# DISTRIBUTION AND POPULATION STRUCTURE OF *PRUNUS AFRICANA* IN MOUNT KENYA FOREST

**Stem of *Prunus africana***


**By**

**Esther Mbithe Nguta**

**BSc. (Hons), UoN.**


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DECLARATION

This thesis is my original work and has not been presented for any other degree to the best of my knowledge.

Signature.................................. Date....5 / 3 /2012........

This thesis has been submitted for examination with our approval as supervisors:

Dr. J. Githaiga

School of Biological Sciences

University of Nairobi

Signature.................................. Date....5\03\2012....

Dr. E. Mwangi

School of Biological Sciences

University of Nairobi

Signature.................................. Date....05/03/2012....

Dr R. Kindt

Centre for agroforestry, ICRAF

Signature.................................. Date...5-MAR-2012

# DEDICATION

*I dedicate this thesis to my husband, Julius Kioko and children: Mutheu, Muthama and Mbesa for their support and inspiration and to our house-help, Tabitha Kavevo.*

## ACKNOWLEDGEMENTS

I would like to express my gratitude to Dr. J. Githaiga, Dr. E. Mwangi and Dr. R. Kindt for their supervision, Prof. Kinyamario and Dr. Chira both of the University of Nairobi; for facilitation of the project funding and initial proposal development, to Paulo van Breugel of International Livestock Research Institute (ILRI) for his assistance in designing and field-testing sampling methods. I would also like to thank the office of the director, National Museums of Kenya (NMK) for allowing me time to study, and osteology section of the zoology department for giving me office space and access to their facilities. I would like to express my gratitude to Kenya Wildlife Service (KWS) and Kenya Forest Service (KFS) for granting me permission to conduct this research, for providing security escorts during field work and for waiving entry fees to Mount Kenya forest. I am indebted to Meru KFS Guards: Franklin Mutwiri and Matthew Matu for the wonderful work they did in the field. Special thanks go to rockefeller foundation through the initiative of Vegetation and Climate change in Eastern Africa (VECEA) project for funding this study. And finally, to my husband and children for allowing me their time to complete this work.

To all, may the almighty God bless you.

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ANOVA | Analysis of variance |
| CITES | Convention on International Trade in Endangered Species of wild fauna and flora |
| DBH | Diameter at Breast Height |
| DFO | District Forest Officer |
| EWP | Emergency Watershed Protection |
| FAO | Food and Agriculture Organization |
| GPS | Geographical Positioning System |
| ICRAF | International Centre for Research in Agroforestry |
| ILRI | International Livestock Research Institute |
| IUCN | International Union for Conservation of Nature |
| KFS | Kenya Forest Service |
| KWS | Kenya Wildlife Service |
| VECEA | Vegetation and Climate change in Eastern Africa |

## ABSTRACT

*Prunus africana* has been declining over much of its geographical range due to unsustainable harvesting of the bark for its medicinal properties. In Kenya, bark harvesting for trade began in the 1970s from unknown forests, and the effects of this harvesting on the species' distribution and population structure are not well known. One of the locations where this species occur in Kenya is Mt. Kenya forest where this study was conducted. The goal of the study was to establish the distribution and population structure of *P. africana* in Mt. Kenya forest to provide information useful for knowledge about population status, management, conservation and monitoring of the species.

Thirty eight (38) belt transects (50m x 500m) subdivided in to 25m x 25m plots were established at varying altitudes on four broad vegetation types (moist montane, moist intermediate, dry intermediate and dry montane) of Mt. Kenya forest and used for sampling. Farms were estimated in acres and sampled too. The data collected on *P. africana* included abundance, Diameter at breast height (DBH), and phenology. Tree species identification and measurements were done for the three tree species nearest to *P. africana* in the study plots. One-way-ANOVA was used to test for differences in abundance and size of the species (*P. africana*) among vegetation types, canopy cover classes and different altitudes.

The altitudinal distribution of *P. africana* ranged between 1600m to 2500m above sea level. Four hundred and thirty six (436) individuals of *P. africana* were observed in 207 out of 1500 plots sampled in forest while 116 individuals were observed in 31 out of 48 farms sampled. The mean density of *P. africana* in the study forest was 4.8 tree/ha while in the farms it was 5.2 trees/ha. Density in the forest varied significantly among vegetation types ($F_{3, 34} = 10.32$, $P < 0.05$) and canopy cover classes ($F_{2, 30} = 21.53$, $P < 0.05$). There was significant difference in number of individuals in different developmental stages in forest ($F_{2, 24} = 11.49$, $P < 0.05$) while there was no significant difference in number of individuals in farms ($F_{2, 12} = 0.21$, $P > 0.05$). A total of 44 tree species belonging to 23 families were found to comprise the three nearest neighbours of *P. africana* in different vegetation types.

This study provided crucial information in establishing the status of *P. africana* in Mt. Kenya forest. It was concluded that vegetation type, general canopy cover and altitude are some of the factors that influence the distribution and population structure of *P. africana*. The study confirmed earlier reports that the species prefers open to closed canopy forests ·

# CHAPTER ONE

## 1.0 INTRODUCTION AND LITERATURE REVIEW

### 1.1 Introduction

Plants form the major structural and functional basis of forest ecosystems (Musila *et al.*, 2009). Forests play a key role in maintaining the planet's basic environmental balance and ecosystem stability, and provide an important component of the habitats for animal life. In addition, many thousands of wild plants have great economic and cultural importance, providing food, medicine, fuel and shelter for vast numbers of people throughout the world. Forest destruction increases vulnerability of forest community which leads to micro environmental changes that drastically influence the forest composition (Chen, *et al.*, 1992). Tropical ecosystems suffer profoundly as a result of human over-exploitation (Chapin *et al.*, 2000). Extensive deforestation, habitat fragmentation and local disturbance threaten survival of species (Aldrich & Hamrich, 1998) and thus result to changes in biodiversity, structure of species and numbers of individuals (Musila *et al.*, 2009).

*Prunus africana* (Hook. f.) Kalkm. is a geographically wide spread tree growing in highland forest in Africa and outlying islands (Kalkman, 1965), having been reported from 22 countries, mostly in the Eastern part of the continent (Navarro-Cerrillo *et al.*, 2008). About 45 years ago, the bark extracts of *P. africana* were found to be effective in the treatment of benign prostatic hyperplasia, a disease that cause non-concerous enlargement of the prostate in older men (Bombardelli & Morazzoni, 1997).

Its use by Africans as medicine for bladder pains attracted attention of European researchers and a patent was issued to Dr. Jacques Debat in 1966 (Cunningham *et al.*, 1998). Currently, *P. africana* bark is entirely wild collected in many countries for this medicinal trade and this has led to its population decline (Steward, 2003; Hall *et al.*, 2000a; Cunningham & Mbenkum, 1993). The decline has also been due to extensive replacement of forests by other ecosystems (Hall *et al.*, 2000a).

Kenya has been reported as one of the countries where harvesting of *P. africana* started (Navarro-Cerrillo *et al.*, 2008). It has also been reported as one of the countries supplying a French firm with bark of *P. africana* as raw material (Betti, 2008). For two decades until the year 2003 when export license was revoked by the then environment minister through KWS, Kenya was involved in trade of the species whereby 1000 kg were exported per year to France (Betti, 2008). Although this volume was entirely collected from unknown forests, no research has been done to provide current data on distribution and population structure of the species in various regions of the country. The current study established the distribution and population structure of *P. africana* by sampling in four broad vegetation types of Mt. Kenya forest namely: - moist montane (Plate 3.1) moist intermediate (Plate 3.2), dry intermediate (Plate 3.3) and dry montane (Plate 3.4). The study provided essential information on population status important for monitoring, management and conservation of the species in the area.

The outputs of the study will assist in updating a new vegetation map of Eastern Africa through an initiative by Vegetation and Climate change in Eastern Africa (VECEA) project. The new map is accompanied by detailed descriptions of vegetation types and a database that documents the distribution of tree species over the mapped vegetation types.

## 1.2 Justification of the study

It is recognized globally that *P. africana* is declining from its natural range, and even getting locally extinct from some of the ranges. This has prompted many studies to seek to track changes in the species' population over time. Most studies have been done in Cameroon where the rate of decline has been high. In Kenya however, only a few localities have been studied (in Kakamega forest by Farwig *et al.*, (2007); Fashing, (2004); Nzilani, (1999) and therefore it is difficult to say whether the species population is declining or stable (Betti, 2008). There is substantial data on genetic variance of the species in Kenya but data on population abundance and structure is lacking (Betti, 2008). The abundance data at a site is attainable and the acquisition of these approximate datasets is a requirement as a baseline for drawing up overall conservation policies or making sound conservation and management recommendations. There was a practical need to conduct a study on the distribution and population structure of *P. africana* to get practical knowledge necessary for the species conservation and restoration.

Due to lack of prior *P. africana*'s surveys and owing to its heterogeneous ecosystems, Mt. Kenya forest offered an excellent opportunity for this study. The complexity of the environment is evidenced by the four major vegetation types as outlined by Trapnell & Langdale-Brown (1972). The survey of *P. africana* in Mt. Kenya forest which is surrounded by human pressures was an important step towards the conservation of the forest's biodiversity in general (BPPP, 1999). The tree species database developed by VECEA project needed verification using some representative species. *Prunus africana* was an important representative to study due to the increasing demand of its bark leading to serious declines worldwide. This study highlighted the population and conservation status of the species.

## 1.3 Objectives of the study

### 1.3.1 Main objective

The main objective of the study was to establish the spatial and altitudinal distribution, and population structure of *P. africana* in Mt Kenya forest. The study also determined the tree species which occurred near *P. africana*.

### 1.3.2 Specific objectives

1. To determine the distribution and abundance of *P. africana* in Mt. Kenya forest vegetation types along altitudinal gradients.
2. To determine the population structure of *P. africana* in Mt. Kenya forest vegetation types along altitudinal gradients.

3. To identify tree species occurring near *P. africana* in different vegetation types in Mt. Kenya forest.

## 1.4 Hypotheses

**Ho:** the distribution and population structure of *P. africana* is similar among vegetation types;

**Ha:** the distribution and population structure of *P. africana* differ among vegetation types in Mt. Kenya forest.

Ho: the distribution and population structure of *P. africana* is similar along altitudinal gradient;

Ha: the distribution and population structure of *P. africana* differ along altitudinal gradient in Mt. Kenya forest.

## 1.5 Literature review

### 1.5.1 Biology of *Prunus africana*

*Prunus africana* also known commonly as the African Cherry belongs to subfamily Prunoideae within the Rosaceae family. There are around 200 species in the genus *Prunus*, divided into two sub-genera: *Padus* (deciduous) and *Laurocerasus* (evergreen). The *Laurocerasus* sub-genus includes *P. africana*, the only one found in Africa and Madagascar (Navarro-Cerrillo *et al.*, 2008).

It is an evergreen canopy tree which grows up to 40m tall with a thick, fissured bark and straight bole (Plate. 1.1) that can reach a diameter of 1.5m (Orwa *et al.*, 2009; Betti, 2008). Its leaves are alternate and simple while the flowers are small, white and fragrant (Navarro-cerrillo *et al.*, 2008). Flowers are produced in elongated clusters, and are basically insect pollinated (Hall *et al.*, 2000b). The intensely bitter fruit is a small pinkish-brown bilobed drupe and its skin (epicarp) squeezes off easily between fingers, exposing green fresh (mesocarp) surrounding the bony endocarp. The fruits are dispersed by birds and monkeys (Farwig *et al.*, 2007). Seeds have the same shape as fruit and there exist one seed per fruit and germination is apical (Fraser *et al.*, 1996).

**Plate 1.1: Stem of *Prunus africana***

This species begins its reproduction at an age of 15 years (Simons *et al.*, 1998). The flowering period extends from June to November and fruiting period from February to May (Orwa *et al.*, 2009). Poor establishment condition for the seedlings is known to be one of the main causes of the species population decline (Orwa *et al.*, (2009). Seedlings grow well when they are established on exposed sites with good moisture such as collapsed roads (Ndam, 1996).

A high proportion of fallen fruits remain close to the parent tree and germinate there, even in heavily shaded areas (Gachie, 2002). Nevertheless as a light demanding species, it does not maintain a large seedling bank in the forest understorey (Ndam, 1998). Most or all such seedlings die while still young (Sunderland & Nkefor, 1996). Stumps do not often produce coppice shoots (Ndibi & Kay, 1997).

The species grows well in sub-montane and montane forest at an altitude of 900m-3500m (Navarro-Cerrillo *et al.*, 2008; Tchouto, 1996; Cunningham & Mbenkum, 1993; Vivien & Faure, 1985; Kalkman, 1965) and prefers fertile loam soil. Distribution of *P. africana* could be related to mean annual temperature and rainfall and/or cloud cover (Hall *et al.*, 2000b). It grows in forests where annual rainfall exceeds 900 mm, but generally between 1100 and 1500 mm (Navarro-Cerrillo *et al.*, 2008) and requires mean annual temperature of 18-26$^{o}$c (Orwa *et al.*, 2009).

*Prunus africana* is limited in areas of high elevation where frost days arise in more than three months, suggesting it can withstand mild or infrequent frost, but not severe or prolonged frost (Hall *et al.*, 2000a). The species occurs both in forests transitional between lowland and afromontane and in a range of afromontane forest types from those dominated by a mixture of broad-leaved species to those dominated by conifers. It is well represented in rocky areas or boulder accumulations but absent from the surrounding terrain (Chapman & White, 1970). *Prunus africana* is very characteristic of forest edges, where fires are frequent events and the thick bark imply a fair degree of fire resistance (Gachie, 2002).

In Kenya the species grows in slopes of Mt. Kenya, Mt. Elgon, the Aberdares range, Cherangani hills, Tugen hills, Mau range, Timboroa, Nandi and Kakamega forests (Orwa *et al.,* 2009; Gachie, 2002; Albrecht, 1993; ICRAF, 1992). The species is often found in association with species such as *Albizia gummifera, Anigera adolfi-friederici, Cassipourea malosana, Celtic africana, Podocarpus falcatus and Polyscias kikuyuensis* (Orwa *et al.*, 2009).

### 1.5.2 Importance of *Prunus africana*

The fruits of *P. africana* are drupaceous, fleshy and red-purple in colour and are eaten by a variety of birds and mammals (Cunningham & Mbenkum, 1993). Destruction of *P. africana* in a certain area affects the population of frugivorous faunal populations significantly (Sunderland & Nkefor, 1996; Cunningham & Mbenkum, 1993). It has been found to constitute a vital component of *Colobus guereza*'s diet in Kakamega forest when other foods are not available (Fashing, 2004). According to Chapman & Chapman, (2002), *P. africana* constituted up to 17% of the annual diet of red colobus monkeys in Kibale, Uganda.

The timber of *P. africana* is of very high value. It is a hardwood which has been exported for veneer and paneling (Brown, 1978). The wood has been used by farmers in Cameroon and Kenya as a source of axe and hoe handles, agricultural implements and construction because of its durable nature (Vivien & Faure, 1985).

