowa (9015.5ha), Malagat (3137.9ha), Sorget (6856.60ha), and Masaita (4152ha). This research was done in parts of natural forests within North West forest blocks of Mau.

The rainfall pattern is bimodal in distribution, peaking in April and August, and ranges from 1000 to 2000 mm per year with the rain days ranging from 120 to 200 per year. Mean annual temperatures range from 12^{0}C to 16^{0}C, with greatest diurnal variation during the dry season. July is the coldest month. The potential evapotranspiration ranges from 1400 to 1800 mm per annum. The soils are well drained mollic andosols, derived from tertiary volcanic parent material with inclusions of cambisols.

3.2 Sampling and Sampling Procedure

Stratified sampling was used to lay a total of six transects and six quadrats in each of the forest blocks. The six plots sampled in each sampling block were proportional to the forest area covered by each class. Distances between 0 and 500m were drawn between the succesive transects and quadrats marked. In each of the 50x50m square quadrats, corners were marked using GPS coordinates for geo-referencing. Two quadrats were placed at the beginning, two at the middle and the remaining two at the end of the marked transect per sampling block.

Plate 3. 1: An aerial view of Kedowa Forest where some of the data were collected

3.3 Data Collection

Both primary and secondary data were collected. Physical counting of the trees was done and the plant height and diameter measured using Suunto clinometers and girth tapes, respectively. Disturbance types such as number of debarked trees and cut down *P. africana* trees in each forest block were noted and recorded.

Within each 50m x 50m quadrat, community structure attributes such as number of mature trees, seedlings, saplings and tree height were recorded. Bark condition was qualitatively described and noted. Their number and presence or absence of insect damage or herbivory damage were noted. The number of seedlings with insect or herbivory damage was noted along with presence of any disease. The affected seedlings and saplings (herbivory and diseases) were fenced off to offer protection until next visit for the purpose of determining survival. Hand held GPS receiver was used to record the positions for each seedling and sapling. Other features observed near the quadrats were recorded. They included footpaths, fuel wood collection, bark harvesting, charcoal kilns and cattle grazing incidences.

Diameter at Breast Height (DBH) measurements of individual *P. africana* stands and their heights were taken using Suunto clinometers and girth tapes, respectively. The DBH was taken at 1.3m height on a straight tree trunk. The trees that had a DBH of between 5cm and 10cm were counted as saplings while those that had DBH of more than 10cm were counted as trees. Such measurements are useful when monitoring growth and related physiological and phenological changes over a given period of time.

Respondents for this study was drawn from those who stay within 50 metres from the study block was done for the purpose of data collection. From each block, 30 respondents were interviewed using structured questionnaires to determine how they use the target tree and their perceptions on the factors affecting the tree. The respondents were selected using stratified sampling method to represent the various groups in terms of age and economic status. Key informants such as herbalists and provincial administrators were also interviewed with separate set of questions.

Photograph taking was also part of the ways of collecting data but were taken when appropriate. This helped in capturing salient information on the ongoing activities in the forest. They were later used to support the discussion and explain some facts about the study.

3.4 Piloting and Validation of Research Instruments

Before the actual socio-economic data collection, a pilot study was done with 14 respondents and the results subjected to reliability testing. In this study, the split half technique was used to ascertain the reliability of the questionnaires. In this case the questionnaire items were split into two equal parts and filled in by the same respondents. Subject scores from one part were correlated with scores from the second part using Pearson correlation to establish the consistency of the scores. The reliability coefficient of 0.851 was obtained, an indication that the questionnaires are reliable. Kothari (2004) recommended that reliable questionnaires should possess a reliability coefficient of 0.6 and above.

3.5 Data Analysis and Presentations

All the data generated were entered in excel spreadsheet for the purpose of storage and management. Continuous data such as tree height were first descriptively represented in form of mean ± SE of the mean while differences between the stations was tested using one way ANOVA followed by turkey test done *post hoc* to separate the means. The count data were organized in form of proportions and densities while their differences were tested using Kruskal-Wallis and Mann-Whitney tests.

Qualitative data were converted into quantitative form and represented in form of proportions. The influences of human activities and herbivory was tested using chi-square statistics at 95% confidence levels. Correlation analysis was further done to determine the relationship between human activities and herbivory on one hand and population structure.

CHAPTER FOUR: RESULTS

4.1 Introduction

This section presents the results of hypothesis testing and other related population, structure and distribution studies of *P. africana*.

4.2 Abundance and Population Structure of *P. africana.*

4.2.1 Abundance of *P. africana.*

From the study, 305 *P. africana* trees were identified and recorded from all the 24 quadrats from the four blocks of Western Mau forest that were studied. This translates to an average of approximately 13 plants in a 50m × 50m quadrat translating to approximately 130 trees per ha. On a spatial scale, Masaita block had the highest density of *P. africana* plant (185 individuals per ha) representing 36.4% while Kerisoi had 57 ndividuals per ha which was the least (11.8%) where as Kedowa and Sorget were second and third in total abundance respectively (Fig. 4.1).

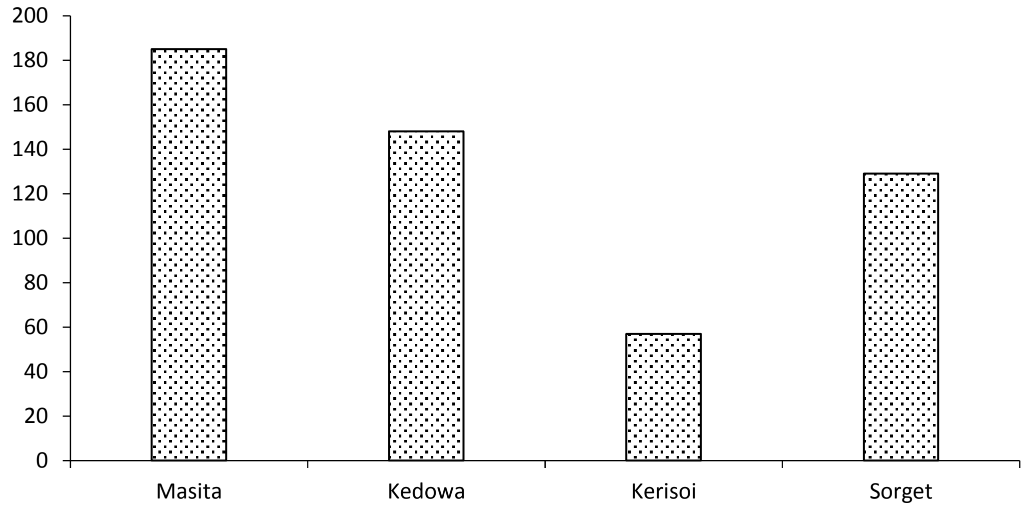

Figure 4.1: Population density of *Prunus africana* per block within western Mau forest during the study period

Kruskal-wallis test revealed significant variation in total abundance between the blocks (p = 0.041) though Mann Whitney u test grouped together Masaita and Kedowa but separated kerisoi and Sorget from the two blocks.

4.2.2 Population structure of *P. africana.*

Three age categories of *P. africana* namely seedlings, saplings, and trees were observed and recorded in varying proportions. The forest was generally dominated by seedlings accounting for 39.0% of the total population recorded followed by saplings (36%) while the mature trees (25%) were the lowest in proportion (Fig. 4.2).

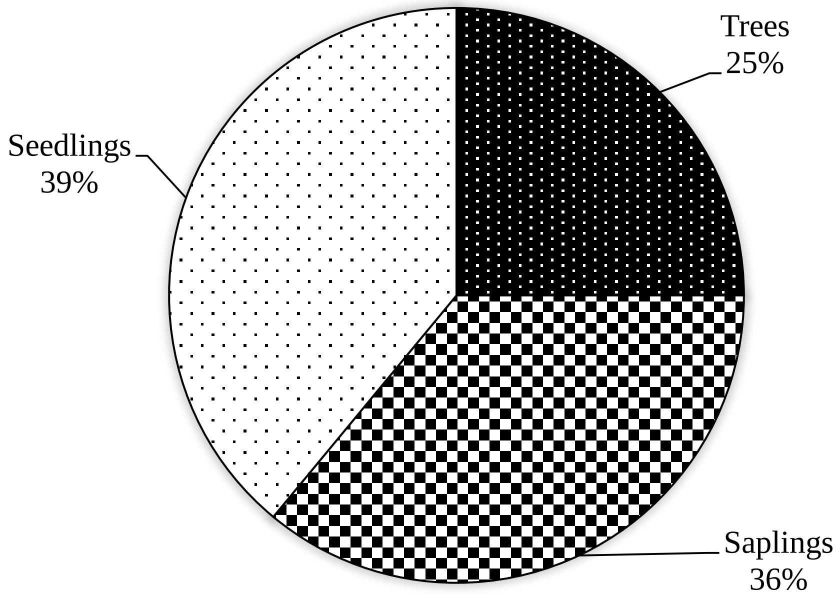

Figure 4.2: Proportions of trees, saplings, and seedlings of *Prunus africana* within western Mau forest during the study period

On examining the various age categories per site, the populations of *P. africana* in Kedowa and Kerisoi were dominated by saplings followed by seedlings and finally trees (Fig. 4.3). Masaita had an almost equal proportion of saplings and seedlings while trees were the least in proportion. Sorget had seedlings being the most dominant whereas saplings were the least in proportion.

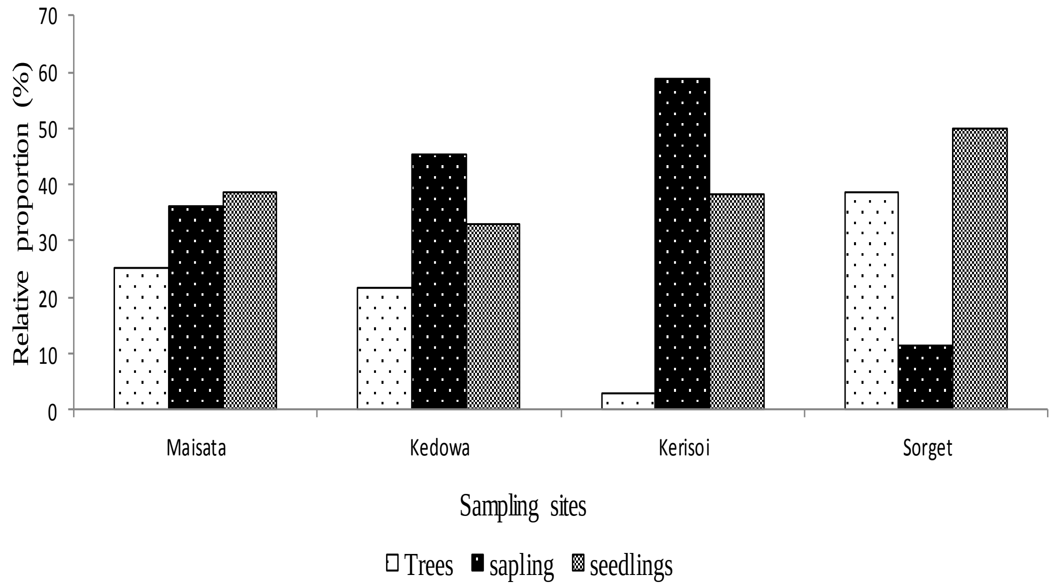

Figure 4. 3: Proportions of trees, saplings, and seedlings of *Prunus africana* at the various sites within western Mau forest

The highest density of seedlings was found in Masaita with an average density of 72 seedlings per hectare followed by Sorget with 58 seedlings per hectare while Kerisoi block had the lowest density (Table 4.1). A log transformed one way ANOVA revealed that there was no significant difference in the number of seedlings between the blocks ($p > 0.05$). Turkey test further grouped Masaita, Kedowa, and Sorget blocks in one sub set as c and separated Kerisoi from them as b an indication that Kerisoi block differed significantly from the other three blocks in terms of seedling abundance. Just like for seedlings, a higher density of saplings were recorded in Masaita though this was followed by Kedowa block and not Sorget which was the least dense. One way ANOVA revealed significant difference in number of saplings recorded between the blocks ($p <0.05$). Turkey test grouped the blocks in three sub sets, putting Masaita and Kedowa together in one sub set as c where as Kerisoi and Sorget were in different sub sets as b and a respectively as shown in Table 4.1 below. The trees exhibited an almost similar trend as that of seedlings with highest densities at Masaita and Sorget and the lowest at Kerisoi block. One way ANOVA revealed that there was no significant variation in the number of trees between the blocks ($p > 0.05$) but Turkey test separated Kerisoi as a from the rest which were grouped as c.