*Prunus africana* is also used for firewood, charcoal, furniture, poles, bee forage, shade and windbreak (Ndam, 1998). In western Uganda; large *P. africana* trees are popular source of "beer bouts" for making banana beer (Cunningham, 1992).

The bark, leaf and fruit of the species have a long history of use by traditional healers for the treatment of infections. The bark has been ground and drunk as tea against urinary tract problems, allergies, inflammation, kidney disease, malaria, stomachache and fever, among other illnesses (Orwa *et al.*, 2009). It is for treating the urinary tract problems that extracts from the bark have been developed to meet an international herbal market demand as a remedy for Benign Prostatic Hyperplasia, a disease causing non-cancerous enlargement of the prostate in older-aged men (Dawson & Rabevohitra, 1996).

### 1.5.3 Threats to conservation

In forest condition, *P. africana* bole is slim, straight and cylindrical and may be free of branches for 20m or more, two thirds of the total tree height (Letouzey, 1978). The wood is heavy, hard, durable, and planes well (Orwa *et al.*, 2009). *Prunus africana* fire wood is of high quality (Gachie, 2002) and being a forest edge species, it is threatened by exploitation through selective logging for firewood and poles that may contribute to decreased number of individuals in a species close to human settlements (Mligo *et al.*, 2009). The species occurs in densely populated highlands which are very suitable for farming and therefore, vulnerable to fires and clearing for farmlands (Betti, 2008).

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Natural population of *P. africana* present conservation challenges because of low and patchy stocking levels and the frequent under representation of small individuals (Hall *et al.*, 2000a). The tree grows slowly, has recalcitrant seeds and is a light demanding species. It does not maintain a large seedling bank in forest understorey unless they are in gaps (Gachie, 2002). These pose a great problem in the species regeneration especially in the natural environment.

Threats of *P. africana* may also have indirect impacts on the ecosystem in which it occurs. According to Bioko primate protection programme (BPPP) in 1997, new access routes opened in to the forest of Pico Basile on Bioko to harvest *P. africana.* These access routes gave bush meat hunters easier access to the habitat of a seriously threatened endemic subspecies of the primate Preuss's quenon (*Cercopithecus preussi insularis*), which has contributed to its endangered status (BPPP, 1999).

Bark harvesting rates of *P. africana* have reached high levels in countries where European pharmaceutical companies are involved in commercial processing and transportation. Although traditional methods of harvesting bark were non-destructive, the international market demand has led to illegal and destructive harvesting. *Prunus africana* is African's most intensively exploited medicinal plant by volume (Cunningham *et al.*, 2002). The extract from its bark has led to an annual international trade worth approximately US$ 220 million in the final pharmaceutical product (Cunningham *et al.*, 1997).

To supply this demand, approximately 4,000 tonnes of bark have been collected annually by felling of trees from natural stands, leading to concerns on the long term sustainability of harvesting and the conservation of the species. The species is exported from Africa to Europe where the active compounds in the bark are used for drug production (Walter & Rakotonirina, 1995). Between 1988 and 1993 in Madagascar, the amount of bark harvested doubled from 300 tonnes/year to 600 tonnes/year and in 1995, the estimated figure doubled again to 1200 tonnes (Dawson & Rabevohitra, 1996). Between 1986 and 1991, Cameroon exported an average of 1923 tonnes/year to France, Zaire exported 300 tonnes/year (of *P. africana* and *P. crassifolia*) to Belgium and France, Kenya exported 193 tonnes in 1993 to France and Uganda exported 96 tonnes in 1993 (Walter & Rakotonirina, 1995) Fig 1.1.

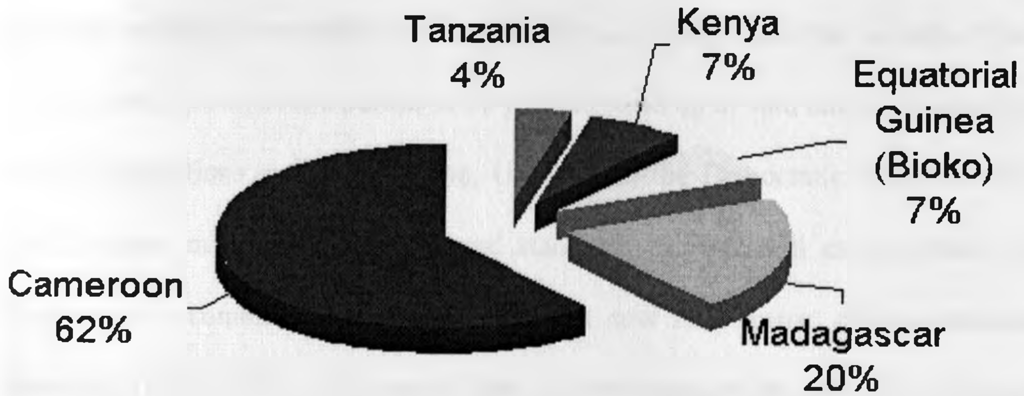


**Figure 1.1:** ***Prunus africana*** **bark entering world market (adopted from Cunningham** ***et al.*****, 1997).**

As a result of over exploitation, trade in *P. africana* is regulated under Appendix II of the Convention on International Trade in Endangered Species (CITES) of wild fauna and flora (Cunningham *et al.*, 1997). In addition, the Food and Agriculture Organization (FAO) panel of experts on forest gene resources lists this species as one of 18 top priority species for action in Africa (FAO, 1997). The species is listed as Vulnerable by International Union for Conservation of Nature (IUCN) due to unsustainable levels of harvesting of its bark across Africa (IUCN, 2002).

*Prunus africana* is declining in Sub-Saharan Africa due to unsustainable harvesting despite the protection accorded to it. *Prunus africana* was once well distributed throughout Africa, from Ethiopia to South Africa and from the west coast to the island of Madagascar (Kalkman, 1965). Since its medicinal properties became widely known, it has been ruthlessly harvested (Cunningham *et al.*, 1997). All that is left of the tree, which usually grows over a period of 30 years to stand up to 40m tall, is a limited number of wild populations mainly in Kenya, Uganda and the Democratic Republic of Congo (DRC) where moderately sized natural stands of the tree still exist (ICRAF, 2000). *Prunus* was a common tree in Cameroon, but now it is scarce, due to unsustainable harvesting (Betti, 2008). In Uganda, there are few traces of the tree left in the southern Kabale hills, where it was until recently in abundance, mainly due to over-cultivation (Achieng, 1999).

In Kenya, it has been experiencing rapid mortality in Kakamega forest (Hall *et al.*,2000a) and according to Fashing, (2004) the decline was not mainly due to bark harvesting but also due to illegal logging for timber, charcoal and firewood in Isecheno, Kakamega forest. Although Kenyans are aware of its medicinal values, the tree is fast disappearing, to make way for settlements (Achieng, 1999).

# CHAPTER TWO

## 2.0 STUDY AREA

### 2.1 Location

The study was carried out in Mt. Kenya forest reserve (Chuka, Chogoria, Ruthumbi, Kibaranyaki, Meru, Rocky and Nanyuki forest blocks) and Imenti forest reserve (Kithoka and Nchoroiburu forest blocks), Fig. 2.1. Mt. Kenya forest is located in eastern and central provinces of Kenya on the equator about 193 Km north east of Nairobi. The forest is 70,520 ha and occurs at an altitude of 1200-3400m.

### 2.2 Climate

The study area experiences two wet and dry seasons in a year (Thompson, 1966). The climate in Mt. Kenya varies considerably over the mountain and has different zones of influence. The lower, south eastern slopes are the wettest as the predominant weather system is influenced by the Indian Ocean. This leads to very dense montane forest on these slopes. High on the mountain most of the precipitation falls as snow, but the most important water source is frost.

Mt. Kenya is characterized by two rainy seasons from March to June and from October to November with the amount of rainfall on the mountain ranging from 900 mm in the North to 2,300 mm on the south-eastern slopes (Castro, 1995). The area is getting drier presently than in the past (Erwin *et al.*, 1984).

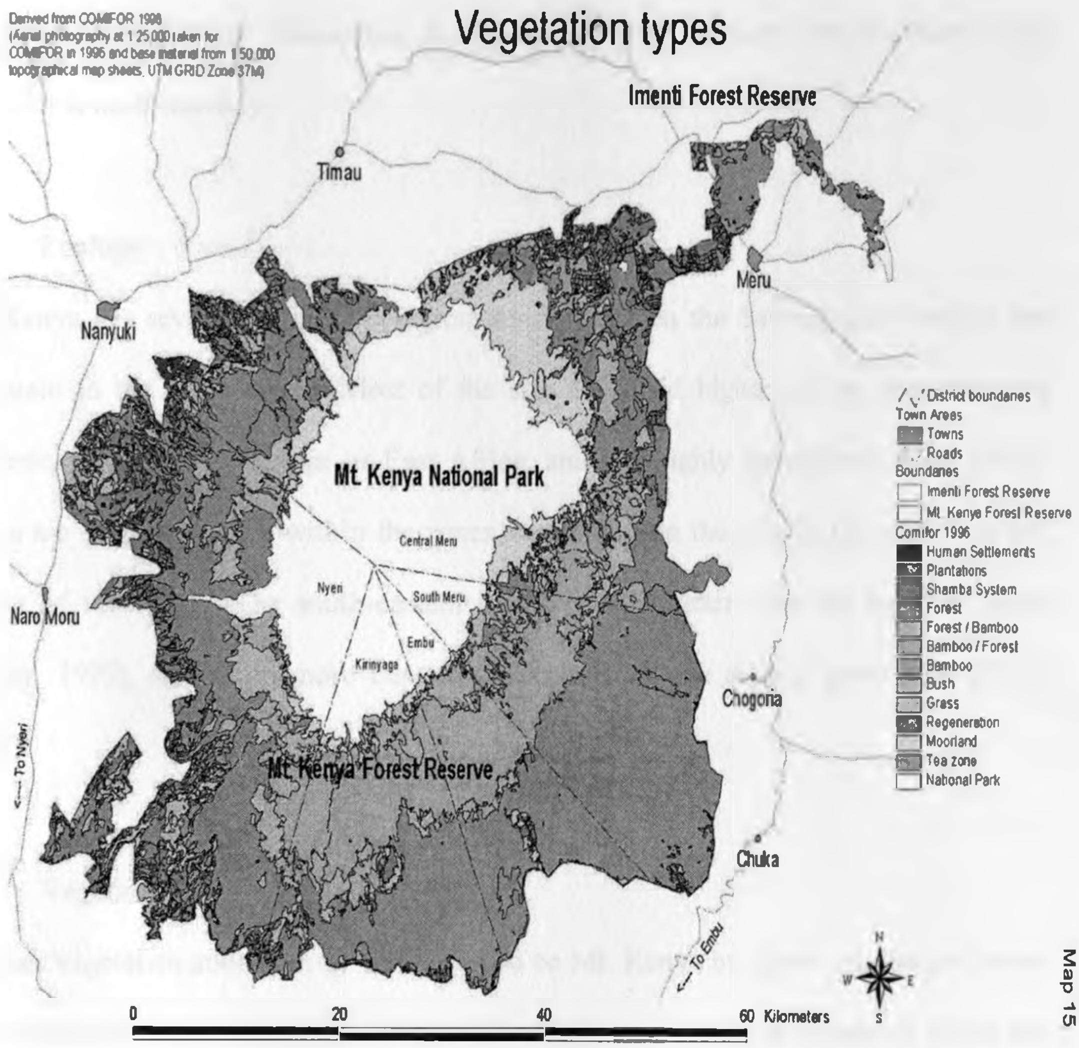


**Figure 2.1: Map of Mt. Kenya showing vegetation types and location of Forest Reserves**

The temperatures span a wide range, which diminishes with altitude and in the lower alpine zone they usually do not go below 12°C (Erwin *et al.*, 1984). Snow and rain are common from March to December, but especially in the two wet seasons. The wet seasons combined account for 83% of the annual precipitation.

The monsoon winds, which control the wet and dry seasons, means that most of the year there are south-easterly winds, but during January and February the dominant wind direction is north-easterly.

## 2.3 Ecology

Mt. Kenya has several distinct ecological zones, between the Savanna surrounding the mountain to the nival zone. Most of the species found higher up the mountain are endemic, either to Mt. Kenya or East Africa, and are highly specialized (Coe, 1967). There are also differences within the zones, depending on the side of the mountain and aspect of the slope. The south-eastern side is much wetter than the northern slope (Ojany, 1993), so species more dependent on moisture are able to grow here (EWP, 2007).

## 2.4 Vegetation

Various vegetation zones can be distinguished on Mt. Kenya but forest vegetation covers the major part of the mountain. Most of the indigenous forest is protected within the forest reserves with some small areas falling within Mt. Kenya national park. Due to the wide range of altitude that spans the indigenous forest and the major climatic differences between the slopes, the forest vegetation of Mt. Kenya is characterized by a high diversity of forest types, with a rich alpine and sub-alpine flora (KWS, 1999).

*Juniperus procera* and *Podocarpus spp.* are predominant in the drier parts of the lower zone (below 2,500 m); with rainfall between 875 and 1,400 mm while *Cassipourea malosana* predominates in wetter areas in the south-west and north-east (over 2,200 mm/year). However, most of this lower altitude zone is not within the reserve and is now used for growing wheat (KWS, 1999).

Higher altitudes (2,500 m-3,000 m with rainfall over 2,000 mm/year) are dominated by bamboo *Arundinaria alpina* on south-eastern slopes, and a mosaic of bamboo and *Podocarpus milanjianus* with bamboo at intermediate elevations (2,600 m-2,800 m), and Podocarpus at higher and lower elevations (2,800-3,000 m and 2,500-2,600 m). Towards the west and north of the mountain, bamboo becomes progressively smaller and less dominant. *Hagenia abyssinica* and *H. revolutum* predominate in areas of maximum rainfall 2,000 m-3,500 m with up to 2,400 mm/year. Above 3,000 m, cold becomes an important factor, tree stature declines, and *Podocarpus* is replaced by *Hypericum spp.* A more open canopy results in a more developed understorey (Musila *et al.*, 2009; KWS, 1999; KWS, 1996).

There are a variety of grasses on well-drained ground and along the streams and river banks such as *Megaphytic senecio battescombei* and *Helichrysum kilimanjari*.
Continuous vegetation stops at about 4,500 m although isolated vascular plants have been found at over 5,000 m. Mt. Kenya has 81 plant species that are endemic (KWS, 1996).

The most common species of large trees on Mt. Kenya include Camphor (*Ocotea usambarensis*), Cedar (*Juniperus procera*), Wild Olive (*Olea europaea*), Meru Oak (*Vitex keniensis*), Podo (*Podocarpus latifolius*), East African Rosewood (*Hagenia abyssinica*), Croton (*Croton macrostachyus*), and Fig tree (*Ficus thonningii*) (KWS, 1999).