Table 4.1: Mean density of *Prunus africana* per ha in different blocks within the Western Mau Forest (different superscript letters in a row show significant variation)

Plant type	Study sites				Statistics	
	Masaita	Kedowa	Kerisoi	Sorget	F value	p value
Seedlings	72^{c}	48^{bc}	22^{b}	58^{c}	1.51	0.284
Saplings	67^{c}	65^{c}	33^{b}	13^{a}	5.09	0.029*
Trees	47^{c}	32^{c}	2^{a}	45^{c}	3.93	0.054

4.2.3 Height and Diameter at Breast Height

Majority of the trees in Western Mau forest had a height between 20m and 40m representing 75.7% of all the trees measured while only 10.0% were of a height above 40m. The remaining 14.3% had heights below 20m. Figure 4.4 below shows the distribution of trees within Western Mau forest in terms of height. Majority of the tall trees of height above 40m were recorded in Kedowa representing 25.0% of the trees within the block and 57.1% of all the trees above 40m within Western Mau forest.

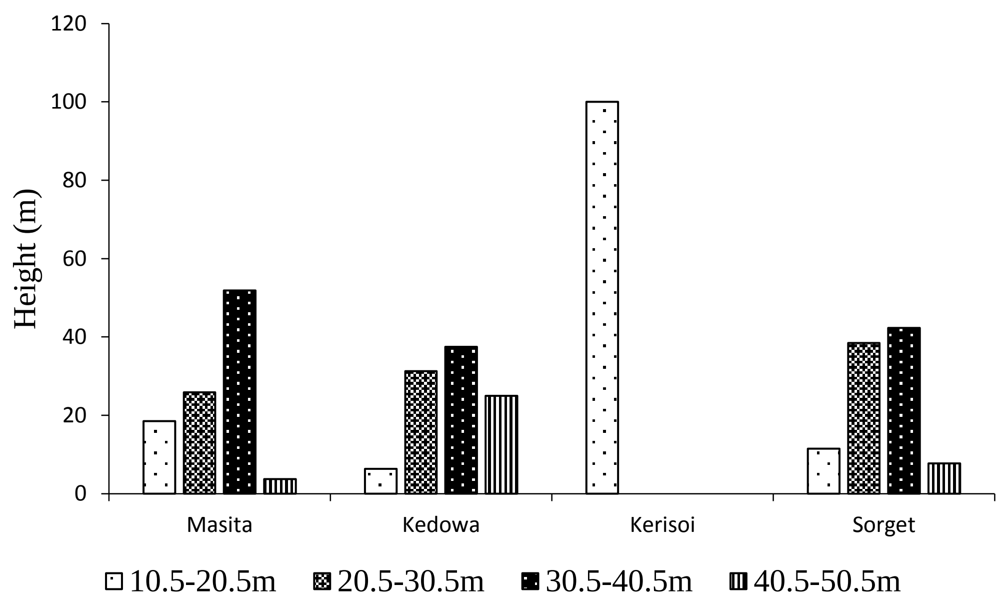

Figure 4. 4: Distribution of trees based on height within Western Mau forest

The tallest tree sampled measured 50.1m and was found in Sorget block where as the shortest was recorded in Masaita block and measured 10m. On average, Kedowa block recorded the highest mean height (33.63 ± 1.89m) while Kerisoi had the lowest average tree height (19.40 ± 0.98) as shown in figure 4.5 overleaf. One way ANOVA revealed significant difference between the blocks ($p = 0.048$) but Turkey test grouped together

Masaita, Kedowa, and Sorget, only leaving out Kerisoi as the possible reason for the significant variation.

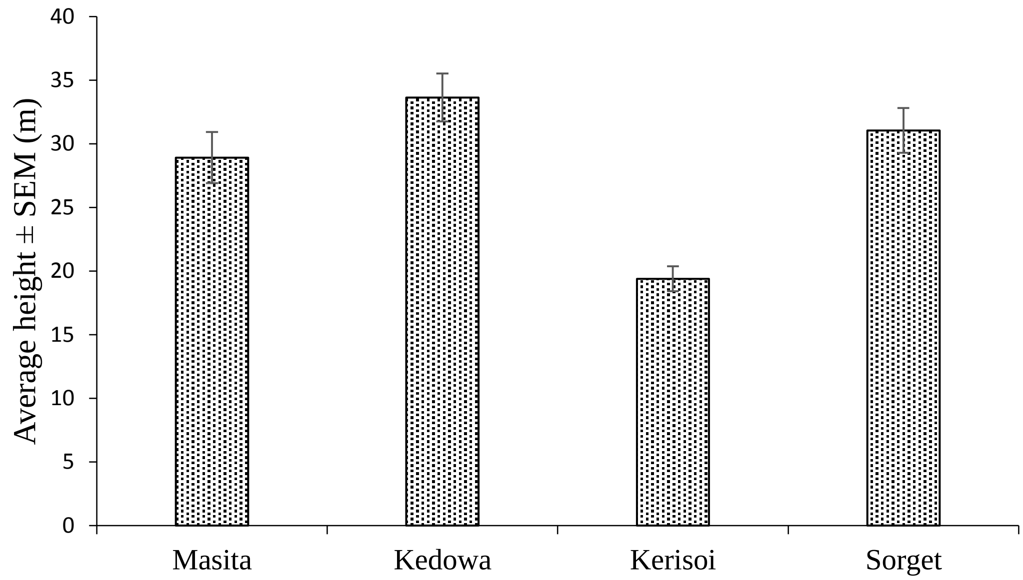

Figure 4. 5: Spatial variation in average tree height within Western Mau forest

Most of the trees sampled within the forest had a DBH ranging between 40cm and 50cm (28.17%) while trees with a DBH ranging between 10 and 20cm accounted for only 1.41% (Fig. 4.6). The first and second largest trees in terms of DBH were recorded in Masaita (123cm and 120cm) while the third came from Kedowa and Masaita block (114cm). .

Masaita block recorded the largest mean DBH (48.49 ± 2.17 cm) followed by Sorget block (42.65 ± 4.15 cm) where as Kerisoi recorded the smallest with only 15.4 ± 1.09cm (Fig. 4.7). Just like with the height, inferential statistics revealed significant variation between the blocks (p = 0.017) but post hoc test only separated Kerisoi block from the other three.

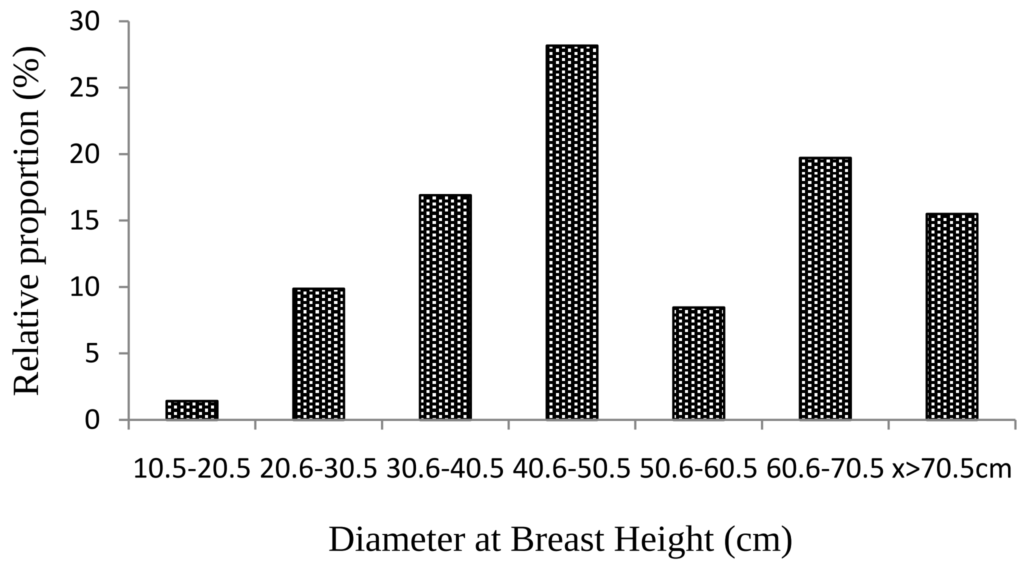

Figure 4. 6: Distribution of trees based on DBH within Western Mau forest

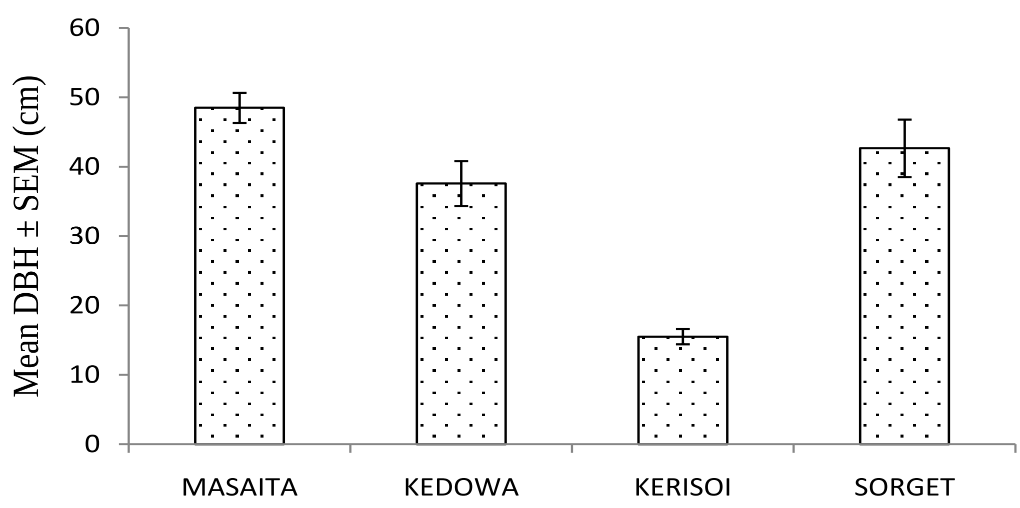

Figure 4. 7: Spatial variation in average tree DBH within Western Mau forest

4.3 Uses and Status of *P. africana* in Western Mau Forest

4.3.1 Respondent Characteristics

From the respondents interviewed, 64 respondents (53.3%) were males and 56 (46.7%) were females. Majority of the respondents were between 30 years and 40 years (39.17%) while the lowest proportions were below 20 years and above 50 years respectively (Figure 4.8a).The results further showed that most of the respondents had completed secondary education followed by primary school graduates and middle level college graduates in that order while very few had university degrees (5.5%) as shown in Figure 4.8b. The respondents were dominated by farmers, accounting for 45.2% followed by businessmen (27.5%). Those in formal employment accounted for 20 respondents (16.8%) while the rest were herbalists (Figure4.8c). On examining distances from homes to the forest, it was observed that over 60% of the respondents (73 respondents) were within 15Km and only 19 respondents (16.3%) lived more than 25Km from the forest (Figure4.8d).