### 2.5 Fauna

In the lower forest and bamboo zone the mammals found include the giant forest hog (*Hylochoerus meinertzhageni*), tree hyrax (*Dendrohyrax arboreus*), white-tailed mongoose (*Ichneumia albicauda*), elephant (*Loxodonta Africana*), black rhinoceros (*Diceros bicornis*), suni (*Neotragus moschatus*), black-fronted duiker (*Cephalophus nigrifrons*) and leopard (*Panthera pardus*) (which has also been seen in the alpine zone) (Musila *et al*., 2009; KWS, 1999; KWS, 1996). Moorland mammals include: localized Mt. Kenya mouse shrew (*Myosorex polulus*), hyrax (*Procavia johnstoni mackinderi*) and common duiker (*Sylvicapra grimmia altivallis*). There have also been reported sightings of the golden cat (*Felis aurata*). The endemic mole-rat (*Tachyoryctes splendens*) is common throughout the northern slopes and the hinde valley at elevations up to 4,000 m (KWS, 1996).

Forest birds include green ibis (*Mesembrinibis cayennensis*) (local Mount Kenya race), Ayre's hawk eagle (*Hieraaetus dubius*), Abyssinian long-eared owl (*Asio abyssinicus*), scaly francolin (*Francolinus squamatus*), Ruppell's robin-chat (*Cossypha semirufa*) and numerous sunbirds (Nectariniidae).

Other birds include scarlet-tufted malachite sunbird (*Nectarinia johnstoni*), mountain francolin (*Francolinus psilolaemus*), Mackinder's eagle owl (*Bubo capensis mackinderi*) and the locally threatened scarce swift (*Schoutedenapus myioptilus*). The alpine swift (*Apus melba africanus*) is near endemic (Bennum & Njoroge).

Reptiles existing in the area include the endemic Mt Kenya bush viper (*Atheris desaixi*), Montane viper (*Montatheris hindii*), Montane side stripped chameleon (*Kinyongia excubitor*), Jackson's three horned chameleon (*Chamaeleo jacksoni*), Von Hoehnel's chameleon (*Chamaeleo hoehneli*) and the Alpine meadow lizard (*Adolfus alleni*) (Spawls *et al.*, 2002).

# CHAPTER THREE

## 3.0 MATERIALS AND METHODS

### 3.1 Selection of study sites

Roads and footpaths network in the study forest were identified and geo-referenced to be used in access of the forest. The way-points were uploaded in to the vegetation and climate map of Mt. Kenya in order to find out the gradient covered by each road/footpath. A total of eleven forest blocks were selected from the four vegetation types. These included five representatives from moist montane (Chuka, Chogoria, Ruthumbi, Kibaranyaki and Meru), two from dry montane (Rocky and Nanyuki), moist intermediate (upper Kithoka and upper Nchoroiburu) and dry intermediate (lower Kithoka and lower Nchoroiburu) respectively (Fig 3.3). The differential selection of the forest blocks depended on the size of the vegetation types. Existing vegetation boundaries were downloaded to garmin Geographical Positioning System (GPS) receiver to help identify the vegetation type in which sampling was being done. Roads and foot paths were used to access the forest blocks selected. The study was conducted between the month of October 2009 and January 2010.

### 3.2 Sampling for abundance and structure

Belt transects were employed in sampling. The reference point for the first belt transect was selected 200m from the forest edge and on the baseline. GPS reading for altitude was recorded at the point. From the baseline, one side of the forest was chosen randomly either right or left facing the mountain direction by tossing a coin.

**Plate 3.1: Moist montane vegetation type with thick vegetation and few undergrowths**

**Plate 3.2: Dry montane vegetation type (Nanyuki) with fallen trees and undergrowths**

**Plate 3.3: Moist intermediate vegetation types with relatively few trees and thick undergrowths**

**Plate 3.4: Dry intermediate vegetation type with fewer trees, undergrowths and tracks**

From this side, a belt transect of width 50m and length 500m was established (Fig. 3.1) perpendicular to altitudinal gradient. A GPS reading was recorded for each belt transect to mark its location (Appendix 1).

Abundance was determined by recording the number of trees in plots of 25m x 25m within the belt transect. Each belt transect was divided in to two sub-belts for ease of sampling (Fig 3.1). Forty plots were derived from each belt transect though in some belt transects which did not run for 500m due to poor terrain like deep trenches, plots were less than forty. Sampling started in one sub-belt and on reaching the end, turned to the right and continued in the next sub-belt moving towards the opposite direction (as shown by arrows inside Fig. 3.1). Trees on the belt transect boundary were considered if more than half of their bases lay inside the plot.

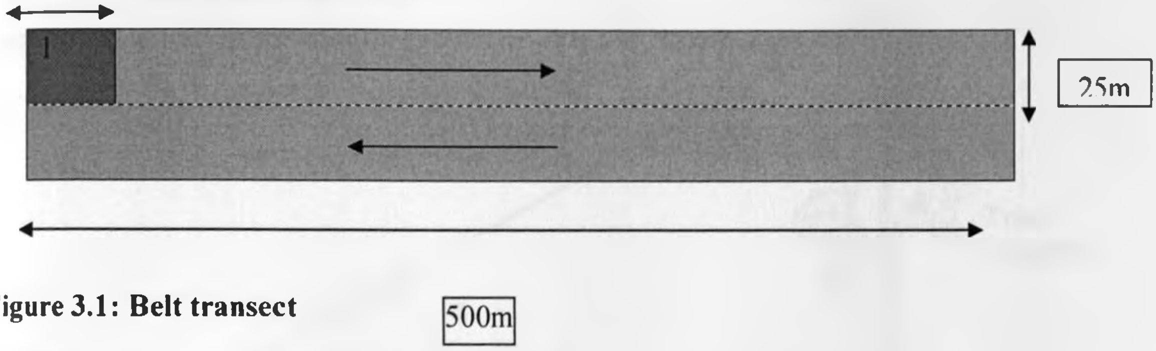


**Figure 3.1: Belt transect**

In the same plots used in sampling abundance, diameter was recorded at breast height (DBH) using a tape measure. Trees <1.5m in stem height had their diameter recorded at the trunk base. In cases where there were swellings, wounds or branches at breast height, diameter was taken above and below them and the measurements averaged. Buttresses were assumed to be part of the stem.

Still in the same plots used above, tree heights ≥ 5m were estimated using Suunto clinometer following Abed & Stephens (2003). A horizontal baseline distance was chosen in which its length was the maximum distance from the tree where the top and the bottom of the tree could be seen through the clinometers (D). The two angles of inclination (formed when looking at the bottom (b) and at the top (a) of the tree) were recorded. The height of the tree was calculated using the two angles of inclination and the baseline distance (Fig 3.2). Trees with height <5m were estimated using Meter ruler.

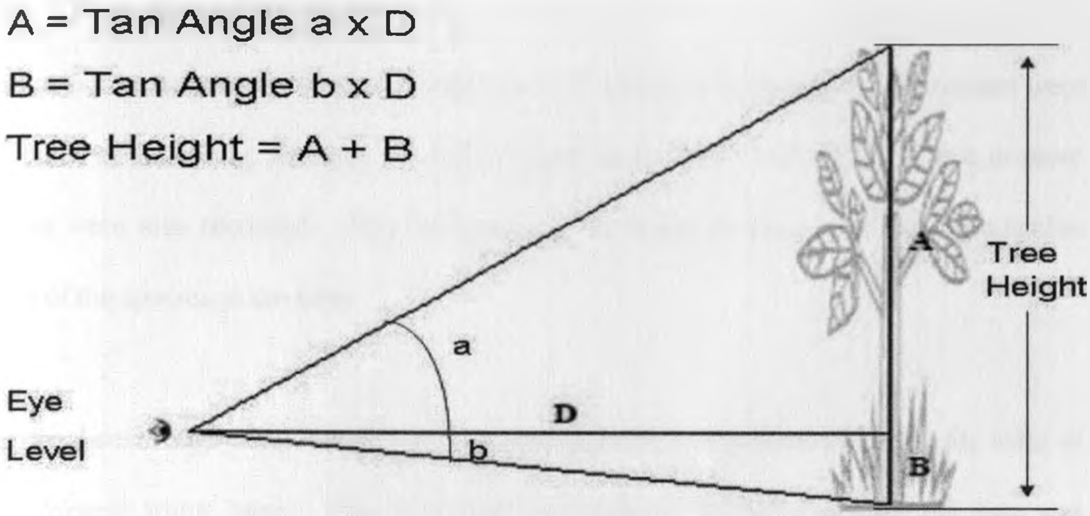


**Figure 3.2: Illustration of trigonometric principles for measuring tree height**

General plot canopy cover was estimated in all plots (used in above sampling) in order to establish whether it influenced distribution and structure of *P. africana.* A digital camera viewfinder was used to estimate canopy cover from the centre of the sample plots. The area covered by the vegetation was expressed as a fraction of the total view.

Subsequent belt transects were obtained after an altitudinal change of 100m moving away from the previous belt transect along the same baseline. However, forests with gentle slope (e.g. Imenti forest); subsequent belt transects were selected after a distance of 1km as measured using GPS receiver along the same baseline. A total of 38 belt transects were selected, 22 from moist montane, 8 from moist intermediate and 4 from dry intermediate and dry montane respectively.

### 3.3 Phenology of *Prunus africana*

Reproductive stages of every individual tree of *P. africana* found in the belt transect were recorded as flowering, fruiting, seeding, vegetative or none. Individuals in two or more stages were also recorded. This information was meant to determine the reproductive state of the species at the time.

Seasonal seedlings were sampled in four quadrats (1m x 1m) from two opposite sides of *P. africana* trunk base. The first side was selected as the direction the tree was encountered from while the second side was directly opposite. The first quadrat was taken immediate to the tree trunk base and each quadrat separated from the other by a distance of 5m. Only trees found within the sample belt transects were considered for seed germination sampling.

### 3.4 Destruction of *Prunus africana*

In every sampling belt transect, all stumps and fallen logs were counted. Every individual of *P. africana* encountered in the belt transect was assessed for debarking and the level of debarking recorded as 'high' (80-100%), 'medium' (50-79%) and 'low' (<50%). Debarking was categorized as natural (animal) if it had tooth or claw marks (plate 3.5) and/or anthropogenic (human) if it had cut marks (plate 3.6).

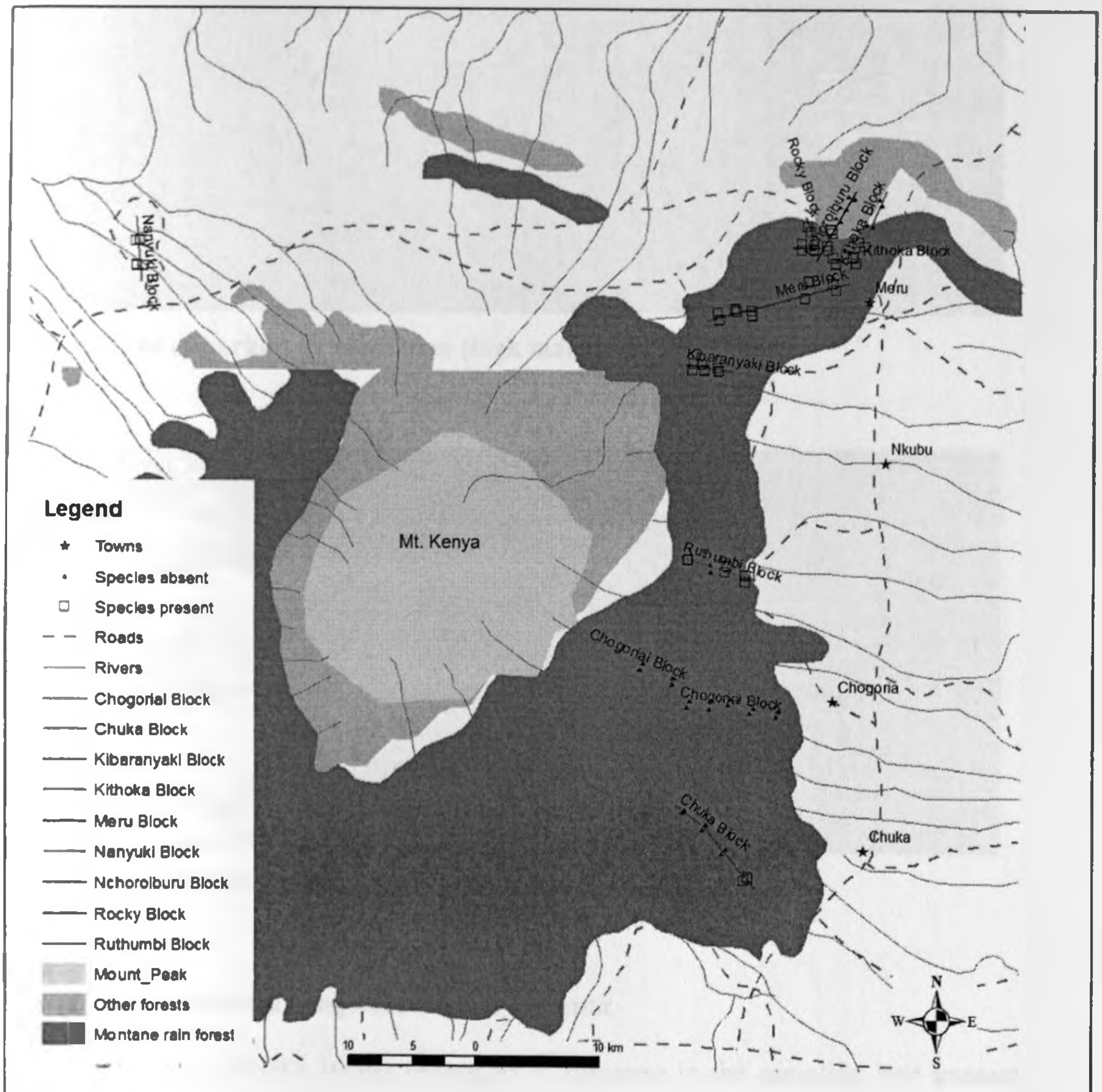


Figure 3.3: Map of Mt. Kenya forest showing sampling sites

**Plate 3.5: Tree debarked by elephants (tusk marks, 4/11/2009)**

**Plate 3.6: Tree debarked by humans (cut marks, 4/11/2009)**

### 3.5 Tree species occurring near *Prunus africana*

Three mature trees (DBH≥ 10cm) nearest to *P. africana* in the sampling belt transect were identified. Their DBH, heights and distance from *P. africana* were recorded. This information was meant to determine the species which occurred in the proximity of *P. africana.*

### 3.6 Farm sampling

Farms were selected in areas near the forest starting with the farm immediate to the forest. Farms were separated by a distance of 1km measured using GPS receiver. A total of forty eight farms were sampled along five roads (farm blocks). The size of the farm was estimated in acres and data collected the same way as described in the forest.

### 3.7 Specimen identification and preservation

Most trees were identified in the field by use of Beentje, (1994) identification guide. Others which could not be identified in the field, were collected, pressed and taken to the East African Herbarium (EA), Nairobi for identification.