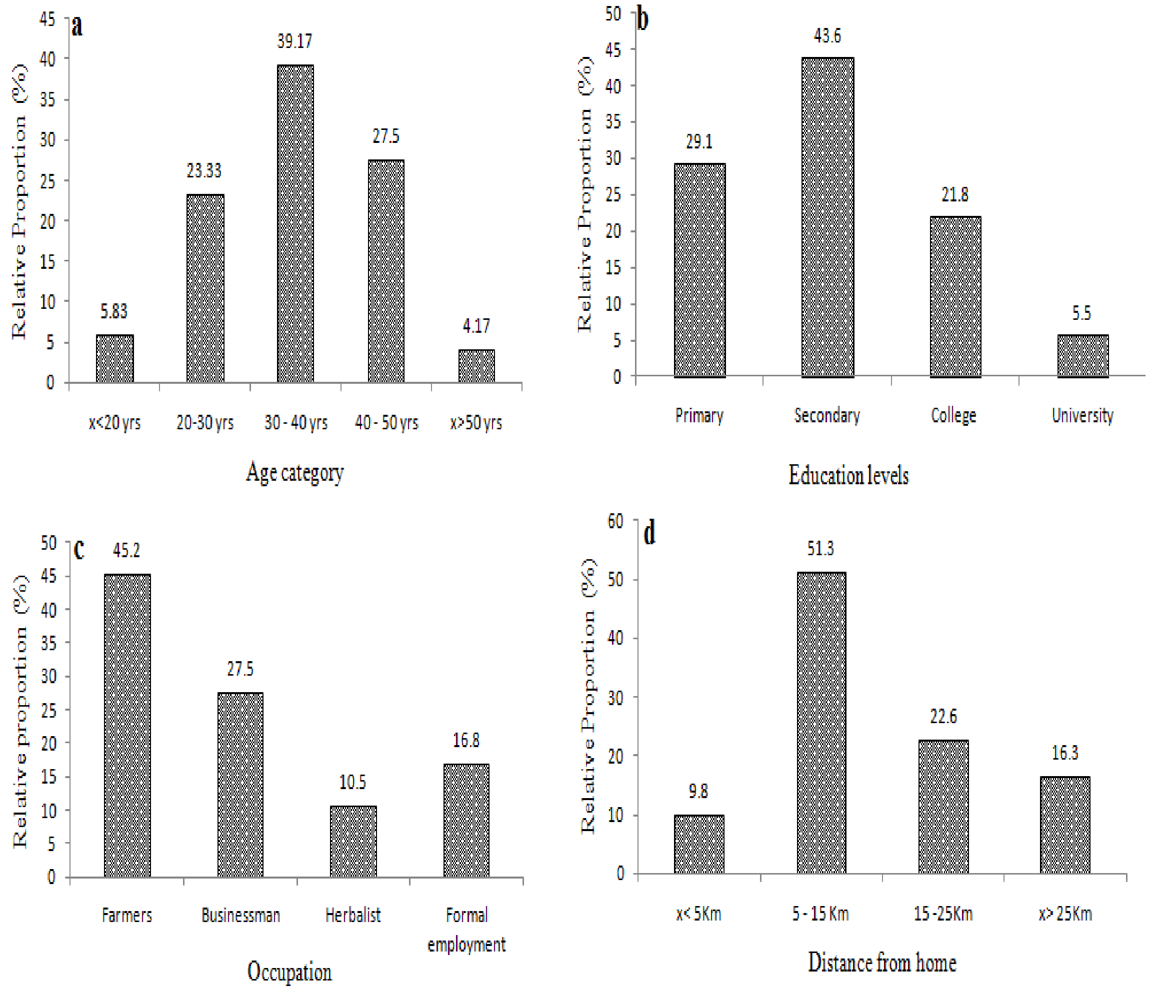

Figure 4. 8: Characteristics of respondents interviewed during the study.

4.3.2 Forest Management

A large proportion of respondents of over 85% (103 respondents) from western Mau forest have neither read nor discussed the contents of the current forest conservation and management act 2016 (Figure 4.9a). Further, the few who reported to have read or discussed the Act could not explain clearly what it was all about. Concerning forest management responsibility, 36.3% of the respondents were of the opinion that it's the role of both the government and local communities to ensure that the forest is well managed where as 31.2% and 26.8% thought it was the role of government and local communities respectively. The remaining 5.7% had no idea of who should manage the forest as shown in figure 4.9b. While examining the role of the local communities in the conservation of Western Mau forest (Figure 4.9c), 58.1% of the respondents are of the view that the community does not take an active role in the management of the forest while 35.6% of the respondents were of the opinion that the community plays an active role in the management. Some of the initiatives they pointed out included planting of highly targeted trees at home and regular sensitizations at local meetings. All the respondents however reported that the forest is of great importance to them and should not be destroyed to extinction. They were very concerned about the current state of affairs. In fact, only 8.7% were happy with the way the forest is currently being managed whereas over 10% were very disappointed at the current state of management of Western Mau forest (Figure 4.9d). They specifically pointed out political interference, compromised law enforcers, and unsustainable utilization due to lack of knowledge from the local community as the main reasons behind poor management.

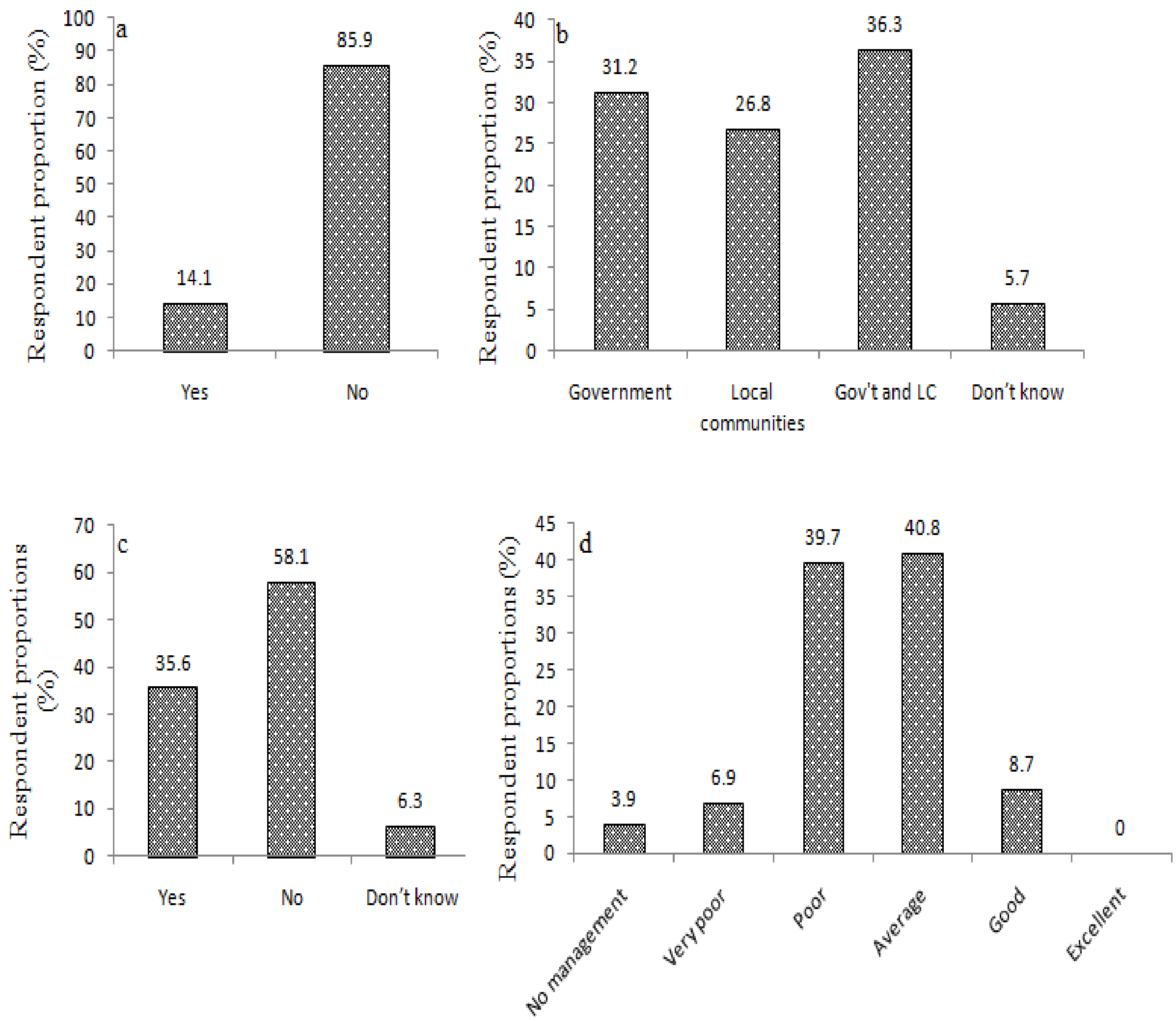

Figure 4.9: Community perception on the status of forest management

(a – knowledge of the forest conservation and management act, 2016; b – respondents' perception on who is responsible for forest management; c – respondents' perception on whether the community takes part in forest management; d – nature of current management system.)

4.3.3 Uses of *Prunus africana*

Based on observation and interviews with the respondents, it was established that the community has five main uses for *Prunus africana*. These include medicinal purposes, timber, fuelwood, and charcoal burning. A very large proportion of respondents (93.3%) reported that they use the tree for medicinal purposes though they reported that they use different parts. Majority of them use the bark for the treatment of *Benign Prostatic Hyperplasia*, erectile dysfunction, male baldness, chest pain and inflammation, urinary tract disorders, kidney disease, wound dressing, and stomach upset. The leaves on the other hand were found to be useful in improving appetite and treatment of genital infection.

Table 4.2: Uses of *P. africana*, parts used and proportion of respondent for each use

Use	Part(s) used	Proportion (%)
Herbal medicine	Bark, leaves, and roots	93.3
Timber	Stem	28.3
Fuel wood	Whole tree except leaves	98.3
Charcoal	Whole tree except leaves	35.8

4.3.3.1 Observed human activities

During the survey and site visits, a total of six human activities that impact on population, distribution and health of *Prunus africana* were observed. These include animal grazing, debarking, tree felling, *P. africana* seed collection, firewood collection, and charcoal burning. Other uses though not precisely related to the tree were picnics by people of youthful age, educational tours, and research.

Debarking, presumably for medicinal purposes, had the highest number of occurrence with an average of 7 debarked trees per visit. It was further observed that 70% of the debarked trees died out, an indication that the process was not done in a sustainable and recommended manner. At least four new tree stumps were also observed within the forest every sampling expedition. Tree stumps are usually the best indicators of tree felling or logging though the purpose can hardly be deduced. Cattle, sheep and donkeys were observed grazing within the forest. This could imply that the tree not only provide food to animals via its leaves but also provides favourable environment for animal pasture. Seed and firewood collectors were also observed though not as frequent as grazing animals and freshly debarked trees. An average of one charcoal burning incident per visit was observed though the exact source of wood and tree type could not be ascertained since those doing the burning could not be found for interview.