### 3.8 Data analysis

All data were entered into Excel spread sheets and analyzed using STATISTICA (version 6.0), PAST (version 1.36) software and Microsoft Office Excel 2003. All statistical significance levels were reported at 0.05.

*Prunus africana* abundance was expressed in terms of number of individuals observed in belt transects. Population structure was summarized using histograms of diameter size classes. The size of the belt transect and farms were converted to hectares ($1m^2$ = 0.0001ha and 1acre = 0.40469ha respectively). Density was calculated as the number of trees per hectare in each of the belt transect or farm sampled. Age classes were determined from DBH such that seedlings were < 1.5m thus no DHH, saplings were < 10cm in DBH while Mature trees were $\geq$10cm in DBH.

Basal area was calculated as the cross section area of the trunk measured at breast height of all tree individuals inventoried, expressed as square meter per hectare.

Analysis of variance (ANOVA) was used to test for differences in species density, DBH and height among vegetation types, canopy cover classes and different altitudes. ANOVA was also used to test for difference in abundance among age classes, seed germination among vegetation types, number of individuals among reproduction stages, number of trees among vegetation types and distances from *P. africana* among five commonest species occurring near it. T-test was used to test for difference in densities between farms and forests.

Data on density, phenology and reproductive stages were log transformed before analysis to permit use of parametric statistics. In data sets that contained zeros, one was added to every observation before transformation (i.e $X^1 = \log(X + 1)$ to eliminate the zeros. Data on percentages were arcsine transformed to remove the imposed limits before analysis.

# CHAPTER FOUR

# 4.0 RESULTS

## 4.1 Abundance and structure of *Prunus africana* in forest

A total of 436 individuals of *P. africana* were observed in 207 out of 1500 plots sampled in the study forest representing a mean density of 4.8 trees/ha.

### 4.1.1. Abundance, density, DBH and height relative to vegetation types

The density was significantly higher in dry montane than in other vegetation types ($P<0.05$) while DBH and height were significantly higher in moist montane ($P<0.05$) (Table 4.1 & 4.2).

**Table 4. 1: Density, DBH and height of *Prunus africana* in vegetation types**

| Vegetation type | Abundance | Density (trees/ha) | Mean DBH (cm) | Mean height (m) |
|---|---|---|---|---|
| Moist montane | 137 | 2.5 | 75.1 | 24.8 |
| Moist intermediate | 46 | 2.4 | 72.5 | 24.3 |
| Dry intermediate | 0 | 0 | 0 | 0 |
| Dry montane | 253 | 32.6 | 42.8 | 18.5 |

**Table 4.2: One-way-ANOVA test of density, DBH and height of *Prunus africana* among vegetation types**

| Variable | F-value | Df | P-value |
|---|---|---|---|
| Density | 10.32 | 3,34 | 0.00056 |
| DBH | 33.2 | 2,405 | 0.0478 |
| Height | 11.3 | 2,372 | 0.00017 |

In moist montane vegetation type, the highest frequency of overall distribution by diameter class was at <10.9cm (Fig. 4.1), the highest frequency in moist intermediate was at 41-70.9cm (Fig. 4.2), while in dry montane vegetation type, the highest frequency was at 31-40.9cm (Fig.4.3).

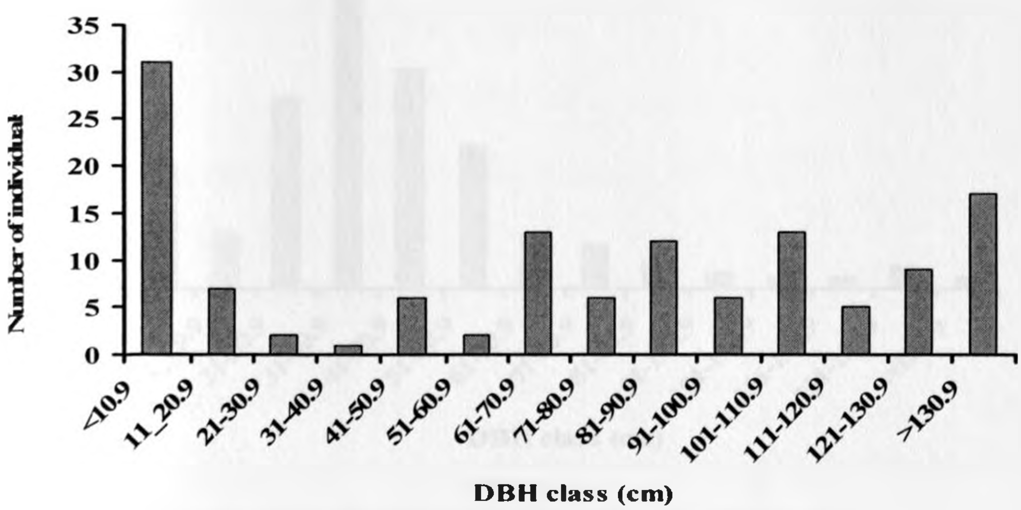


Figure 4.1: DBH size class distribution in moist montane vegetation type

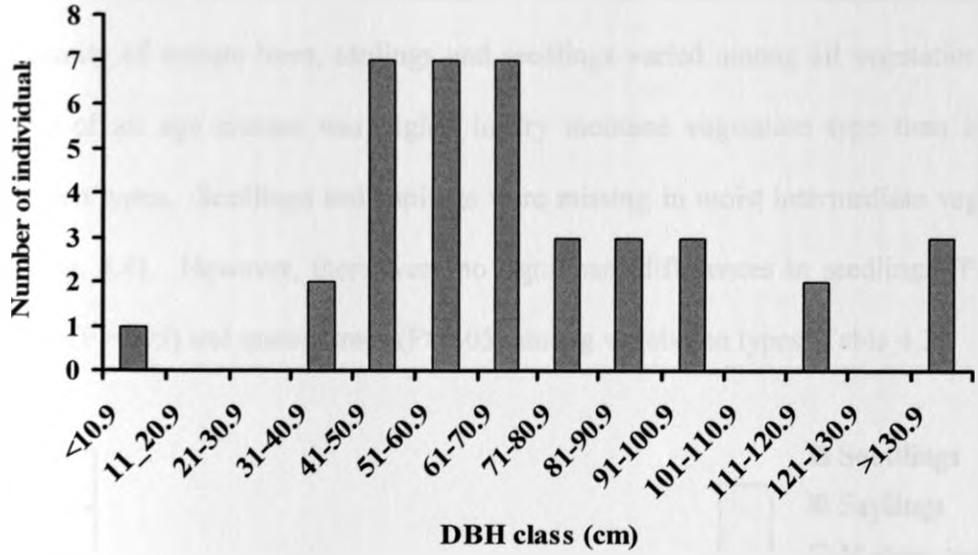


Figure 4.2: DBH size class distribution in moist intermediate vegetation type

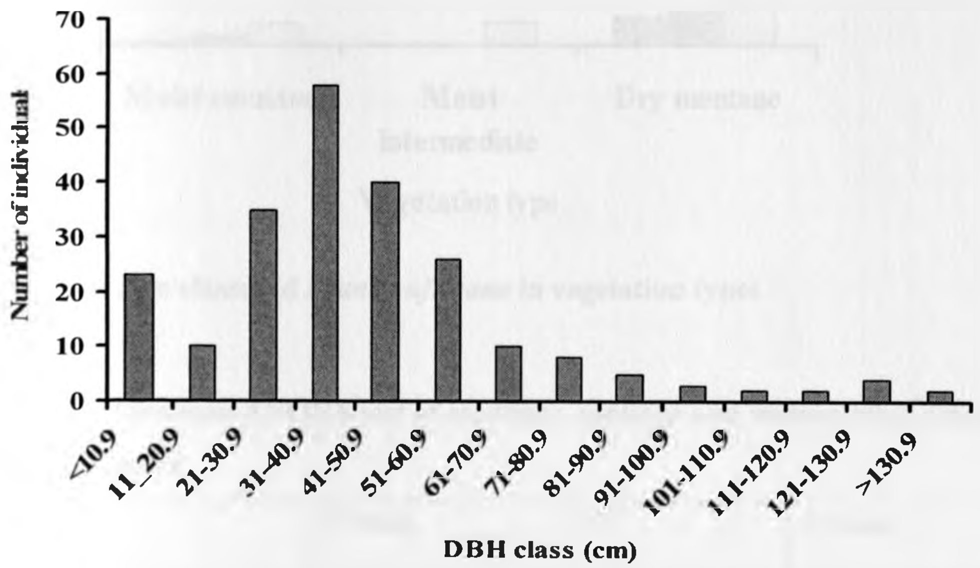


Figure 4.3: DBH size class distribution in dry montane vegetation type

### 4.1.2 Density of mature trees, sapling and seedlings relative to vegetation types

The density of mature trees, saplings and seedlings varied among all vegetation types. Density of all age classes was higher in dry montane vegetation type than in other vegetation types. Seedlings and saplings were missing in moist intermediate vegetation type (Fig. 4.4). However, there were no significant differences in seedlings (P>0.05), saplings (P>0.05) and mature trees (P>0.05) among vegetation types (Table 4.3).

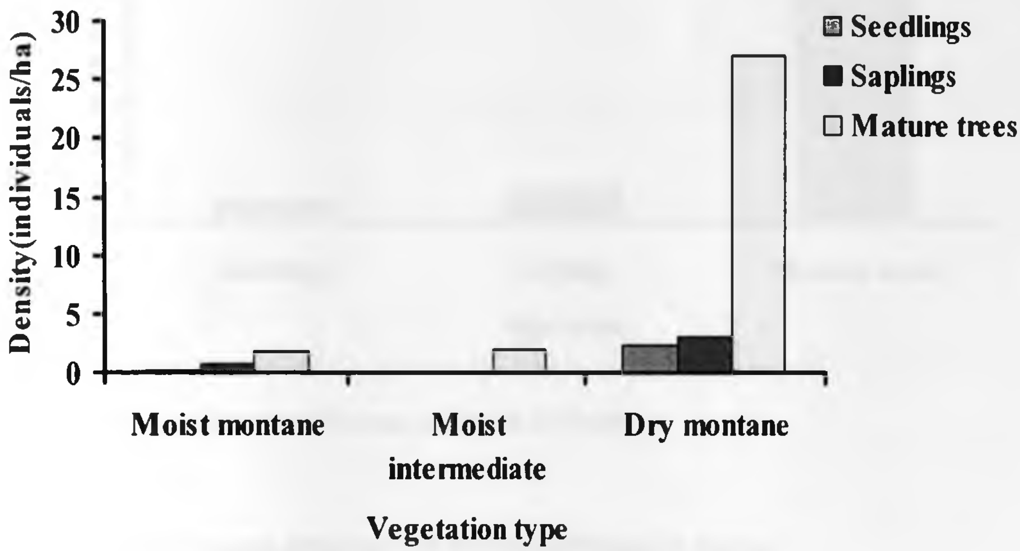


**Figure 4.4: Age classes of *Prunus africana* in vegetation types**

**Table 4.3: One-way-ANOVA test of seedlings, saplings and mature trees among vegetation types**

| Valuable | F-value | Df | P-value |
|---|---|---|---|
| Seedlings | 0.58 | 2,6 | 0.59 |
| Sapling | 2.59 | 2,6 | 0.16 |
| Mature trees | 1.29 | 2,6 | 0.34 |

The mean density of seedlings in the forest was 0.28 individuals/ha, that of saplings was 0.59 individuals/ha while that of mature trees was 3.9 individuals/ha (Fig. 4.5). However, the density of mature trees was significantly higher than that of seedlings and saplings in the forest ($F_{2, 24}$=11.49, P <0.05).

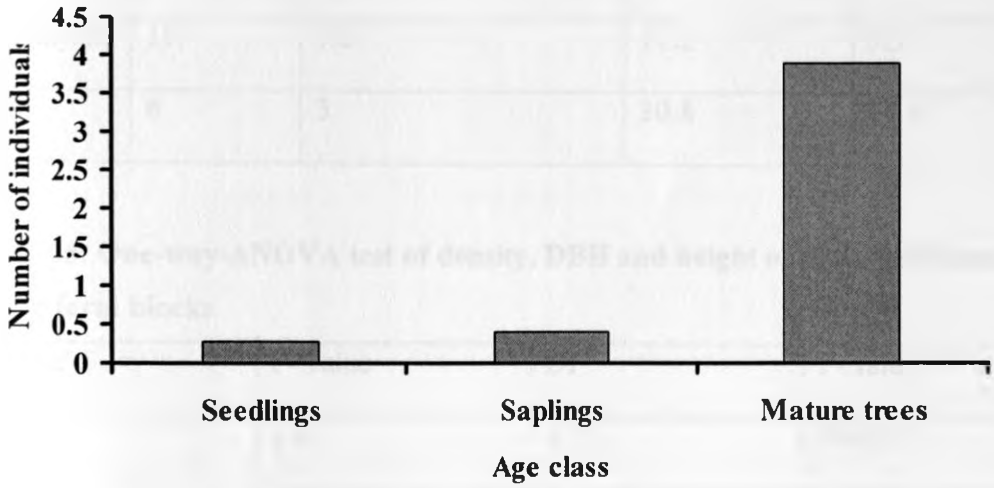


**Figure 4.5: Age classes of *Prunus africana* in forest**

### 4.2 Abundance and structure of *Prunus africana* in farms

A total of 116 individuals of *P. africana* were observed in 31 out of 48 farms studied representing a mean density of 5.2 trees/ha. However, there were no significant difference in density (P>0.05) and DBH (P>0.05) among farm blocks while there was significant difference in the height (P<0.05) Table 4.4 & 4.5.

**Table 4. 4: Density of *Prunus africana* in the farms**

| Forest block | Abundance | Density (individuals/ha) | Mean DBH(cm) | Mean height(m) |
|---|---|---|---|---|
| Chogoria | 10 | 1.7 | 17.8 | 4.6 |
| Ruthumbi | 43 | 6 | 13.8 | 6.6 |
| Chuka | 36 | 7.4 | 22.5 | 8.7 |
| Kibaranyaki | 19 | 9.8 | 11.2 | 5.3 |
| Meru | 8 | 3 | 30.8 | 14.1 |

**Table 4.5: One-way-ANOVA test of density, DBH and height of *Prunus africana* among farm blocks**

| Variable | F- value | Df | P- value |
|---|---|---|---|
| Density | 1.8 | 4,22 | P>0.05 |
| DBH | 2.2 | 4,75 | P>0.05 |
| Height | 3.8 | 4,155 | P<0.05 |

The mean density of seedlings in farms was 2.0 individuals/ha, that of saplings was 1.4 individuals /ha while that of mature trees was 1.7 individuals/ha (Fig. 4.6). There was no significant difference in the density among age classes in farms ($F_{2, 12}$=0.21, P>0.05).