On comparing the intensity of logging based on number of stumps and charcoal burning incidences between the blocks, it was observed that Kerisoi had the highest incidences while Kedowa recorded the lowest (Figure 4.10). Out of all the charcoal burning incidences recorded within the study area, 47.3% were spotted in Kerisoi block but only 12.3% and 9.2% were observed in Masaita and Kedowa respectively. The same trend, though with varying proportions, was witnessed for number of stumps which was directly linked to logging.

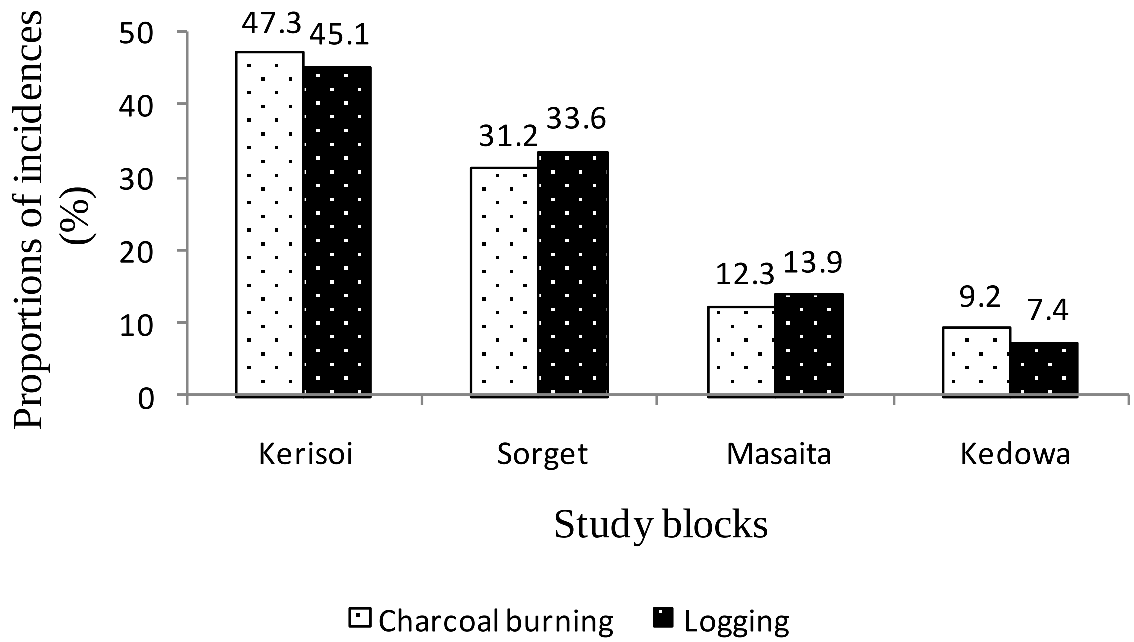

Figure 4.10: Incidences of charcoal burning and logging across the blocks during the study

4.3.4 Community perception on status

When the 120 respondents were asked of their perception on the conservation status of *P. africana*, they gave varied opinions (Table 4.3). Regarding the population density, majority of the respondents (73%), especially those above 30 years were of the opinion that the tree population density is very low compared to the last three decades. None of the respondents said it has not changed whereas 27% were non committal since they were not around then. The respondents (73.1%) further claimed that it was hardly possible to find the big sized trees currently as these were the targets for wood loggers. They were of the opinion that the average tree sizes have greatly reduced with majority of trees felled before attaining 30m height. A small proportion (14.3%) gave a dissenting opinion, arguing that the average tree sizes have not changed. Interestingly, 2.4% argued that the average sizes had increased between the time of the interview and the last three decades.

Slightly over 50% of the respondents were of the opinion that the rate and frequency of debarking had increased, whereas about 34.7% thought the frequency and the rate has not changed. None of the respondents was of the view that the practice has reduced while 12.2% declined to give a comment. Generally, the respondents were of the view that human presence in Western Mau forest has greatly increased for various reasons and they think this is a threat to the trees within the forest including *P. africana*.

Table4.3: Community perceptions on the status of *P. africana* within Western Mau forest

Indicators	Community Perceptions (%)			
	Increased	**Not changed**	**Decreased**	**Don't Know**
Population density	0	0	73	27
Average tree sizes (height and diameter)	2.4	14.3	73.1	10.2
Logging and tree felling	93.7	0	2.5	3.8
Debarking of *prunus africana*	53.1	34.7	0	12.2
Charcoal burning	61.3	0	3.9	34.8
Seed and seedling collection	89.3	0.4	1.3	9
General human presence	95.6	4.4	0	0

4.3.4.1 Influence of Age on Community Perceptions

Results of this study revealed that there was a relationship between age of the respondents and their perceptions (χ^2=14.46, $p < 0.05$). A clear shift in perception was shown across the ages with minimal or no overlap in perception between the age categories except for charcoal burning and debarking (Figure 4.11). Majority of those who did not know the variation in the status of the tree over time were below 30 years. The young, below 20 years of age, reported not to know of any change, the elderly (over 40 years of age) on the other hand, reported negative change such as reduced density, reduced average tree sizes, increased debarking, increased logging, and increased charcoal burning. The middle age between 30 and 40 years, however, reported both negative and positive change though others were of the opinion that there has been no change.

Majority of the respondents were of the opinion that the population density of *P.africana* has decreased over the past years, however, those below 30 years of age did not know whether there has been a change or not (Figure 4.11a). Chi-square statistics further revealed significant relationship between the perceptions and the ages (χ^2=20.95, $p < 0.05$) and grouped the respondents into two separate age categories.

In terms of tree sizes, a relatively similar trend was observed with all the respondents aged over 40 years reporting that the average sizes has decreased while all those below 20 years did not know whether there has been a change or not (Figure 4.11b). Those between 20 years and 30 years had varied opinions though majority of them were of the perception that the average sizes had not changed. Inferential statistics showed that there was significant relationship between the age and the perceptions concerning changes in average tree sizes over time (χ^2=110.98, $p = 0.001$). On pairwise comparison, age categories 30-40 years, 40-50 years, and above 50 years were found to have similar perception on the changes in average tree sizes. The respondents were thus grouped into three categories i.e. those below 20 years, 20-30 years, and above 30 years.

Just like population density and average size, community perception on the status of logging and felling of trees varied with age (Figure 4.11c). All those respondents over 30 years of age were of the opinion that the activity has increased with majority of the respondents between 20 years and 30 years agreeing with them. However, for those below 20 years old, 3.8% did not know if there has been a change while 93.7% thought it had increased and 2.5% were of the opinion that the activity is on a decline. The influence of age on community perception concerning logging and tree felling was observed to be significant (X^2=59.66, p = 0.002).

Debarking was perceived to have increasedacross all the age categories though over 34% of the respondents spread across the age categories thought the intensity has not changed (Figure 4.11d). All the respondents of age over 50 years argued that the practice has increased greatly and currently people of all ages collect the tree bark as opposed to long ago when few elderly herbalist did debarking. Even though respondents from all the age categories were in agreement that debarking is in the increase, the proportion increased from young respondents to the older ones, same trend for those who thought it had not changed. Only respondents below 30 years of age did not know whether there has been a change. The respondent perception on the status of debarking over time was significantly influenced by age as shown by chi-square statistics (X^2 = 43.34, p = 0.001).

Charcoal burning (Figure 4.11e) and seed collection (Figure4.11f) were perceived to have increased by respondents from all the age categories. Unlike other forest variables, a relatively large proportion were non-committal on the status of charcoal burning and said they do not know, the only variable where respondents over 50 years of age claimed not to know if there has been any change. As for seed and seedling collection, it was almost unanimous that the practice has increased and is destined to continue due to the fact that local administration are encouraging planting of indigenous trees in private farms. Chi-square statistics revealed that the perceptions on both charcoal burning and seed collection were also influenced by age of the respondents ($X^2 = 11.93$, $p = 0.001$ and $X^2 = 42.42$, $p = 0.018$ respectively).

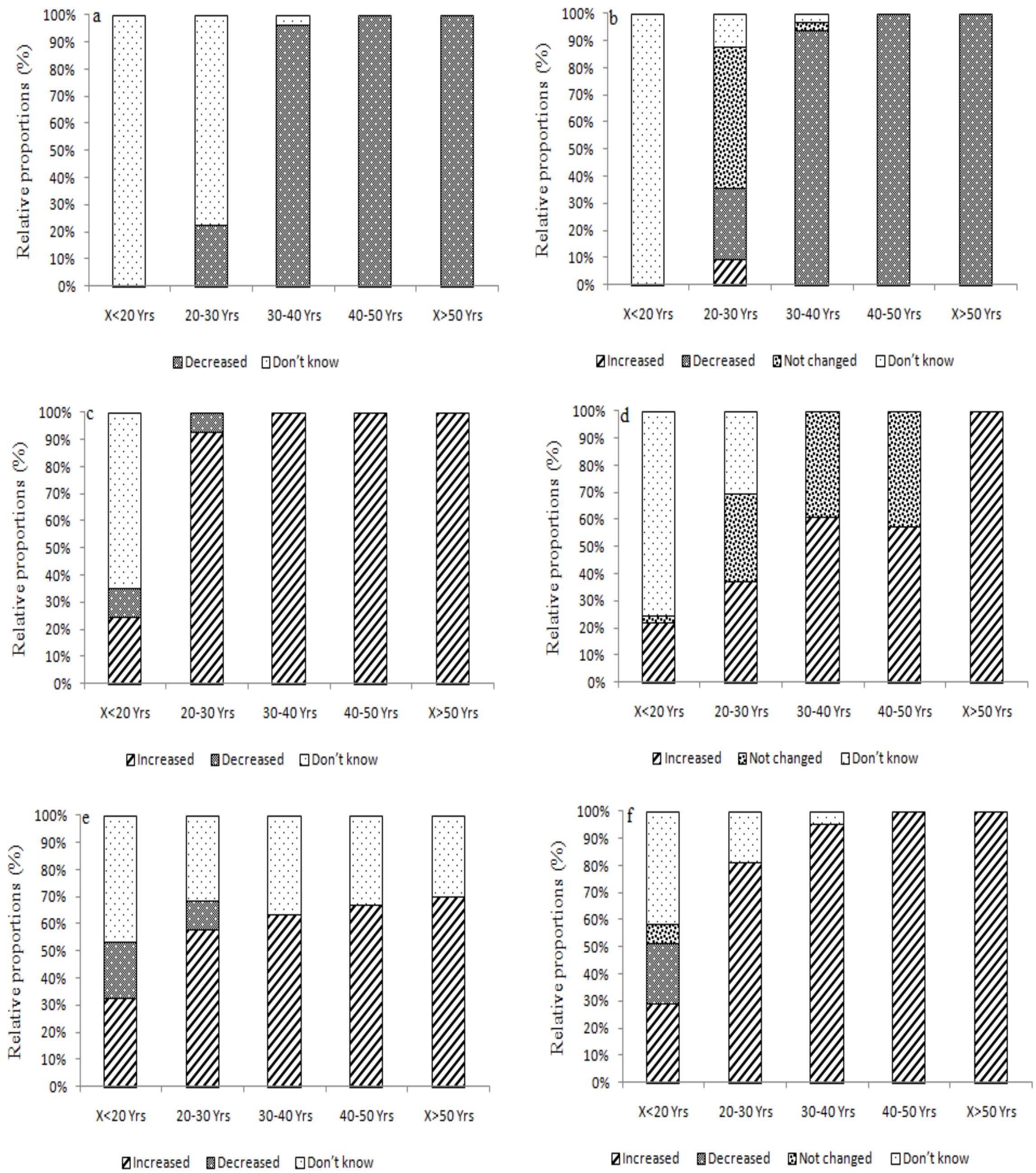

Figure 4.11: Influence of age on community perceptions concerning various attributes of *P. africana* within Western Mau forest

(a – population density, b – average tree size, c – felling and logging, d – debarking, e – charcoal burning, f – seed and seedling collection).