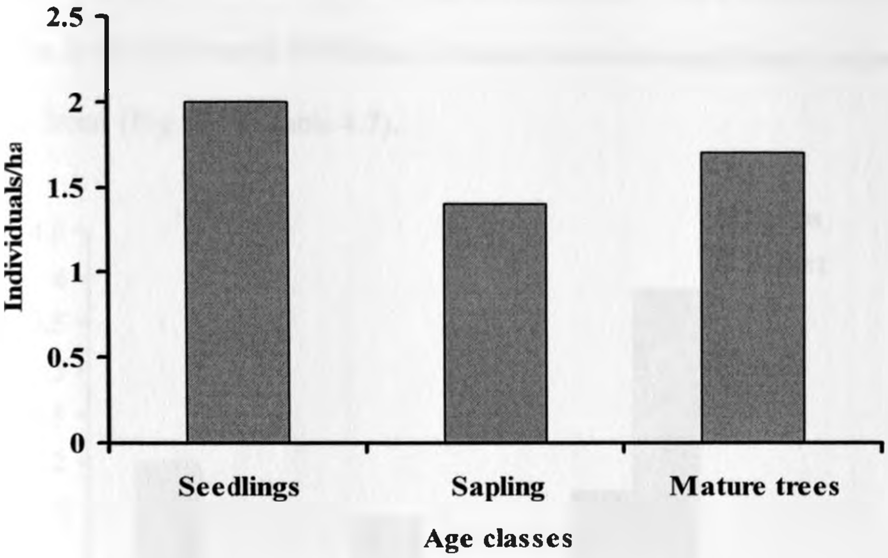


**Figure 4.6: Age classes of *Prunus africana* in farms**

## 4.3 Comparison of density DBH and height, between forest and farm

The mean density was significantly higher in farms than in forests while the mean DBH and height were significantly higher in forests than in farms (Table 4.6).

**Table 4. 6: T-test for differences in density, DBH and heights, between farm and forest**

| Variable | $n_1$ | $n_2$ | $\bar{x}_1$ | $\bar{x}_2$ | t- value | df | P- value |
|---|---|---|---|---|---|---|---|
| Density | 27 | 38 | 6.2 | 5.6 | 2.1 | 63 | P<0.05 |
| DBH | 88 | 410 | 18.6 | 55.5 | 8.1 | 496 | P<0.05 |
| Height | 160 | 507 | 6.7 | 21.9 | 13.9 | 663 | P<0.05 |

Where $n_1$ is the number of observation in the farms and $n_2$ is the number of observations in the forests. $\bar{x}_1$ is the mean of the variable in the farms and $\bar{x}_2$ is the mean in the forest.

The variation in the densities of seedlings and saplings was not statistically different between farms and forests, while that of mature trees was significantly higher in forest than in farms (Fig. 4.7 & Table 4.7).

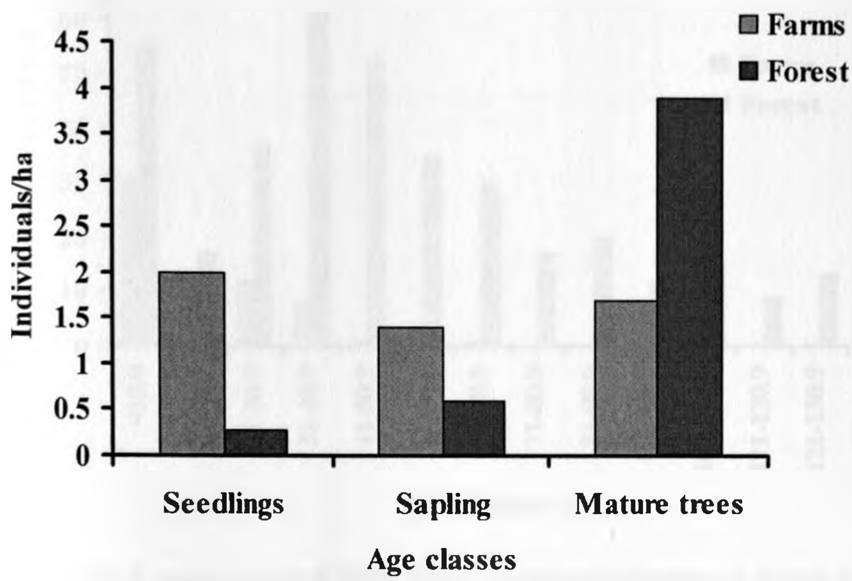


**Figure 4.7: Comparison of age classes between forest and farms**

**Table 4.7: T-test for differences in density, DBH and heights between farm and forest**

| Variable | $n_1$ | $n_2$ | $\bar{x}_1$ | $\bar{x}_2$ | t- value | df | P- value |
|---|---|---|---|---|---|---|---|
| Seedlings | 9 | 5 | 0.48 | 0.97 | 1.3 | 12 | 0.21 |
| Saplings | 9 | 5 | 1.24 | 0.91 | 0.4 | 12 | 0.7 |
| Mature trees | 9 | 5 | 2.4 | 0.43 | 4.1 | 12 | 0.001 |

In the forests, the highest frequency of overall distribution by diameter class was at 31-40.9cm while in the farms the frequency was at <10.9cm (Fig.4.8).

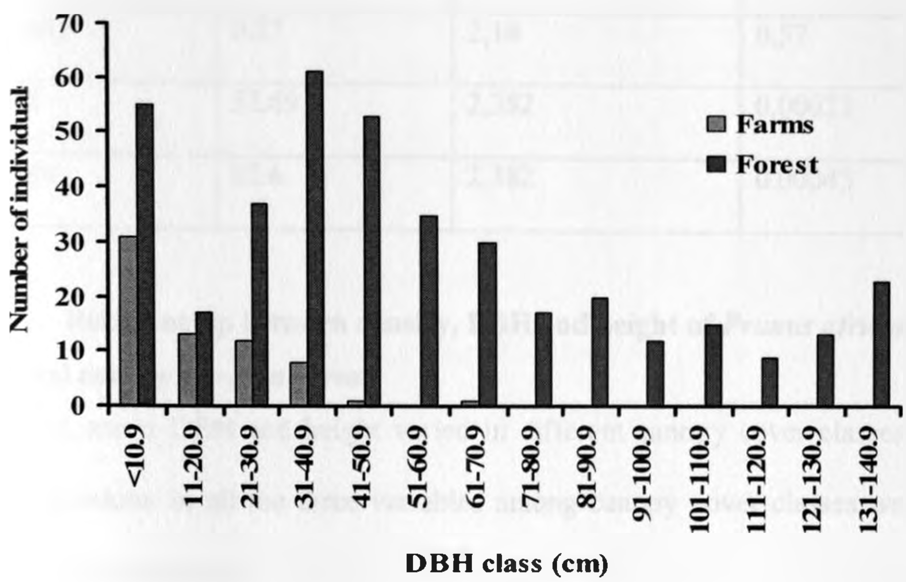


**Figure 4.8: Comparison of DBH class distribution between forest and farms**

## 4.4 Relationship between density, DBH and height of *Prunus africana*, and altitude

Density, DBH and height of *P. africana* varied among different altitude classes (Table 4.8). However, density was not significantly different among altitude classes while DBH and height were significantly higher in lower altitude class (Table 4.9).

**Table 4. 8: Relationship between densities, mean DBH & mean height and altitudes**

| Altitude | 1600-1900m | 1900-2200m | 2200-2500m |
|---|---|---|---|
| Density(trees/ha) | 3.8 | 19.7 | 6.8 |
| Mean DBH (cm) | 86.9 | 44.1 | 38.4 |
| Mean height (m) | 22.6 | 19.4 | 18 |

**Table 4.9: One-way-ANOVA test of Density, DBH and height of *Prunus africana* among altitudes classes**

| Variable | F-value | df | P-value |
|---|---|---|---|
| Density | 0.57 | 2,18 | 0.57 |
| DBH | 55.69 | 2,382 | 0.00023 |
| Height | 22.6 | 2,382 | 0.00045 |

## 4.5 Relationship between density, DBH and height of *Prunus africana*, and general canopy cover in forest.

Density, mean DBH and height varied in different canopy cover classes (Table 4.10). The variations in all the three variables among canopy cover classes were statistically different (Table 4.11).

**Table 4.10: Relationship between densities, mean DBH and mean height, and percent canopy cover**

| Variable | ≤30 | 31-60 | >60 |
|---|---|---|---|
| Density(trees/ha) | 15.5 | 4.9 | 0.7 |
| Mean DBH (cm) | 43.2 | 82 | 49 |
| Mean height (m) | 19.2 | 25.1 | 17.5 |

**Table 4.11: One-way-ANOVA test of Density, DBH and height of *Prunus africana* among canopy cover classes**

| Variable | F-value | df | P-value |
|---|---|---|---|
| Density | 21.53 | 2,30 | P<0.05 |
| DBH | 43.65 | 2,399 | P<0.05 |
| Height | 16.48 | 2,538 | P<0.05 |

### 4.6 Relationship between general canopy cover and vegetation types

The average canopy cover in moist montane vegetation type was 80%, in moist intermediate was 44% while in dry intermediate and dry montane were 48% and 38% respectively. However, the means of arcsined percentage canopy covers were statistically different among the vegetation types ($F=_{3,38}=10.25$, $P<0.05$).

### 4.7 Seed germination in *Prunus africana*

Large numbers of even-aged seedlings were observed in this study (Plate. 4.1). The mean density of seasonal seedlings was 19.1seedlings/$m^2$ in the forest but varied among vegetation types. It was 38.2seedlings/$m^2$ in moist montane, 2.41seedlings/$m^2$ in dry montane and 0.006seedlings/$m^2$ in moist intermediate vegetation type which was infested by thick undergrowth of *Lantana sp.* (Plate 4.2). The variation in densities of seasonal seedlings among vegetation types were statistically different ($F=_{2,193}=16.99$, $P<0.05$).

**Plate 4. 1: Seedlings of *Prunus africana* found under the mother tree (4/11/2009 and 6/1/2010 respectively)**

**Plate 4. 2: Imenti forest infested by *Lantana sp.* (12/11/2009)**

## 4.8 Phenology of *Prunus africana*

More than half of the trees were not in any reproductive stage (211 trees). Some trees (57 trees) had only old fallen seeds on the ground. Thirty four of the trees had fruits; twenty six had fallen seeds and fruits while other 25 trees had flowers and fruits. Three trees had flowers (Appendix 3). However, the variation in the number of individuals among developmental stages of *P. africana* was statistically significant ($F_{5, 210} = 6.61$, $P<0.05$).

## 4.9 Destruction of *Prunus africana*

Sixty two (12.4%) destroyed trees (stumps and logs) of *P. africana* were recorded out of a total of 498 stems ( both live and destroyed). The destroyed trees were expressed as a proportion of total stems in every forest block (Table 4.12). Nchoroiburu (32.5%) followed by Kithoka (17.4%) and then by Nanyuki (15.9%) forest blocks had the highest proportion of *P. africana* stumps and logs.

**Table 4.12: Destroyed trees of *Prunus africana* in different forest blocks**

| Forest blocks | Total tree stems | Stumps | Logs | % of fallen trees/ block |
|---|---|---|---|---|
| Chuka | 24 | 0 | 0 | 0 |
| Chogoria | 0 | 0 | 0 | 0 |
| Ruthumbi | 46 | 2 | 0 | 4.3 |
| Kibaranyaki | 45 | 1 | 0 | 2.2 |
| Meru | 49 | 1 | 0 | 2.0 |
| Kithoka | 23 | 4 | 0 | 17.4 |
| Nchoroiburu | 40 | 13 | 0 | 32.5 |
| Nanyuki | 258 | 6 | 35 | 15.9 |
| Rocky | 13 | 0 | 0 | 0 |
| Total | 498 | 27 | 35 | 12.4 |

Debarked trees were 164 out of 436 live trees sampled (37.6%). Out of these, Animals (elephants, Plate 4.3) were responsible for 33% of debarking while humans were responsible for 4.6%. Debarking was highest in Rocky, followed by Meru and then by Kithoka forest block (Table 4.13).

**Plate 4. 3: Elephants and camels in Imenti forest (12/1/2010)**

**Table 4.13: Debarked *Prunus africana* in different forest blocks**

| Forest blocks | Total Abundance | Debarking | | Debark rating | | | % debarked/ |
|---|---|---|---|---|---|---|---|
| | | Human | Others | high | medium | low | |
| Chuka | 24 | 0 | 0 | 0 | 0 | 0 | 0 |
| Chogoria | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ruthumbi | 44 | 5 | 0 | 2 | 1 | 2 | 11 |
| Kibaranyaki | 44 | 0 | 10 | 4 | 5 | 1 | 23 |
| Meru | 48 | 10 | 21 | 14 | 8 | 9 | 65 |
| Kithoka | 19 | 3 | 9 | 0 | 3 | 9 | 63 |
| Nchoroiburu | 27 | 0 | 9 | 0 | 0 | 9 | 33 |
| Nanyuki | 217 | 1 | 86 | 31 | 33 | 23 | 40 |
| Rocky | 13 | 1 | 9 | 4 | 5 | 1 | 77 |
| Total | 436 | 20 | 144 | 55 | 55 | 54 | 38 |

## 4.10 Tree species occurring near *Prunus africana*

A total of 41 species belonging to 23 families were found near *P. africana* (Table 4.14).

**Table 4.14: Tree species found near *Prunus africana***

| Species name | Family | Number of individuals |
|---|---|---|
| *Bersama abyssinica* Fres. | Melianthaceae | 5 |
| *Calodendrum capense* (L.f.)Thunb. | Rutaceae | 3 |
| *Casaeria battiscombei* R.E. Fries | Flacourtiaceae | 23 |
| *Celtis africana* Burm. F. | Ulmaceae | 13 |
| *Chionanthus battiscombei* (Hutch.)Stearn | Oleaceae | 1 |
| *Clausena anisata* (Willd.) Benth | Rutaceae | 2 |

| | | |
|---|---|---|
| *Cordia africana* Lam. | Boraginaceae | 17 |
| *Croton sylvaticus* Hochst. | Euphorbiaceae | 4 |
| *Diospyros abyssinica* (Hiern) F. White | Ebenaceae | 1 |
| *Dovyalis abyssinicus* (A. Rich.) Warb | Flacourtiaceae | 1 |
| *Ehretia cymosa* Thonn. | Boraginaceae | 20 |
| *Fagaropsis angolensis* (Engl.) Dale | Rutaceae | 5 |
| *Ficus sur* Forssk. | Moraceae | 1 |
| *Ficus thonningii* Bl. | Moraceae | 2 |
| *Ilex mitis (L.) Radlk.* | Aquifoliaceae | 2 |
| *Juniperus procera* Endl. | Cupressaceae | 23 |
| *Kigelia africana* (Lam.) Benth | Bignoniaceae | 4 |
| *Macaranga kilimandscharica* Pax | Euphorbiaceae | 1 |
| *Markhamia lutea* (Benth.) K. Schum. | Bignoniaceae | 2 |
| *Millettia tanaensis* Gillett | Papilionaceae | 9 |
| *Neoboutonia macrocalyx* Pax | Euphorbiaceae | 30 |
| *Olea africana* L. | Oleaceae | 51 |
| *Olea europaea* (Mill.) P. Green | Oleaceae | 2 |
| *Oncoba spinosa* Forssk. | Flacourtiaceae | 8 |
| *Peddiea fischeri* Engl. | Thymeleaceae | 7 |
| *Pittosporum viridiflorum* Sims. | Pittosporaceae | 9 |
| *Podocarpus falcatus* Mirb. | Podocarpaceae | 90 |
| *Podocarpus latifolius* (Thunb.) Mirb. | Podocarpaceae | 6 |
| *Premna maxima* T.C.E. Fries | Verbenaceae | 16 |
| *Prunus africana* (Hook.f.) Kalkm | Rosaceae | 33 |
| *Rapanea melanophloeos* (L.) Mez. | Myrsinaceae | 4 |
| *Rothmannia urcelliformis* (Hiern) Robyns | Rubiaceae | 8 |
| *Senna septemtrionalis* (Viviani) Irwin & Barneby | Caesalpiniaceae | 1 |
| *Syzygium guineense* (Wild.)DC. | Myrtaceae | 12 |
| *Tabernaemontana stapfiana* Britten | Apocynaceae | 52 |
| *Vangueria madagascariensis* Gmel. | Rubiaceae | 5 |
| *Vitex keniensis* Turrill | Verbenaceae | 29 |
| *Xymalos monospora* (Harv.) Warb | Monimiaceae | 58 |
| *zanthoxylum gillettii* (De Wild.) Watern. | Rutaceae | 5 |

There were 33 tree species in moist montane, 17 and 22 tree species in moist intermediate and dry montane vegetation types respectively (Appendix 5). However, the variation in the number of trees species among vegetation types was not statistically significant ($F_{2, 69}$=1.67, P>0.05).