4.4 Influence of Human Activities on Population Structure of *P. africana*

4.4.1 Debarking

Debarking (plate 4.1) which was very rampant, impacted negatively on the tree. This was mainly when it was done in a non sustainable manner. Some of the negative impacts include death of the tree, stunted growth, and reduced population size.

Plate 4. 1: Image of a debarked *P. africana* tree observed in Western Mau forest

It was observed that over 90% of the dead *P.africana* trees had been debarked (Figure 4.12). On examining freshly debarked trees over time, it was further observed that over 70%, most of which were of smaller diameter (x<30cm) died while the rest recovered and eventually survived. Results from interviews with the respondents further corroborated the observation. Over 80% of the respondents were of the opinion that reckless debarking leads to death of trees and as such training needs to be done since the activity may not end any time soon.

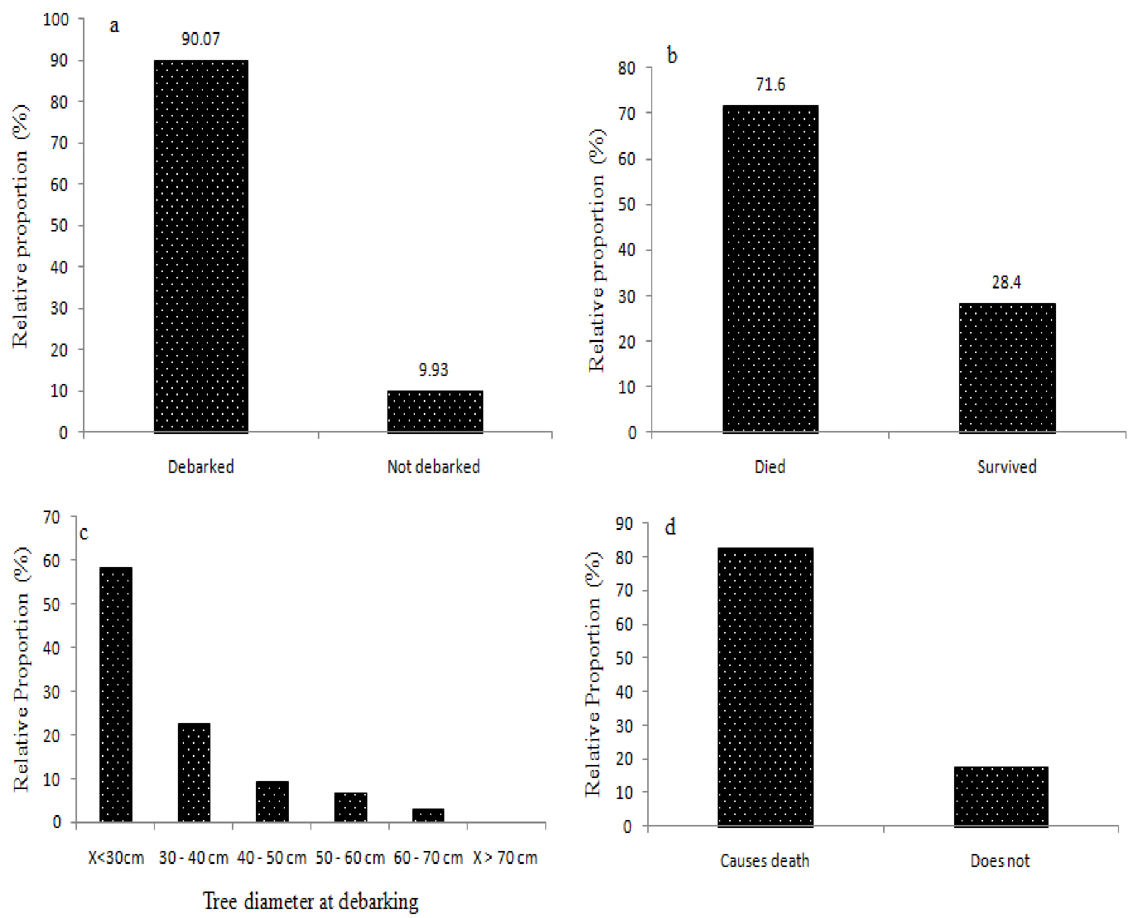

Figure 4.12: Proportion of dead trees due to debarking within Western Mau forest

(a – dead trees, b – de-barked trees after some time, c - dead trees in terms of diameter, d – Community perception).

Respondents' interviews further revealed that the community is of the opinion that due to death of de-barked trees, the activity plays a major role in reducing tree population. A considerable proportion of respondents (63.2%) were also of the opinion that debarked trees experience stunted growth if they don't die. This was however observed only during the rainy season with smaller trees of diameter below 30cm.

4.4.2 Charcoal Burning

According to the respondents interviewed, the main cause of forest fires is charcoal burning (Plate 4.2) though forest fires were not observed during the study period. About the general effect of charcoal burning, the respondents gave four main effects which included forest fires, deforestation, wilting of adjacent trees, and killing of undergrowth.

Plate 4. 2: Image of a charcoal burning kiln observed in Western Mau forest

On examining the main impact arising from charcoal burning, the respondents gave varied opinions with majority citing deforestation (41.8%). Death of adjacent trees received minimal score (15.2%) as shown in figure 4.13.

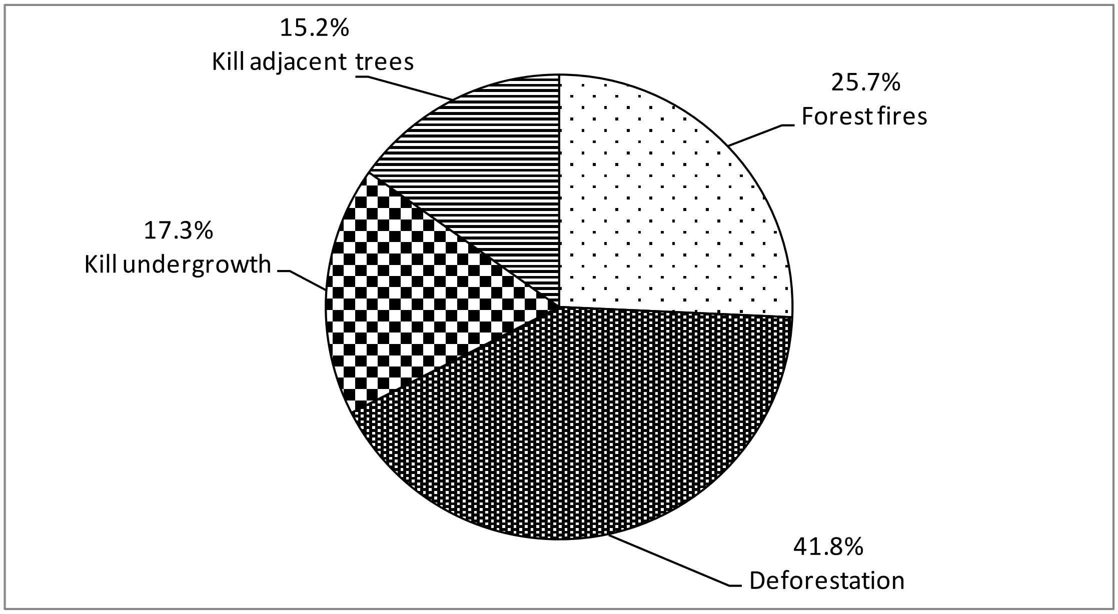

Figure 4.13: Community perceptions on the main effect of charcoal burning on forest ecosystem within Western Mau forest

Even though it is very difficult to ascertain the identity of the trees used in charcoal burning, there was a strong positive and significant correlation between number of fresh *P. africana* stamps and charcoal burning incidences (r^2 = 0.87, p = 0.015). This is an indication that *P. africana* could be among the trees used. According to the local community, there is strong preference for charcoal from the tree under study.

4.4.3Animal Grazing

During the study, it was observed that the local community frequently uses the forest as pasture for their animals. The animals commonly grazed here were cattle, sheep and donkeys (Plate 4.3)

Plate 4. 3: Photograph of cattle and sheep observed grazing in Western Mau forest

From the grazing areas it was observed that there were several impacts. The impacts included damaged seedlings through trampling, eaten saplings, reduced undergrowth leading to erosion, and broken young trees. Also there was wide spread presence of animal faecal matter within the forest making picnic and tourism activities unpleasant.Respondent interviews corroborated these observations at varied proportions. Majority of the respondents (94.3%) were of the opinion that animal grazing negatively affect the forest whereas the remaining 5.7% argued that animal grazing add nutrients thereby enhancing plant growth.Killing of seedlings either by eating or trampling was the most popular among the respondents (89.3%) where as very few were of the opinion that the activity leads to dirty environment (2.4%). The other impacts recorded from respondent interviews were damaging of seedlings and saplings majorly through trampling, breakages of young trees, and clearing of undergrowth leading to soil erosion (Figure 4.14).

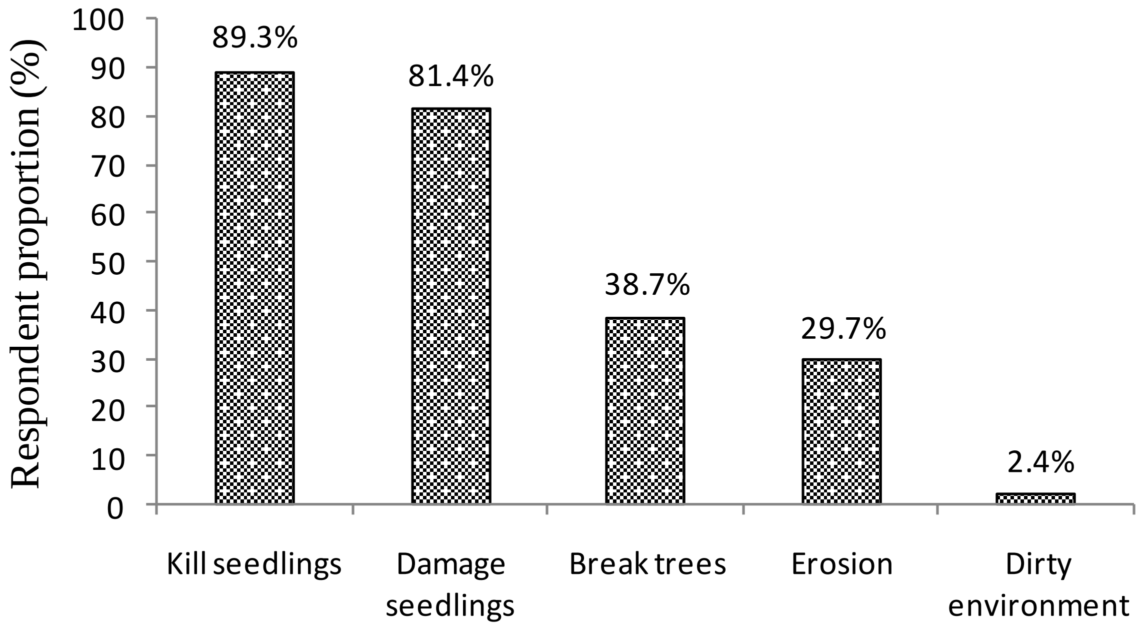

Figure 4.14: Community perceptions on the impacts of animal grazing on forest ecosystem within Western Mau forest

4.4.4 Fuelwood Collection

During the study period, women and youths from the local community were observed leaving the forest carrying fuelwood (Plate 4.4) though of several tree types. An average of four fuel wood collectors per visit was observed across Western Mau forest, an indication that the practice is very popular. Slightly over 80% of those observed were women while aproximately 15% was young boys below 18 years of age where as adult men only accounted for 5%.