The commonest tree species occurring near *P. africana* in moist montane vegetation type were: *Xymalos monospora* (18%), *Tabernaemontana stapfiana* (17.5%), *Neoboutonia macrocalyx* (10%) and *Vitex keniensis* (9%). In moist intermediate they were *Teclea simplicifolia* (24%), *Cordia africana* (12%), *Celtis africana* (9%), and *Oncoba spinosa* (9%) while in dry montane they were *Podocarpus falcatus* (27%), *Olea africana* (19%), *Teclea simplicifolia* (12%) and *Juniperus procera* (9%) (Appendix 5).

*Prunus africana* had the highest mean basal area among individuals with DBH ≥10cm (4336$cm^2$) as compared to other five commonest species whose mean basal areas were: *P. falcatus* (698$cm^2$), *T. stapfiana* (570$cm^2$), *O. africana* (515$cm^2$), *T. simplicifolia* (260$cm^2$) and *X. monospora* (258$cm^2$). The variation in basal areas of the species was statistically difference ($F_{5, 659}$=24.59, P<0.05).

The mean distances of the five commonest species from *P. africana* were: 2.05m (*X. monospora*), 2.12m (*T. stapfiana*), 4.26m (*P. falcatus*), 4.86m (*T. simplicifolia*) and 5.09m (*O. africana*). The variation in the distances from *P. africana* among the five species was statistically significant ($F_{4, 301}$ = 9.75, P < 0.05).

# CHAPTER FIVE

## 5.0 DISCUSSION AND CONCLUSION

### 5.1 Discussion

The Mt. Kenya forest *P. africana* described here was observed at an altitude between 1600 and 2500m above sea level within moist montane, moist intermediate and dry montane vegetation types (Appendix 2). Earlier research by Hall, *et al.*, (2000a); Trapnell & Brunt, (1987); Trapnell, (1997) found the species in montane forests above 1500m a.s.l. in Kenya.

The results of this study showed density of *P. africana* being higher in dry montane than in other vegetation types probably due to low percentage canopy cover since *P. africana* requires lighted areas to recruit from seedlings to saplings (Navarro-Cerrillo *et al.*, 2008; Ndibi, 1996; Ewusi *et al.*, 1992; Geldenhugs, 1981). However, individuals recorded in this vegetation type were smaller in DBH compared to those in other vegetation types. Using the principle of percentage canopy cover, it was expected that moist intermediate which had more open canopy than moist montane would rank number two in terms of density. This was not the case and the reason could have been due to exploitation through selective logging for firewood and poles that may contribute to decreased number of individuals in a species close to human settlements (Mligo *et al.*, 2009).

The height of the tallest tree observed in this study concurred with the one found by Navarro-Cerrillo *et al.,* (2008); Steward, (2003) of 30m to over 40m, but the DBH size went far beyond that recorded by Orwa *et al*., (2009); Betti, (2008) of 1.5m, Hitimana, (2000) of 1.1m record from Mt. Elgon and Dale, (1936) of 0.9-1m in Kenya, (Appendix 2). The biggest tree in terms of DBH and height was recorded in Meru forest block probably because it occurred in a secondary forest. The original forest was harvested back in 1933 for commercial purpose and replanted with indigenous trees (including *P. africana*) to restore the previous vegetation (DFO Meru, Pers. Comm.). This might have given *P. africana* opportunity to develop before other species came up and closed the area. This supports many reports (Ndam, 1998; Cunningham *et al*., 1998; Sunderland & Nkefor 1997; Cunningham & Mbenkum, 1993; Ewusi *et al*., 1992) that *P. africana* is a secondary forest species.

Tree regeneration patterns are normally identified by structural analysis of population (Taylor & Zinsheng, 1988). Results of this study showed that *P. africana* in the forest had a bell shaped diameter distribution pattern with poor representation in both lower and upper DBH size classes (Fig 4.8). Mligo *et al*., (2009) described this kind of structure as interrupted owing to poor recruitment of seedlings. Age structure exhibited by the species was J-shaped whereby mature trees were statistically more abundant than sapling and seedlings (Fig 4.5). This structure has also been described by Hall *et al.,* (2000a, b) and it is indicative of a more or less unstable population structure (Mligo *et al*., 2009). Most individuals (young) were found at the beginning of belt transects in Ruthumbi forest block.

This was attributed to the fact that the road used to access the belt transects led to a place where a camp (Themwe camp) was under construction, and therefore there was a lot of tree felling to give way. Ewusi *et al.*, (1992) found *P. africana* most abundant in disturbed areas with 63% of *Prunus* trees along forest margins.

Distribution of plant species is often influenced by habitat conditions and human activities (Mligo *et al.*, 2009). Habitat conditions like the amount of rainfall and temperature which may affect growth of plants are directly or inversely related to altitude. Results in this study showed no statistical difference in density of *P. africana* among altitude classes (Table 4.9). This may imply that the variations in the habitat conditions along altitude were not significant. It could also mean that the species grows in a wide range of conditions. From another perspective, these could be explained by one, human settlements occurring at lower altitudes that could affect species abundance due to human activities like grazing and fuel-wood collection and second, by shade intolerance of the species in undisturbed forests (Hall *et al.*, 2000a,b; Tchouto, 1996). These effects could have acted to balance the density of the species in different altitude classes. Also the character of intolerance to shading could contribute towards the significant variations in DBH and heights of the species in different altitude classes due to competition for light in shaded areas.

Ndam, (1998) studied the impact of habitat and population fragmentation on the regeneration of *P. africana* in Mount Cameroon.

He found that seedlings density and frequency were higher in agricultural fallow habitat than in secondary and primary forest habitats. In contrast, results in this study showed no statistical difference in seedlings and saplings density between farms and forests (Table 4.7). The study farms were found in areas with high human population and in highly productive land where people give priority to food farming and to fast growing exotic trees, leaving very little space for slow growing indigenous trees. This probably affected regeneration of *P. africana* in farms. Individuals of *P. africana* in farms were present due to interests of the farmers and therefore their survival dependent on the farmers themselves. Some farmers harvested the species in their farms for firewood while others harvested for construction poles. This resulted to few individuals in the upper DBH size class than in lower DBH in the farms unlike in the forest where harvesting was not legally allowed.

Canopy cover has considerable effects on stem and natural regeneration of plants (Genc, 2004). Density of *P. africana* was higher in open canopy areas than in closed canopy areas (Table 4.10). Although *P. africana* was found to prefer open canopies, it was also present in some areas with closed canopies though only mature individuals were observed. Lack of associated recruitment in these canopies suggests that, *P. africana* could be a secondary successional species (Tchouto, 1996).

Regeneration of *P. africana* has been reported to be generally good (Terry *et al.*, 1999). Although density of older *P. africana* was highest in dry montane vegetation type (Table 4.1), recently germinated seedlings density was highest in moist montane in this study.

This was attributed to the fact that moist montane was wetter (due to higher moisture resulting from the tree crowns intercepting the wind driven moisture, part of which drips to the ground, and also from bryophytes) than moist intermediate and dry montane; therefore the seeds could be requiring high moisture to germinate (Ndam, 1996). It could also be attributed to the fact that dry montane and moist intermediate vegetation types were more disturbed by animals (elephants and camels which were many in the areas, plate 4.3) and this could have affected seed development due to shaking of mother trees. Results implied that light is not a requirement in *P. africana*'s germination (Ndam, 1998; Geldenhuys, 1981.

Likewise, a thick undergrowth of *Lantana sp.* (Plate 4.2) in dry montane and moist intermediate vegetation types could contribute to low density of seedlings by hindering seed germination and recruitment (Ewusi *et al.*, 1992; Fashing, 2004). This study showed that recruitment of seedlings to maturity could be limited as exhibited by low density of older trees in moist montane (Table 4.1) which had the highest density of seedlings. Sunderland & Nkefor, (1997) found high initial seed germination rates in closed-canopy forest but were immediately followed by almost 100% seedling mortality.

Frugivorous birds and mammals have been reported to play an important role in *P. africana*'s seed dispersal (Orwa *et al.*, 2009; Sunderland, 1995). This study found dispersal of seeds/fruits from parent trees negligible since majority of the seedlings were observed within crown line of the mother tree (Appendix 4). This concurred with the results of Ndam, (1998), who found higher density of seedlings under mother trees.

Hall, (2000); Kalkman (1965) suggested that frugivores played an important role in opening the seeds for germination to take place. Some seedlings were observed under crowns of other tree species especially in areas where *P. africana* occurred in clusters. In such instances, the aspect of dispersal by arboreal animals was evident.

Phenology of *P. africana* is very variable from year to year as well as from area to area within a particular country (Tonye *et al.*, 2000). Flowering has been found to peak between November and February while sporadic flowering has been reported to occur all year round in Kakamega forest (Orwa *et al.*, 2009; Tonye *et al.*, 2000). In this study, *P. africana* was in different reproductive stages, highest proportion being not in any observable reproduction stage (Appendix 3). This showed that the species was out of its reproduction season during the time of sampling. Irregularity of seed production as mentioned by Were & Munjuga, (1998) could also be an explanation to this observation.

Variation in habitat and effects of human activities could have been among the factors that contributed to the observed variation in number of tree species among vegetation types. It was found that moist intermediate and dry montane vegetation types had the lowest number of tree species (Appendix 5). These vegetation types occur in areas near human settlements and therefore some of the species might have been exploited through cultivation and grazing on the forest edge as have been reported by Mligo *et al.*, (2009).

Decreased species numbers close to human settlements might also been due to fuel wood harvesting and pole cutting for settlement construction since majority of houses in the area were build from wood material. As a result of tree removal, most of these areas were encroached by fast growing species (*Lantana sp*., Plate 4.2) which would hinder establishment of other tree species. The species recorded in every vegetation type were similar to those recorded by Trapnell & Brunt (1987); Trapnell *et al*., (1986). Some were recorded by Trapnell, (1997) as characteristic for or indicative of the vegetation types.

In forest condition, *P. africana*'s stature and wood are very suitable for fuel, furniture and construction poles (Orwa *et al*., 2009; Gachie, 2002; Letouzey, 1978). Destruction of *P. africana* in the study area was mostly in areas near human settlements and in areas preferred by elephants. Nchoroiburu and Kithoka forest blocks which were surrounded by human settlements and with many elephants (Plate 4.3) had the highest percentage of *P. africana* stumps as compared to other forest blocks (Table 4.12).

Equally, most logs were recorded in Nanyuki forest block (Plate 3.2 & Table 4.12) where population of elephants was present. Falling of trees could be due to leaning by the elephants, the effect of winds and soil types.

Bark of *P. africana* is traditionally used by communities surrounding Mt. Kenya forest as medicine to relief stomachache, improve appetite, remove allergies and as purgative for cattle. Though many uses, the communities were using the species sustainably (Table 4.13).

The bark of the species seemed to be preferred much by animals other than humans especially elephants (Table 4.13) and thus wildlife were found to be the major threat to the species in Mt. Kenya forest (Musila *et al.*, 2009).

## 5.2 Conclusions and Recommendations

This was the first study to provide *P. africana*'s abundance and population structure data in Mt. Kenya forest. It was a positive step towards the assessment of population status due to the mounting concern over global declines of the species. From the study, it has been observed that:-

- The distribution of *P. africana* in the study area was disjointed, varying from one vegetation type and canopy cover class to the other.
- Density of the species did not differ among altitude classes while DBH and height differed significantly.
- Seedlings of *P. africana* preferred areas with light penetration for development although they germinated in very shaded places.
- The population structure of *P. africana* was characterized by high number of medium sized trees with a poor representation in both lower and higher DBH size classes.
- Felling of mature trees of *P. africana* in Mt. Kenya forest has affected the structure and distribution pattern of the species.

It was recommended that, to safeguard the future of *P. africana*, the human threats to the forest need be minimized and/or inhibited.

'his can be done through encouraging cultivation of *P. africana* in private farms to rovide services to the community those are otherwise derived from the forest. ıvestigation on the cause of drying of *P. africana* in some belt transects in Nchoroiburu orest block where most individuals were found dry was also recommended.