Plate 4. 4: Photograph of young girls leaving Western Mau forest carrying firewood

The purpose of fuelwood collection varied between the gender and age. When asked the purpose of collecting fuelwood, two reasons emerged though some declined to give a response. Majority of the women collectors (both young and adult) did it for domestic use whereas over 70% of adult men collected fuelwood for sale in local food kiosks and homes (Figure 4.15). Collection of fuelwood was perceived to have minimal negative impacts on the forest (95%). According to the respondents, most collectors targeted the dry fallen branches except for those doing the collection for sales that cut down mature trees and make timber out of them.

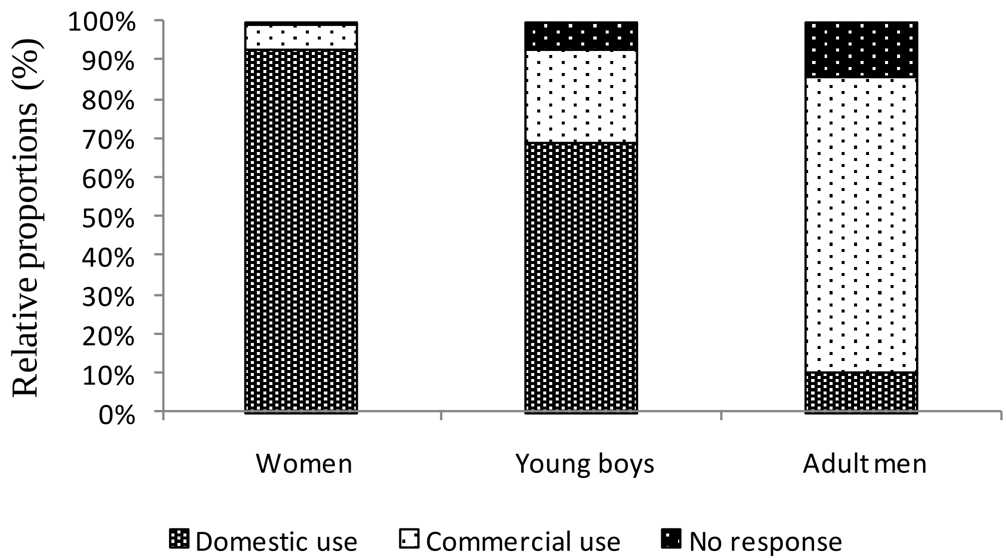

Figure 4. 15: Purpose of fuel wood collection from Western Mau forest.

4.5 Influence of herbivores and diseases on seedling survival

Seedlings and saplings of *P. africana* were observed to suffer from herbivory mainly arising from insects and mammals. Some of the animals observed were cattle, sheep, and donkeys. Some of the herbivores' pellets and dung were also found proving that herbivores are grazing in the area and most likely some times can feed on the leaves of seedlings and saplings since 70% of the seedlings and 50% saplings were noted to be browsed. In some instances, herbivorous insects were observed perching and feeding on the seedling leaves.

Approximately 70% of the seedlings and saplings observed during the study had been fed on by unknown herbivores as evident by the browsing marks on them (Plate 4.5). Out of the browsed seedlings, 18.3% developed other leaves but the rest withered and died off.

Browsed *P. africana* seedling in kedowa Forest

Plate 4. 5: Browsed leaf of a seedling in Kedowa

Apart from herbivory, seedlings and saplings were also found to suffer from shot hole disease (Plate 4.6) which affected seedling survival within the forest. Out of all the seedlings observed, 30% were infected by shot hole disease whereas over 90% of the infected ones withered and died off.

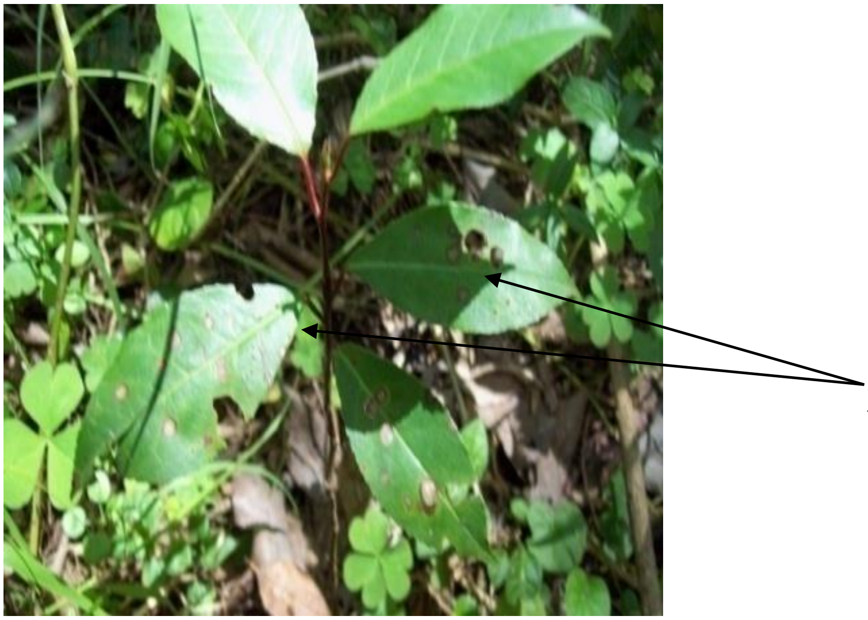

Plate 4. 6: Seedling leaf infected by short hole disease

Chi-square statistics further revealed significant relationship between herbivory and seedling survival (χ^2=11.96, p = 0.014) thereby determining the population of adult trees. Just like herbivory, short hole diseases significantly affected the survival of seedlings and saplings within Western Mau forest (χ^2=20.21, p = 0.003).

CHAPTER FIVE: DISCUSSION

5.1 Abundance and Population Structure of *P. africana.*

5.1.1 Abundance of *P. africana*

The high number of *P. africana* plants in Masaita block and low numbers in Kerisoi were probably due to variation in the intensity of human activities such as charcoal burning and logging within the blocks. Previous studies have shown strong negative correlation between logging incidences and sizes of trees (Bolognesi *et al*., 2015). The absence of bigger trees in Kerisoi as opposed to Kedowa and Masaita blocks can therefore be attributed to charcoal burning and logging.

The presence of more seedlings and saplings in the forest indicates that Prunus is regenerating while the bigger trees are constantly being felled. Research has shown high preference of bigger trees for logging and charcoal burning purposes (Hansen *et al*., 2013). It can therefore be deduced that the low population of *Prunus* tree in Kerisoi was as a result of human logging. Sedano *et al* (2016) reported that charcoal burning is one of the major causes of forest degradation and reduced tree population density. Previous studies have shown that charcoal burning not only leads to deforestation from logging but also causes death of other trees around the kiln (Hansen *et al*., 2013; Rembold *et al*., 2013; Bolognesi *et al*., 2015). A strong negative correlation has been shown to exist between the intensity of charcoal burning kilns and tree population in the surrounding area (Sedano *et al*., 2016). The result of this study therefore corroborates these earlier conclusions.

In a normal functioning forest system, it is expected that the seedlings will be highest in proportion followed by saplings then finally mature trees (Nowak and Crane, 2002), a situation that was only observed in Masaita block. Deviation from this trend is a clear sign of disturbance. Population of mature trees are usually influenced by logging where as that of saplings are influenced by herbivory and to a small extent disease infestation (Nowak *et al*., 2004).

Sorget block which had the highest frequency of animal grazing recorded the lowest proportion of saplings relative to other two groups i.e. mature trees and seedlings. Low number of saplings and seedlings in an area can be attributed to poor germination and low post germination survival as a result of several factors both natural and anthropogenic (Kuijper, 2011; Clasen *et al*., 2015; Apollonio *et al*., 2017). These include damage due to foot path creation, herbivory both insect and animal, diseases, and smothering during charcoal burning (Apollonio *et al*., 2017). Since there were more seedlings, the small number of saplings can thus not be as a result of poor germination but poor post germination survival probably due to herbivory and presence of several foot paths in Sorget block.

5.1.2 Height and Diameter at Breast Height

From the study it was evident that majority of *P. africana* trees from Western Mau forest were of the height between 20m and 40m. This height concurred with the one found by Navarro-Cerrillo *et al*., (2008); Stewart, (2003) of 30m to over 40m. This is an indication that the tree height within the country has generally not changed much over the years. The diameter at breast height largely ranged between 40cm and 50 cm though previous studies in Kenya have recorded DBH of over 1m (Hitimana, 2000; Betti, 2008; Orwa *et al*., 2009).

Tree size such as height and girth is influenced generally by age and conditions of growth such as soil type, disturbance, and rainfall pattern among others (Mligo *et al*., 2009). Being that all the blocks experienced relatively similar weather pattern, soil characteristics and rainfall pattern were probably similar. The variation in height can thus be attributed to age of tree, human disturbance, or both. The presence of several stamps in an area is an indication that bigger trees are being harvested for timber and charcoal leaving behind only small ones that cannot serve the purpose. Hansen *et al.* (2013) recorded a negative correlation between number of bigger trees and logging incidences consequently attributing the low number of bigger trees to logging. The result of this study corroborates their finding.

5.2 Uses and Status of *P. africana* in Western Mau forest

From field observations and respondent interviews, it was established that the community has five main uses for the African cherry tree within Western Mau forest. These include medicinal purposes, agro-forestry, timber, fuelwood, and charcoal burning.Each of these activities affects forests and specific trees in different ways, and the magnitude of the effects is dependent on the methods of exploitation, and the type of forest among other factors within and around the ecosystem.According to Sedano *et al*. (2016), human activities affect any or all the three major forest aspects which include the total forest area or cover, forest configuration, and forest structure and composition. In the event of a specific tree species being targeted, the effects may be first realized on the target tree species but this will eventually spread to the whole forest due to biodiversity interdependence.

During this study, it was observed that for medicinal purposes, the users harvest the bark, leaves, or sometimes the roots and seeds of *P. africana* for treatment and prevention of prostate cancer in men and retrieval of retained placenta in dairy animals.The part frequently used, however was the bark since it was perceived to be the most effective. The harvesting of the bark can be reckless or sustainable depending on the knowledge of the harvester (Wittemyer *et al.*, 2008). Reckless de-barking has been reported to cause death to the affected trees (Stewart, 2003). Results of field observations and respondent interviews further revealed that de-barking causes tree death thereby leading to reduced populations. This corroborates the findings of Stewart (2009) who recorded similar results. *Prunus africana* has the rare ability to regenerate its bark, as long as the vascular cambium is not destroyed (Stewart, 2003). In most cases, herbalists destroy the cambium thereby leading to death of the tree. From this study it was observed that all the de-barked trees whose cambiums were destroyed eventually died which is in agreement with earlier findings (Stewart, 2003; Wittemyer *et al.*, 2008; Ingram, *et al.*, 2009; Stewart, 2009). It can thus be concluded that de-barking plays a major role in the declining population of *P. africana* in the Western Mau forest.

Logging of *P. africana* that was observed in western Mau forest was presumably for both charcoal burning and timber as kilns and tracks ferrying logs were observed. Logging has a primary effect on the population structure and size. It reduces the population density of the target species leading to dominance of smaller trees (Bolognesi *et al*., 2015), a finding that is in agreement with the results of this study where Kerisoi block recorded more stumps of *P. africana* and was dominated by smaller trees. Population density was equally low at Kerisoi block as compared to the other blocks which is probably as a result of logging.

Other than population density and structure, there were other associated effects of logging which include increase in access and resultant hunting which determine the status of forest biodiversity and the likelihood for preservation (Vander Werf *et al*., 2009). Logging which has a positive correlation with deforestation is a key driver to climate change (Dons *et al*., 2015) which partly explains the reasons behind changes in rainfall pattern around the Mau complex water tower. Felling of a big tree leads to death of several untargeted trees which not only opens the forest to further human presence but rapidly reduces forest cover (Chidumayo and Gumbo, 2013). There is high preference for *P. africana* timber compared to other trees in the forest with the loggers targeting the bigger ones,but the felling of big ones leads to destructions of other untargeted tree species.

5.3 Influence of Herbivores and Diseases on Seedling Survival

Generally plants form the basis on which communities and ecosystems are assembled and food webs built. It is therefore expected that there is some form of herbivory on every plant species in a forest ecosystem. Herbivory however, has several negative impacts on vegetation more so the young ones. Studies have shown that animal and insect herbivory causes death to tree seedlings eventually reducing the number transitioning to mature trees (Nowak *et al*., 2004). Even though herbivory resulting from natural forest interactions have minimal negative impacts, human induced herbivory through animal grazing have been shown to modify population structure of the preferred plants (Hitimana, 2000). In an area of high animal grazing, the population of seedlings and saplings would be lower compared to mature trees (Sedano *et al*., 2016), a scenario observed in Sorget block where the saplings were the lowest in proportion. Sorget block on the other hand recorded the highest frequency of animal grazing which explains the structure observed. This situation has far reaching consequences in that the tree population would be greatly reduced over time and can even become extinct due to lack of transition from seedlings all the way to mature trees.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Abundance and population structure of *P. africana* in Western Mau forest varied on a spatial scale mainly due to human factors. From this study it can be deduced that activities such as de-barking, logging, and animal grazing greatly influenced the distribution, abundance and population structure of the tree within the forest. The three activities (de-barking, logging, and animal grazing) were the most common activities across the study area. The local community was further in agreement from the interviews that these are the main factors influencing the status of the forest.

Population density of *P. africana* is greatly decreasing within Western Mau forest based on community perception and in comparison to other previous studies within Kenya and outside. This is an indication that the conservation status is deteriorating or the tree is threatened and the situation could be made worse if no action is taken to regulate the ever increasing human pressureon the tree. The local community expressed preference for the tree stem for charcoal making and above all its bark for medicinal use. These human activities negatively affect the forest as a whole.

Seedlings and saplings of *P. africana* within Western Mau forest experience herbivory from domestic animals grazing in the forest, wild mammals, and insects. Apart from herbivory, the young trees also had disease infestation. These factors greatly affected the survival of seedlings and saplings which eventually had an influence on the population structure.

6.2 Recommendations

Based on these study findings, the following are recommended,

i. A comprehensive and all inclusive training be organized and implemented on sustainable de-barking of *P. africana* as this activity is not likely to stop.

ii. Logging for any purpose and charcoal burning within and around the forest should be strictly regulated.

iii. Animal grazing during the post seeding period should be discouraged to allow seedling growth and transit to adult tree for the purpose of continuity. Trees have a predetermined cycle and likely to seed and seedling sprout at a predicted time of the year.

iv. The community should be encouraged to collect seedlings of *P. africana* from the forest in order to plant them in their farms.

v. There should be a control of unsustainable exploitation.

6.3 Recommendation of other research

i. In-situ and ex-situ conservation of the *P. africana* tree should be encouraged.

ii. Further research to be done on effects of insects on the *P. africana* seedlings

REFERENCES

Achard, F., DeFries, R., Eva, H., Hansen, M., Mayaux, P. and Stibig, H.J. (2007). Pan-tropical Monitoring of Deforestation *Environmental Resources Letters*. **2:** 045-052.

Apollonio, M., Belkin, V. V., Borkowski, J., Borodin, O. I., Borowik, T., Cagnacci, F., Danilkin, A. A., Danilov, P. I., Faybich, A., Ferretti, F., Gaillard, J. M., Hayward, M., Heshtaut, P., Heurich, M. and Hurynovich, A. (2017). Challenges and Science-based Implications for Modern Management and Conservation of European Ungulate Populations. *Mammal Research* **62**:209-217.

Betti, J.L. (2008). Non-detriment Findings Report on *Prunus africana* (rosaceae) in Cameroon. NDF Workshop Case Studies WG1 – Trees Case Study 9.

Bolognesi, M., Rembold, F. and Gadain, H. (2015). Rapid Mapping and Impact Estimation of Illegal Charcoal Production in Southern Somalia Based on WorldView-1 Imagery *Energy for Sustainable Development.* **25** 40–9

Chapin, F. S., III, E. S., Zavaleta, V. T., Eviner, R. L., Naylor, P. M., Vitousek, H. L., Reynolds, D. U., Hooper, S., Lavorel, O. E., Sala, S. E., Hobbie, M. C.M. and Diaz, S. (2000). Consequences of Changing Biodiversity. *Nature*, **405**:234– 242.

Chapman, C.A., and Chapman, L.J., (2002). Foraging Challenges of Red Colobus Monkeys: Influence of Nutrients and Secondary Compounds. *Comparative Biochemistry and Physiolology* **133:** 861–875.

Chazdon, R. L. (2008). Chance and Determinism in Tropical Forest Succession. In: Carson, W. and Schnitzer, S. Eds. Tropical Forest Community Ecology, 384-408. Blackwell Publishers.

Chidumayo, E. N., and Gumbo, D. J. (2013). The Environmental Impacts of Charcoal Production in Tropical Ecosystems of the World: A Synthesis. *Energy for Sustainable Development*, **17:** 86-94. https://doi.org/10.1016/j.esd.2012.07.004.

Clasen, C., Heurich, M., Glaesener, L., Kennel, E. and Knoke, T. (2015). What factors affect the survival of tree saplings under browsing, and how can a loss of admixed tree species be forecast? *Ecological Modeling* **305**:1–9.

Cunningham, A.B., Ayub, E., Franzel, S., Duguma, B. and Asanga, C. (2002). An economic evaluation o f medicinal tree cultivation: *Prunus africana* in Cameroon. People and plant working paper 10. UNESCO, Paris.

Davidson, J. M., Wickland, A.C., Patterson, H. A., Falk, K.R. and Rizzo, D. M. (2005). Transmission of *Phytophthora ramorum* in mixed-evergreen forest in California. *Phytopathology*, **95:** 587–596.

Dawson, I., Were, J.and Lengkeek, A. (2000). Conservation of *Prunus africana*, an over-exploited African medicinal tree. Forest Genetic Resources 28.

Dons, K., Smith-Hall, C., Meilby, H. and Fensholt, R. (2015). Operationalizing measurement of forest degradation: identification and quantification of charcoal production in tropical dry forests using very high resolution satellite imagery *International Journal of Appllied Earth Observations*. Geoinformation publishers. **39:** 18–27.

FAO, (2015). Global Forest Resources Assessment 2015: How have the world’s forests changed? Rome, Italy.

Farwig, N., Bleher, B., Von-der, G.S. and Böhning-Gaese, K. (2007). Does Forest Fragmentation and Selective Logging Affect Seed Predators and Seed Predation Rates of Prunus africana (Rosaceae)? *Biotropica*l **42(2):** 218 - 224.

Fashing, P. J. (2004). Mortality trends in the African cherry (*Prunus africana*) and the implications for colobus monkeys (*Colobus guereza*) in Kakamega Forest, Kenya. *Biological Conservation*. **120:** 449 – 459.

Fashing, P. J. and Mwangi, J. G. (2004). Spatial variability in the vegetation structure and composition of an East African rain forest. *African Journal of Ecology* **42:** 189-197.

Food and Agriculture Organization (2003). Wood Volume and Woody Biomass: Review of FRA 2000 Estimates. FAO, Rome, Italy.

Gachie, P.K. (2002). Variation in Yield and Composition of Bark Chemical Extract of *Prunus africana* and its domestication in Kenya (PHD thesis, Moi University Eldotet, Kenya).

Gray, E. F. and Bond, J. W. (2015). Soil nutrients in an African forest/savanna mosaic: Drivers or driven? *South African journal of Botany*, **101**: 66 - 72.

Hall, J. (2000). Biology of *Prunus africana*: Fruit Development and Seed Dispersal Contribution to *Prunus* monograph.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A. and Tyukavina, A. (2013). High-resolution Global Maps of 21st-century Forest Cover Change *Science* **342:** 850–4.

Hitimana, J., (2000). Structure, Composition and Regeneration of Mt Elgon Moist Lower Montane Forest Kenya with Particular Interest in *Olea capensis* subsp welwitschii. Unpublished MPhil thesis, Moi University, Eldoret.

Ingram, V., Awono, A., Schure, J. and Ndam, N. (2009). Guidance for a national *Prunus africana* management plan, Cameroon. Center for International Forestry Research, Food and Agri- culture Organization: 158. Online document at: www .fao.org/forestry/20776-0928f6e1bca7338bedfca1afabcfe2b89.

Ingram, V., Judy, L., Barbara, V., Ian, D. D., Muchungi, A., Duminil, J. and Awono, A. T. (2015). Ensuring the Future of the Pygeum Tree (*Prunus africana*). Briefing on *Prunus africana* Cultivation and Harvesting". Technical Report.

IUCN, (2002). IUCN Red List of Threatened Species 2002. http://www.redlist.org

Jaenicke, M., Blazejczak, J., Edler, D. and Hemmelskamp, J. (2000). Environmental Policy and Innovation - An International Comparison of Policy Frameworks and Innovation Effects, in Hemmelskamp, J., Rennings, K. and Leone, F., eds., Innovation-Oriented Environmental Regulation, Heidelberg: Physica Verlag, 125-152.

Jimu, L. (2011). Threats and conservation strategies for the African cherry (*Prunus africana*) in its natural range. *Journal of Ecology and Natural Environment*. **3:** 118–130.

Kelatwang, S. and Garzugli, M. (2006). Changes in Forest Area in Africa 1990 - 2005 in International Forestry Review, 8 (1).

Kireger, E.K. (2003). Natural regeration and bark production in Prunus Africana (Hook. F) Kalkman (Rosaceae) and its sustainable utilization and conservation in Kenya, PhD thesis, University of Wales, Bangor.

Kuijper, D. P. J. (2011). Lack of Natural Control Mechanisms Increases Wildlife-forestry conflict in Managed Temperate European Forest Systems. *European Journal of Forest Research*,**130:**895–909.

Lienert, J. (2004). Habitat Fragmentation Effects on Fitness of Plant Populations – a Review. *Journal for Nature Conservation*,**12:** 53–72. http://dx.doi.org/10.1016/j.jnc.2003.07.002.

MacDicken, K. G. (2015). Global Forest Resources Assessment 2015: What, why and how? *Forest Ecolology and Management*, **352:**5-8.

Mligo, C., Lyaruu, H., Ndangalasi, H. and Marchant, R. (2009). Vegetation Community Structure, Composition and Distribution Pattern in the Zaraninge Forest, Bagamoyo District, Tanzania. *Jounal of East African Natural History*. **98:**223–239.