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# APPENDICES

**Appendix 1: Belt transect locations**

| Forest block | Belt transect | Altitude | GPS location | | Vegetation type |
|---|---|---|---|---|---|
| | | | Latitudes | longtitudes | |
| Chuka | 1 | 1677 | -0.350617 | 37.568500 | Moist montane |
| Chuka | 1 | 1678 | -0.350067 | 37.568233 | Moist montane |
| Chuka | 1 | 1597 | -0.350567 | 37.564000 | Moist montane |
| Chuka | 1 | 1581 | -0.350200 | 37.563733 | Moist montane |
| Chuka | 2 | 1769 | -0.329800 | 37.551217 | Moist montane |
| Chuka | 2 | 1747 | -0.332633 | 37.547450 | Moist montane |
| Chuka | 2 | 1772 | -0.333033 | 37.548017 | Moist montane |
| Chuka | 2 | 1774 | -0.329533 | 37.550867 | Moist montane |
| Chuka | 3 | 1877 | -0.316067 | 37.533667 | Moist montane |
| Chuka | 3 | 1835 | -0.312967 | 37.536700 | Moist montane |
| Chuka | 3 | 1877 | -0.315883 | 37.533350 | Moist montane |
| Chuka | 3 | 1836 | -0.312750 | 37.536367 | Moist montane |
| Chuka | 4 | 1957 | -0.302950 | 37.520333 | Moist montane |
| Chuka | 4 | 1944 | -0.304733 | 37.521867 | Moist montane |
| Chuka | 4 | 1961 | -0.303267 | 37.519533 | Moist montane |
| Chuka | 4 | 1948 | -0.305550 | 37.521250 | Moist montane |
| Chogoria | 1 | 1778 | -0.238450 | 37.586600 | Moist montane |
| Chogoria | 1 | 1789 | -0.238300 | 37.586217 | Moist montane |

| | | | | | |
|---|---|---|---|---|---|
| Chogoria | 1 | 1752 | -0.234433 | 37.588367 | Moist montane |
| Chogoria | 1 | 1752 | -0.234283 | 37.587967 | Moist montane |
| Chogoria | 2 | 1887 | -0.236033 | 37.568033 | Moist montane |
| Chogoria | 2 | 1886 | -0.235900 | 37.567633 | Moist montane |
| Chogoria | 2 | 1868 | -0.232567 | 37.570700 | Moist montane |
| Chogoria | 2 | 1873 | -0.232300 | 37.570117 | Moist montane |
| Chogoria | 3 | 2006 | -0.230267 | 37.552483 | Moist montane |
| Chogoria | 3 | 2002 | -0.230300 | 37.551967 | Moist montane |
| Chogoria | 3 | 1973 | -0.226650 | 37.554983 | Moist montane |
| Chogoria | 3 | 1992 | -0.226600 | 37.554550 | Moist montane |
| Chogoria | 4 | 2234 | -0.228033 | 37.524567 | Moist montane |
| Chogoria | 4 | 2237 | -0.227900 | 37.524150 | Moist montane |
| Chogoria | 4 | 2189 | -0.232167 | 37.522483 | Moist montane |
| Chogoria | 4 | 2186 | -0.231950 | 37.522067 | Moist montane |
| Chogoria | 5 | 2318 | -0.216033 | 37.511933 | Moist montane |
| Chogoria | 5 | 2318 | -0.216133 | 37.511417 | Moist montane |
| Chogoria | 5 | 2330 | -0.211883 | 37.513217 | Moist montane |
| Chogoria | 5 | 2333 | -0.212000 | 37.512433 | Moist montane |
| Chogoria | 6 | 2454 | -0.202067 | 37.491183 | Moist montane |
| Chogoria | 6 | 2388 | -0.206283 | 37.489333 | Moist montane |
| Chogoria | 6 | 2388 | -0.206333 | 37.488900 | Moist montane |
| Chogoria | 6 | 2451 | -0.202100 | 37.490750 | Moist montane |
| Chogoria | 7 | 2540 | -0.23444 | 37.614167 | Moist montane |

| | | | | | |
|---|---|---|---|---|---|
| Chogoria | 7 | 2526 | -0.304722 | 37.58333 | Moist montane |
| Chogoria | 7 | 2522 | -0.305556 | 37.542778 | Moist montane |
| Chogoria | 7 | 2542 | -0.235000 | 37.606944 | Moist montane |
| Ruthumbi | 1 | 2118 | -0.140717 | 37.563850 | Moist montane |
| Ruthumbi | 1 | 2118 | -0.140833 | 37.564417 | Moist montane |
| Ruthumbi | 1 | 2125 | -0.145633 | 37.564367 | Moist montane |
| Ruthumbi | 1 | 2125 | -0.145533 | 37.563900 | Moist montane |
| Ruthumbi | 2 | 2248 | -0.138933 | 37.546283 | Moist montane |
| Ruthumbi | 2 | 2254 | -0.138933 | 37.545967 | Moist montane |
| Ruthumbi | 2 | 2186 | -0.137633 | 37.551133 | Moist montane |
| Ruthumbi | 2 | 2186 | -0.137267 | 37.550900 | Moist montane |
| Ruthumbi | 3 | 2499 | -0.1299 | 37.5231 | Moist montane |
| Ruthumbi | 3 | 2499 | -0.1299 | 37.5231 | Moist montane |
| Ruthumbi | 3 | 2517 | -0.1299 | 37.52207 | Moist montane |
| Ruthumbi | 3 | 2517 | -0.1299 | 37.52207 | Moist montane |
| Ruthumbi | 4 | 2499 | -0.129900 | 37.523100 | Dry montane |
| Ruthumbi | 4 | 2499 | -0.130333 | 37.523083 | Dry montane |
| Ruthumbi | 4 | 2517 | -0.129583 | 37.522067 | Dry montane |
| Ruthumbi | 4 | 2517 | -0.130033 | 37.522050 | Dry montane |
| Kibaranyaki | 1 | 2235 | -0.000967 | 37.544817 | Moist montane |
| Kibaranyaki | 1 | 2238 | -0.000783 | 37.544383 | Moist montane |
| Kibaranyaki | 1 | 2247 | 0.003050 | 37.543583 | Moist montane |
| Kibaranyaki | 1 | 2247 | 0.003000 | 37.543133 | Moist montane |

| | | | | | |
|---|---|---|---|---|---|
| Kibaranyaki | 2 | 2288 | 0.001383 | 37.533800 | Moist montane |
| Kibaranyaki | 2 | 2288 | 0.001550 | 37.534217 | Moist montane |
| Kibaranyaki | 2 | 2310 | 0.005383 | 37.531683 | Moist montane |
| Kibaranyaki | 2 | 2303 | 0.005450 | 37.532150 | Moist montane |
| Kibaranyaki | 3 | 2346 | 0.001500 | 37.525300 | Moist montane |
| Kibaranyaki | 3 | 2346 | 0.001917 | 37.525100 | Moist montane |
| Kibaranyaki | 3 | 2357 | 0.006250 | 37.525983 | Moist montane |
| Kibaranyaki | 3 | 2344 | 0.006433 | 37.526317 | Moist montane |
| Meru | 1 | 1775 | 0.057483 | 37.628333 | Moist montane |
| Meru | 1 | 1770 | 0.057533 | 37.628783 | Moist montane |
| Meru | 1 | 1763 | 0.061567 | 37.626350 | Moist montane |
| Meru | 1 | 1763 | 0.062000 | 37.626317 | Moist montane |
| Meru | 2 | 1792 | 0.055933 | 37.623667 | Moist montane |
| Meru | 2 | 1792 | 0.055667 | 37.623350 | Moist montane |
| Meru | 2 | 1806 | 0.058700 | 37.619867 | Moist montane |
| Meru | 2 | 1805 | 0.058883 | 37.620200 | Moist montane |
| Meru | 3 | 2042 | 0.047017 | 37.575217 | Moist montane |
| Meru | 3 | 2033 | 0.047450 | 37.575067 | Moist montane |
| Meru | 3 | 2067 | 0.039233 | 37.568433 | Moist montane |
| Meru | 3 | 2067 | 0.039467 | 37.568250 | Moist montane |
| Meru | 4 | 2159 | 0.041967 | 37.556950 | Moist montane |
| Meru | 4 | 2172 | 0.043417 | 37.555617 | Moist montane |
| Meru | 4 | 2158 | 0.043850 | 37.556633 | Moist montane |

| | | | | | |
|---|---|---|---|---|---|
| Meru | 4 | 2148 | 0.042417 | 37.557783 | Moist montane |
| Meru | 5 | 2281 | 0.036800 | 37.545383 | Moist montane |
| Meru | 5 | 2275 | 0.036083 | 37.544650 | Moist montane |
| Meru | 5 | 2291 | 0.041267 | 37.543900 | Moist montane |
| Meru | 5 | 2305 | 0.041250 | 37.543283 | Moist montane |
| Kithoka | 1 | 1524 | 0.119883 | 37.657650 | Dry intermediate |
| Kithoka | 1 | 1521 | 0.120083 | 37.658283 | Dry intermediate |
| Kithoka | 1 | 1524 | 0.116300 | 37.659883 | Dry intermediate |
| Kithoka | 1 | 1530 | 0.115867 | 37.659483 | Dry intermediate |
| Kithoka | 2 | 1566 | 0.102933 | 37.649083 | Moist intermediate |
| Kithoka | 2 | 1567 | 0.102567 | 37.648850 | Moist intermediate |
| Kithoka | 2 | 1557 | 0.101233 | 37.653233 | Moist intermediate |
| Kithoka | 2 | 1557 | 0.100883 | 37.653200 | Moist intermediate |
| Kithoka | 3 | 1594 | 0.087233 | 37.647450 | Moist intermediate |
| Kithoka | 3 | 1594 | 0.087400 | 37.647883 | Moist intermediate |
| Kithoka | 3 | 1609 | 0.090150 | 37.644017 | Moist intermediate |
| Kithoka | 3 | 1606 | 0.090567 | 37.643800 | Moist intermediate |
| Kithoka | 4 | 1650 | 0.075783 | 37.641900 | Moist intermediate |
| Kithoka | 4 | 1643 | 0.076067 | 37.642267 | Moist intermediate |
| Kithoka | 4 | 1656 | 0.079783 | 37.640000 | Moist intermediate |
| Kithoka | 4 | 1656 | 0.080167 | 37.640267 | Moist intermediate |
| Kithoka | 5 | 1738 | 0.075467 | 37.628550 | Moist intermediate |
| Kithoka | 5 | 1741 | 0.075367 | 37.628117 | Moist intermediate |

| | | | | | |
|---|---|---|---|---|---|
| Kithoka | 5 | 1735 | 0.079650 | 37.626083 | Moist intermediate |
| Kithoka | 5 | 1717 | 0.079600 | 37.626550 | Moist intermediate |
| Nchoroiburu | 1 | 1615 | 0.122033 | 37.636667 | Dry intermediate |
| Nchoroiburu | 1 | 1617 | 0.122433 | 37.636900 | Dry intermediate |
| Nchoroiburu | 1 | 1596 | 0.120183 | 37.640717 | Dry intermediate |
| Nchoroiburu | 1 | 1596 | 0.120517 | 37.640983 | Dry intermediate |
| Nchoroiburu | 2 | 1660 | 0.114900 | 37.631083 | Dry intermediate |
| Nchoroiburu | 2 | 1656 | 0.115167 | 37.631300 | Dry intermediate |
| Nchoroiburu | 2 | 1643 | 0.112983 | 37.635100 | Dry intermediate |
| Nchoroiburu | 2 | 1643 | 0.113267 | 37.635267 | Dry intermediate |
| Nchoroiburu | 3 | 1679 | 0.107517 | 37.627767 | Dry intermediate |
| Nchoroiburu | 3 | 1675 | 0.107717 | 37.628017 | Dry intermediate |
| Nchoroiburu | 3 | 1658 | 0.104750 | 37.631233 | Dry intermediate |
| Nchoroiburu | 3 | 1654 | 0.104967 | 37.631450 | Dry intermediate |
| Nchoroiburu | 4 | 1718 | 0.092217 | 37.624817 | Moist intermediate |
| Nchoroiburu | 4 | 1716 | 0.092767 | 37.625667 | Moist intermediate |
| Nchoroiburu | 4 | 1717 | 0.090550 | 37.626367 | Moist intermediate |
| Nchoroiburu | 4 | 1716 | 0.091067 | 37.627150 | Moist intermediate |
| Nchoroiburu | 5 | 1742 | 0.084833 | 37.622450 | Moist intermediate |
| Nchoroiburu | 5 | 1742 | 0.084850 | 37.622900 | Moist intermediate |
| Nchoroiburu | 5 | 1755 | 0.087583 | 37.621683 | Moist intermediate |
| Nchoroiburu | 5 | 1755 | 0.087733 | 37.622050 | Moist intermediate |
| Nchoroiburu | 6 | 1757 | 0.086183 | 37.619300 | Moist intermediate |

| | | | | | |
|---|---|---|---|---|---|
| Nchoroiburu | 6 | 1757 | 0.086000 | 37.618933 | Moist intermediate |
| Nchoroiburu | 6 | 1772 | 0.090550 | 37.617700 | Moist intermediate |
| Nchoroiburu | 6 | 1766 | 0.090583 | 37.618150 | Moist intermediate |
| Nchoroiburu | 7 | 1811 | 0.089717 | 37.612167 | Moist intermediate |
| Nchoroiburu | 7 | 1813 | 0.090150 | 37.612033 | Moist intermediate |
| Nchoroiburu | 7 | 1787 | 0.094167 | 37.614183 | Moist intermediate |
| Nchoroiburu | 7 | 1783 | 0.094017 | 37.614600 | Moist intermediate |
| Nanyuki | 1 | 1979 | 0.072183 | 37.133983 | Dry montane |
| Nanyuki | 1 | 1974 | 0.071817 | 37.133783 | Dry montane |
| Nanyuki | 1 | 1981 | 0.072467 | 37.129583 | Dry montane |
| Nanyuki | 1 | 1983 | 0.072017 | 37.129583 | Dry montane |
| Nanyuki | 2 | 1970 | 0.086100 | 37.131433 | Dry montane |
| Nanyuki | 2 | 1970 | 0.085633 | 37.131500 | Dry montane |
| Nanyuki | 2 | 1954 | 0.089433 | 37.128950 | Dry montane |
| Nanyuki | 2 | 1954 | 0.088833 | 37.128783 | Dry montane |
| Rocky | 1 | 1793 | 0.097417 | 37.609383 | Dry montane |
| Rocky | 1 | 1792 | 0.097400 | 37.609850 | Dry montane |
| Rocky | 1 | 1803 | 0.101183 | 37.607383 | Dry montane |
| Rocky | 1 | 1800 | 0.101317 | 37.608200 | Dry montane |