Moser, W. K. and Hansen, M. (2006). The Relationship between Diversity and Productivity in Selected Forests of the Lake States Region (USA): Relative impact of species versus structural diversity. Proceedings of the Eighth Annual Forest Inventory and Analysis Symposium.

Musila, W., Githiru, M., Kanga, M.E., Warui, C., Malonza, P., Njoroge, P., Gikungu, M., Mbau, J., Nyingi, D., Malombe, I., Kibet, S. and Nyaga, J. (2009). Mt. Kenya Forest Biodiversity Assessment Technical Report. Kenya Forests Working Group, Kenya Wildlife Service. Nairobi.

Navarro-Cerrillo, R.M., Clemente, M., Padron, E., HernandezBermejo, E., Garcia-Ferrer, A. and Kasimis, N. (2008). Forest Structure in Harvested Sites of Afromontane Forest of *Prunus africana* [Hook.f.] Kalkm., in Bioko (Equatorial Guinea). *African Journal of Ecology*. 46, 620–630.

Nguta, E. M. (2012). Distribution and Population Structure of *Prunus africana* in Mount Kenya Forest, M.Sc thesis, University of Nairobi, Kenya.

Nowak, D.J. and Crane, D.E. (2002). Carbon Storage and Sequestration by Urban Trees in the USA. *Environmental Pollution***116** (3): 381-389.

Nowak, R.S., Ellsworth, D.S. and Smith, S.D. (2004). Functional responses of plants to elevated atmospheric CO_2– do photosynthetic and productivity data from FACE experiments support early predictions? *New Phytologist* **162**: 253–280.

Ochwang'i, D. O., Kimwele, C. N., Oduma, J. A., Gathumbi, P. K., Mbaria, J. M. and Kiama, S. G. (2014). Medicinal Plants Used in Treatment and Management of Cancer in Kakamega County, Kenya. *Journal of Ethnopharmacology*. **151**(**3**): 1040–1055.

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R. and Anthony, S. (2009). Agro-forestry Database: ATree Reference and Selection Guide Version 4.0. World Agroforestry Centre, Kenya.

Pan, Y., Birdsey, R.A., Phillips, O.L. and Jackson, R.B. (2013). The structure, Distribution, and Biomass of the World’s Forests. *Annual Review of Ecology, Evolution, and Systematics*, **44:** 593-622.

Rembold, F., Oduori, S.M., Gadain, H., and Toselli, P. (2013). Mapping Charcoal Driven Forest Degradation During the Main Period of Al Shabaab Control in Southern Somalia. *Energy for Sustainable Development*. **17:** 510–4.

Ryan, C. M., Hill, T., Woollen, E., Ghee, C., Mitchard, E., Cassells, G., Grace, J., Woodhouse, I. H. and Williams, M. (2012). Quantifying Small-scale Deforestation and Forest Degradation in African Woodlands Using Radar Imagery. *Global Change Biol*ogy, **18**: 243–257.

Sedano, F., Silva, J. ., Machoco, A. R., Meque, C. H., Sitoe, A., Ribeiro, N., Anderson, K., Ombe, Z. A., Baule, S. H. and Tucker, C. J. (2016). The Impact of Charcoal Production on Forest Degradation: ACase Study in Tete, Mozambique. *Environmental Science letters* 11(9): 247 – 261.

Stewart, K.M. (2001). The Commercial Bark Harvest of the African Cherry (*Prunus africana*) on Mount Oku, Cameroon: Effects on Traditional Uses and Population Dymanics. Unpublished Ph.D. Dissertation. Florida International University.

Stewart, K.M. (2003). The African Cherry (*Prunus africana*): From Hoehandles to the International Herb Market. *Economic Botany*, **57**(4): 1-11.

Stewart, K.M. (2009). Effects of Bark Harvest and other Human Activity on Populations of the African cherry (*Prunus africana*) on Mount Oku, Cameroon. *Forest Ecology and Management*. doi:10.1016/j.foreco.2009.05.039.

Van der Werf, G. R., Morton, D. C., DeFries, R. S., Giglio, L., Randerson, J. T., Collatz, G. J. and Kasibhatla, P. S. (2009). Estimates of Fire Emissions From an Active Deforestation Region in the Southern Amazon Based on Satellite Data and Biogeochemical Modelling *Biogeosciences* **62:**35–49.

Wittemyer, G. P., Elsen, W. T., Bean, A. C. O. and Brashares, J. S. (2008). Accelerated Human Population Growth at Protected Area Edges. *Science* **321** (58):85-123.

Zulu, L.C. and Richardson, R.B. (2013). Charcoal, Livelihoods, and Poverty Reduction: Evidence from sub-Saharan Africa. *Energy for Sustainable Development*, **17**: 127–137.

Ingram, Verina, Abdon Awono, Jolien Schure, and Nouhou Ndam. 2009. Guidance for a National Prunus africana Management Plan, Cameroon. In Project GCP/RAF/408/EC « Mobilisation et Renforcement des Capacités des Petites et Moyennes Entreprises impliquées dans les Filières des Produits Forestiers Non Ligneux en Afrique Centrale », edited by CIFOR. Yaoundé, Cameroun: FAOCIFOR-SNV-World Agroforestry Center-COMIFAC-GTZ.

APENDICES

APENDIX 1

Field Data Collection Sheet

Abundance and Population Structure

Date	Block	GPS reading	No. of plants	Seedlings	Saplings	Trees

Tree Sizes

Date	Block	GPS reading	Tree identity	Height	DBH

Observed Activities

APENDIX 2

Questionnaire

INTERVIEW NUMBER: __________ DATE __/__/__15

PART A: RESPONDENT CHARACTERISTICS

Gender	Male	Female			
Age (yrs)	X<20 yrs	20-30 yrs	30 - 40 yrs	40 – 50 yrs	X> 50 yrs
Level of education	Primary	Secondary	College	University	
Occupation	Farmer	Business	Herbalist	Formal employment	Not employed
Distance from home	X<5 km	5-15 km	15-25 km	X> 25 km	

PART B: FOREST MANAGEMENT

a. Have you read or discussed the forest Conservation and Management Act of Kenya, 2016? If yes, what does it say concerning the role of local communities in forest conservation?

Yes	No

b. In your opinion, who has the responsibility of managing natural forests in Kenya?

Government	Local communities	Government and local communities	Don't Know

c. Does the community of Western Mau forest take part actively in the conservation and Management of the forest?

Yes	No	Don't know

d. How do you characterize the current conservation and management of Western Mau forest?

No management	Very poor	Poor	Average	Good	Excellent

PART C: USES OF *Prunus africana* within Western Mau forest

a. Do you use the tree in question for any purpose? …………….

b. If yes in **a** above, list the uses and the part of the tree used for the named purpose in the table below. For medicinal uses, specify the kind of illness cured.

	Use	Part (s) used
1		
2		
3		
4		
5		
6		
7		
8		

PART D: COMMUNITY PERCEPTION ON CONSERVATION STATUS OF *Prunus africana* within Western Mau forest

a. From your observation, compare the current status of *Prunus africana* within Western Mau forest and ten (10) years ago based on the following variables.

Variables	**Increased**	**Decreased**	**No change**	**Don't know**
Population density				
Average tree sizes				
Logging and tree felling				
De-barking				
Charcoal burning				
Seed and seedling collection				
General human presence				

b. Additional remarks based on the status above

c. In your opinion, what's the impact of the following activities on forest ecosystem and *Prunus africana* within Western Mau forest

Human activity	**Impacts**
De-barking	
Charcoal burning	
Animal grazing	
Logging	

d. What do you think should be done to save *Prunus africana* within Western Mau forest and Kenya from the eminent danger?

APENDIX 3

Data Summarry

Abundance and Population Structure

Block	No. of plants	Seedlings	Saplings	Trees
Masaita	111	42	41	28
Kedowa	88	29	40	19
Kerisoi	36	13	20	3
Sorget	70	35	8	27
Total	305	119	109	77

Height and Diameter at Breast Height

Block	Tree identity	Height (m)	DBH (cm)
Masaita	1	10.6	14.2
	2	12.7	18.8
	3	13.8	20.1
	4	19.9	31.6
	5	20.1	30.1
	6	22.7	35
	7	24.2	8
	8	25.6	37.1
	9	27.9	38.1
	10	28.6	44.8
	11	29.1	43.7
	12	29.8	39.8
	13	30.8	48.9
	14	30.9	50.2
	15	31.1	60.1
	16	32.4	41.2

	17	32.9	46.7
	18	33.0	51.7
	19	33.3	53.4
	20	33.5	54.1
	21	34.1	55.1
	22	34.5	49.1
	23	35.9	57.9
	24	37.3	114
	25	38.2	59.4
	26	39.1	123
	27	39.9	65.8
	28	46.1	120
Kedowa	1	13.8	15.4
	2	21.9	24.5
	3	24.9	27.8
	4	25.7	31.4
	5	28.1	31.7
	6	28.4	33.2
	7	29.7	34.7
	8	31.1	37.3
	9	33.4	39
	10	34.9	39.2
	11	35.1	39.2
	12	35.1	28.7
	13	35.8	40
	14	37.2	41.6
	15	41.4	46.3
	16	43.6	48.7
	17	44.5	114

	18	46.3	51.7
	19	48.1	53.7
Kerisoi	1	18.7	15.8
	2	19.6	15.6
	3	19.9	14.8
Sorget	1	12.9	15.4
	2	13.8	17.4
	3	18.6	25.2
	4	20.7	27.1
	5	21.7	30.7
	6	22.6	32
	7	25.5	36
	8	26.9	38
	9	27.4	38.8
	10	28.7	40.6
	11	29.7	42
	12	30.3	41
	13	30.4	43
	14	30.8	43.4
	15	31.6	41.3
	16	32.2	45.4
	17	32.9	43.1
	18	33.2	42.9
	19	33.6	47
	20	34.2	48.3
	21	34.5	47.4
	22	35.2	52.4
	23	36.2	51
	24	38.1	53.4

	25	38.4	54
	26	43.1	62.1
	27	50.1	92.7

APENDIX 4

ANOVA Outputs

One-way ANOVA: Height versus Blocks

Source	DF	SS	MS	F	P
Blocks	3	582.7	194.2	2.76	0.048
Error	73	5137.6	70.4		
Total	76	5720.3			

S = 8.389   R-Sq = 10.19%   R-Sq(adj) = 6.49%

```
                                Individual 95% CIs For Mean Based on
                                Pooled StDev
Level     N    Mean  StDev  ------+---------+---------+---------+---
Kedowa   19  33.632  8.885                              (----*-----)
Kerisoi   3  19.400  0.624  (-------------*-------------)
Masaita  28  29.571  8.450                         (---*----)
Sorget   27  30.122  8.293                         (----*----)
                            ------+---------+---------+---------+---
                                14.0      21.0      28.0      35.0

Pooled StDev = 8.389
```

One-way ANOVA: DBH versus Blocks

Source	DF	SS	MS	F	P
Blocks	3	3670	1223	3.62	0.017
Error	73	24683	338		
Total	76	28353			

S = 18.39   R-Sq = 12.94%   R-Sq(adj) = 9.37%

```
                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level     N   Mean  StDev  ----+---------+---------+---------+-----
Kedowa   19  37.57   9.92                      (----*-----)
Kerisoi   3  15.40   0.53  (-------------*------------)
Masaita  28  48.49  25.29                              (---*----)
Sorget   27  42.65  14.74                         (----*---)
                           ----+---------+---------+---------+-----
                               0        16        32        48

Pooled StDev = 18.39
```

Plate 8: A *Prunus africana* tree in Mololo Forest

Plate 9 : A photo of *P. africana* sapling in Masaita Forest