Appendix 2: Area sampled and corresponding densities in different vegetation types

| Vegetation type | Forest block | Belt | Hactares | Abundance | Density (tree/ha) | Mean heights (m) | Mean DBH (cm) |
|---|---|---|---|---|---|---|---|
| Moist montane | Chuka | 1 | 2.5 | 24 | 9.6 | 18.78 | 101.16 |
| Moist montane | Chuka | 2 | 2.5 | 0 | 0 | 0 | 0 |
| Moist montane | Chuka | 3 | 2.5 | 0 | 0 | 0 | 0 |
| Moist montane | Chuka | 4 | 2.5 | 0 | 0 | 0 | 0 |
| Moist montane | Chogoria | 1 | 2.5 | 0 | 0 | 0 | 0 |
| Moist montane | Chogoria | 2 | 2.5 | 0 | 0 | 0 | 0 |
| Moist montane | Chogoria | 3 | 2.5 | 0 | 0 | 0 | 0 |
| Moist montane | Chogoria | 4 | 2.5 | 0 | 0 | 0 | 0 |
| Moist montane | Chogoria | 5 | 2.5 | 0 | 0 | 0 | 0 |
| Moist montane | Chogoria | 6 | 2.5 | 0 | 0 | 0 | 0 |
| Moist montane | Chogoria | 7 | 2.5 | 0 | 0 | 0 | 0 |
| Moist montane | Ruthumbi | 1 | 2.5 | 11 | 4.4 | 12 | 58.1 |
| Moist montane | Ruthumbi | 2 | 2.5 | 10 | 4 | 15.11 | 21.66 |
| Moist montane | Ruthumbi | 3 | 2.5 | 0 | 0 | 0 | 0 |
| Moist montane | Kibaranyaki | 1 | 2.5 | 37 | 14.8 | 19.74 | 42.93 |
| Moist montane | Kibaranyaki | 2 | 2.5 | 6 | 2.4 | 4.87 | 5.48 |
| Moist montane | Kibaranyaki | 3 | 2.5 | 1 | 0.4 | 32.4 | 87.58 |
| Moist montane | Meru | 1 | 2.5 | 22 | 8.8 | 33.14 | 104.14 |
| Moist montane | Meru | 2 | 2.5 | 10 | 4 | 35.92 | 88.28 |
| Moist montane | Meru | 3 | 2.5 | 2 | 0.8 | 41.8 | 148.41 |
| Moist montane | Meru | 4 | 2.125 | 4 | 1.9 | 33.53 | 76.2 |
| Moist montane | Meru | 5 | 2.25 | 10 | 4.4 | 35.07 | 135.44 |
| Moist intermedate | Kithoka | 2 | 2.5 | 0 | 0 | 0 | 0 |
| Moist intermedate | Kithoka | 3 | 2.5 | 0 | 0 | 0 | 0 |
| Moist intermedate | Kithoka | 4 | 2.5 | 7 | 2.8 | 23.2 | 101.34 |
| Moist intermedate | Kithoka | 5 | 2.5 | 5 | 2 | 27.42 | 67.65 |
| Moist intermedate | Nchoroiburu | 4 | 2.5 | 1 | 0.4 | 27.85 | 99.04 |
| Moist intermedate | Nchoroiburu | 5 | 1.625 | 11 | 6.8 | 38.5 | 112.1 |
| Moist intermedate | Nchoroiburu | 6 | 2.5 | 8 | 3.2 | 19.65 | 67.49 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| edate | Nchoroiburu | 7 | 2.5 | 7 | 2.8 | 36.1 | 58.2 |
| diate | Kithoka | 1 | 2.5 | 0 | 0 | 38.5 | 112.1 |
| diate | Nchoroiburu | 1 | 2.5 | 0 | 0 | 0 | 0 |
| diate | Nchoroiburu | 2 | 2.5 | 0 | 0 | 0 | 0 |
| diate | Nchoroiburu | 3 | 2.5 | 0 | 0 | 0 | 0 |
| e | Nanyuki | 1 | 2.5 | 73 | 29.2 | 17.6 | 35.47 |
| ie | Nanyuki | 2 | 2.25 | 144 | 64 | 18.69 | 45.19 |
| ie | Rocky | 1 | 2.375 | 13 | 5.5 | 18.68 | 59.26 |
| ie | Ruthumbi | 4 | 0.625 | 23 | 36.8 | 20.27 | 42.2 |

**Appendix 3: Reproductive stages of *Prunus africana* in the forest**

| Forest block | Belt transect | Flower | Fruit & Flower | Fruit | Fruit & seed | Seed | None |
|---|---|---|---|---|---|---|---|
| Chuka | 1 | 0 | 0 | 0 | 5 | 10 | 8 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| Chogoria | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ruthumbi | 1 | 0 | 0 | 1 | 0 | 2 | 6 |
| | 2 | 0 | 0 | 2 | 0 | 1 | 7 |
| | 3 | 0 | 0 | 5 | 5 | 0 | 12 |
| Kibaranyaki | 1 | 0 | 0 | 5 | 1 | 4 | 12 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 4 |
| | 3 | 0 | 0 | 1 | 0 | 0 | 0 |
| Meru | 1 | 1 | 2 | 2 | 5 | 7 | 4 |
| | 2 | 0 | 0 | 0 | 4 | 2 | 3 |
| | 3 | 0 | 0 | 1 | 1 | 1 | 0 |
| | 4 | 0 | 0 | 1 | 3 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5 | 0 | 0 | 0 | 0 | 7 | 2 |
| Kithoka | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 1 | 1 | 1 | 2 |
| | 4 | 0 | 0 | 0 | 1 | 2 | 3 |
| | 5 | 0 | 0 | 2 | 0 | 1 | 1 |
| Nchoroiburu | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 1 |
| | 5 | 0 | 0 | 0 | 0 | 1 | 3 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 2 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 2 |
| Nanyuki | 1 | 2 | 1 | 12 | 0 | 6 | 39 |
| | 2 | 22 | 0 | 1 | 0 | 1 | 98 |
| Rocky | 1 | 0 | 0 | 0 | 0 | 11 | 2 |
| Means | | 0.69 | 0.08 | 0.94 | 0.72 | 1.58 | 5.86 |

**Appendix 4: Density of seedlings per tree**

| | Moist montane | | | | Moist intermediate | | Dry montane | |
|---|---|---|---|---|---|---|---|---|
| Tree crowns | Chuka | Ruthumbi | Kibaranyaki | Meru | Kithoka | Nchoroiburu | Rocky | Nanyuki |
| 1 | 13.5 | 0 | 32.25 | 0 | 0 | 0 | 0 | 4.13 |
| 2 | 1.5 | 0 | 8.25 | 0 | 0 | 0 | 0 | 3.25 |
| 3 | 197.38 | 0 | 3.75 | 0 | 0 | 0 | 0 | 0.63 |
| 4 | 7.25 | 0.5 | 5.75 | 0 | 0 | 0 | 0 | 1.63 |
| 5 | 5.88 | 0.38 | 4.5 | 0 | 0 | 0 | 0 | 7.13 |
| 6 | 134.5 | 5.38 | 2.38 | 0 | 0 | 0 | 0 | 0.5 |
| 6 | 29.88 | 0.25 | 4.75 | 29.5 | 0 | | 0 | 0.13 |
| 7 | 222.88 | 0.38 | 3.88 | 0.38 | 0 | | 0 | 2.38 |
| 8 | 201.75 | 0.38 | 7.5 | 0.63 | 0 | | 0 | 0.13 |
| 9 | 28.75 | 2 | 3.75 | 0.13 | 0 | | 0 | 2.5 |
| 10 | 30.75 | 4.38 | 0 | 6.25 | 0 | | 0 | 4.25 |
| 11 | 207 | 0.88 | 0 | 86.25 | 0 | | 0 | 1.9 |
| 12 | 104.63 | 9.38 | 0 | 137.25 | 0 | | 0 | 1.5 |
| 13 | 44.38 | 19.88 | 0 | 0.38 | 0 | | 0 | 1.13 |
| 14 | 32.25 | 32 | 0 | 0.38 | 0 | | 0 | 0.63 |
| 15 | 2 | 32.88 | 0 | 5.88 | 0 | | | 0.25 |
| 16 | 2.25 | | 0 | 0.13 | 0 | | | 1.5 |
| 17 | 1 | | 0 | 0 | 0 | | | 2 |
| 18 | 0.13 | | 0 | 0 | 0 | | | 2.75 |
| 19 | 0.38 | | 0 | 0 | 0.13 | | | 1.88 |
| 20 | 0 | | 0 | 0 | 0 | | | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 21 | 0 | | 0 | 0 | 0 | | | 1.13 |
| 22 | | | 0 | 0 | | | | 0.13 |
| 23 | | | 0 | 0 | | | | 0.25 |
| 24 | | | | 0 | | | | 0.38 |
| 25 | | | | 0 | | | | 0 |
| 26 | | | | 0 | | | | 0 |
| 27 | | | | 0 | | | | 0 |
| 28 | | | | | | | | 0 |
| 29 | | | | | | | | 0 |
| 30 | | | | | | | | 0 |
| 31 | | | | | | | | 0 |
| 32 | | | | | | | | 0 |
| 33 | | | | | | | | 0 |
| 34 | | | | | | | | 0 |
| 35 | | | | | | | | 0 |
| 36 | | | | | | | | 0 |
| 37 | | | | | | | | 0 |
| 38 | | | | | | | | 0 |
| 39 | | | | | | | | 0 |
| 40 | | | | | | | | 0 |
| 41 | | | | | | | | 0 |
| 42 | | | | | | | | 0 |
| 43 | | | | | | | | 0 |
| 44 | | | | | | | | 0 |
| 45 | | | | | | | | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 46 | | | | | | | | | 0 |
| 47 | | | | | | | | | 0 |
| 48 | | | | | | | | | 0 |
| 49 | | | | | | | | | 0 |
| 50 | | | | | | | | | 0 |
| 51 | | | | | | | | | 0 |
| 52 | | | | | | | | | 0 |
| 53 | | | | | | | | | 0 |
| 54 | | | | | | | | | 0 |
| 55 | | | | | | | | | 0 |
| 56 | | | | | | | | | 2.5 |
| 57 | | | | | | | | | 16.75 |
| 58 | | | | | | | | | 2.5 |
| 59 | | | | | | | | | 2.13 |
| 60 | | | | | | | | | 5.63 |
| 61 | | | | | | | | | 3.63 |
| 62 | | | | | | | | | 2.25 |
| 63 | | | | | | | | | 2.63 |

**ɔendix 5: Tree species occurring near *Prunus africana* in different vegetation es**

| ʒetation e | Species name | Family | Individuals |
|---|---|---|---|
| ɔist ɔntane | *Macaranga kilimandscharica* Pax | Euphorbiaceae | 1 |
| | *Millettia tanaensis* Gillett | Papilionaceae | 2 |
| | *Xymalos monospora* (Harv.) Warb | Monimiaceae | 52 |
| | *Chionanthus battiscombei* (Hutch.)Stearn | Oleaceae | 1 |
| | *Premna maxima* T.C.E. Fries | Verbenaceae | 10 |
| | *Ficus thonningii* Bl. | Moraceae | 2 |
| | *Dovyalis abyssinicus* (A. Rich.) Warb | Flacourtiaceae | 1 |
| | *Rothmannia urcelliformis* (Hiern) Robyns | Rubiaceae | 7 |
| | *Ficus sur* Forssk. | Moraceae | 1 |
| | *zanthoxylum gillettii* (De Wild.) Watern. | Rutaceae | 5 |
| | *Casaeria battiscombei* R.E. Fries | Flacourtiaceae | 8 |
| | *Kigelia africana* (Lam.) Benth | Bignoniaceae | 4 |
| | *Ehretia cymosa* Thonn. | Boraginaceae | 10 |
| | *Ilex mitis (L.) Radlk.* | Aquifoliaceae | 2 |
| | *Cordia africana* Lam. | Boraginaceae | 9 |
| | *Syzygium guineense* (Wild.)DC. | Myrtaceae | 11 |
| | *Fagaropsis angolensis* (Engl.) Dale | Rutaceae | 3 |
| | *Celtis africana* Burm. F. | Ulmaceae | 4 |

| | | | |
|---|---|---|---|
| | *Clausena anisata* (Willd.) Benth | Rutaceae | 1 |
| | *Bersama abyssinica* Fres. | Melianthaceae | 3 |
| | *Olea europaea* (Mill.) P. Green | Oleaceae | 2 |
| | *Calodendrum capense* (L.f.)Thunb. | Rutaceae | 2 |
| | *Casaeria battiscombei* R.E. Fries | Flacourtiaceae | 9 |
| | *Croton sylvaticus* Hochst. | Euphorbiaceae | 1 |
| | *Neoboutonia macrocalyx* Pax | Euphorbiaceae | 29 |
| | *Vitex keniensis* Turrill | Verbenaceae | 26 |
| | *Peddiea fischeri* Engl. | Thymeleaceae | 6 |
| | *Oncoba spinosa*Forssk. | Flacourtiaceae | 2 |
| | *Prunus africana* (Hook.f.) Kalkm | Rosaceae | 1 |
| | *Tabernaemontana stapfiana* Britten | Apocynaceae | 50 |
| | *Senna septemtrionalis* (Viviani) Irwin & Barneby | Caesalpiniaceae | 1 |
| | *Podocarpus latifolius* (Thunb.) Mirb. | Podocarpaceae | 20 |
| st rmediate | *Syzygium guineense* (Wild.)DC. | Myrtaceae | 1 |
| | *Xymalos monospora* (Harv.) Warb | Monimiaceae | 5 |
| | *Vangueria madagascariensis* Gmel. | Rubiaceae | 1 |
| | *Premna maxima* T.C.E. Fries | Verbenaceae | 4 |
| | *Markhamia lutea* (Benth.) K. Schum. | Bignoniaceae | 2 |
| | *Rothmannia urcelliformis* (Hiern) Robyns | Rubiaceae | 1 |
| | *Pittosporum viridiflorum* Sims. | Pittosporaceae | 3 |

| | | | |
|---|---|---|---|
| | *Calodendrum capense* (L.f.)Thunb. | Rutaceae | 1 |
| | *Casaeria battiscombei* R.E. Fries | Flacourtiaceae | 1 |
| | *Ehretia cymosa* Thonn. | Boraginaceae | 5 |
| | *Cordia africana* Lam. | Boraginaceae | 8 |
| | *Celtis africana* Burm. F. | Ulmaceae | 6 |
| | *Teclea simplicifolia* (Engl.) Verdoorn | Rutaceae | 16 |
| | *Olea africana* L. | Oleaceae | 2 |
| | *Vitex keniensis* Turrill | Verbenaceae | 3 |
| | *Peddiea fischeri* Engl. | Thymeleaceae | 1 |
| | *Oncoba spinosa* Forssk. | Flacourtiaceae | 6 |
| )ry montane | *Millettia tanaensis* Gillett | Papilionaceae | 7 |
| | *Xymalos monospora* (Harv.) Warb | Monimiaceae | 1 |
| | *Vangueria madagascariensis* Gmel. | Rubiaceae | 4 |
| | *Premna maxima* T.C.E. Fries | Verbenaceae | 2 |
| | *Rapanea melanophloeos* (L.) Mez. | Myrsinaceae | 4 |
| | *Clausena anisata* (Willd.) Benth | Rutaceae | 1 |
| | *Pittosporum viridiflorum* Sims. | Pittosporaceae | 6 |
| | *Casaeria battiscombei* R.E. Fries | Flacourtiaceae | 5 |
| | *Juniperus procera* Endl. | Cupressaceae | 23 |
| | *Ehretia cymosa* Thonn. | Boraginaceae | 5 |
| | *Fagaropsis angolensis* (Engl.) Dale | Rutaceae | 2 |
| | *Celtis africana* Burm. F. | Ulmaceae | 3 |
| | *Teclea simplicifolia* (Engl.) Verdoorn | Rutaceae | 32 |

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|---|---|---|---|
| | *Olea africana L.* | Oleaceae | 49 |
| | *Bersama abyssinica* Fres. | Melianthaceae | 2 |
| | *Diospyros abyssinica* (Hiern) F. White | Ebenaceae | 1 |
| | *Croton sylvaticus* Hochst. | Euphorbiaceae | 3 |
| | *Neoboutonia macrocalyx* Pax | Euphorbiaceae | 1 |
| | *Prunus africana* (Hook.f.) Kalkm | Rosaceae | 32 |
| | *Tabernaemontana stapfiana* Britten | Apocynaceae | 2 |
| | *Podocarpus falcatus* Mirb. | Podocarpaceae | 70 |
| | *Podocarpus latifolius* (Thunb.) Mirb. | Podocarpaceae | 6 |