DISTRIBUTION AND POPULATION STRUCTURE OF EAST AFRICAN GREENHEART *(Warburgia ugandensis,* Sprague) PLANT IN MOUNT KENYA FOREST, KENYA

BY

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DECLARATION

I, Anne Wangari Kairu, declare that this is my original work, and has never been presented for a degree in any other University.

Signature--

Date----22nd NOV. 2011----

This work has been submitted for examination with our approval as University Supervisors.

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DEDICATION

This thesis is dedicated it to my loving husband Erastus Kinyua, our precious children Lizz Esther Wandia and Kelvin Karimi for standing by me through the whole course.

My loving mother Esther Muthoni and father Richard Kairu for encouraging, supporting and inspiring me to work hard.

I also dedicate it to my brothers and sisters for continuous support, prayers and encouragement. I truly value their support and encouragement which has been immense.

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TABLE OF CONTENTS

CHAPTER THREE:
STUDY AREA, MATERIALS AND METHODS

CHAPTER FOUR
RESULTS

LIST OF APPENDICES

LIST OF TABLE

LIST OF FIGURES

LIST OF PLATES

ABSTRACT

Effects from past climate, natural disturbances and human activities are significantly affecting current day processes in tropical forests with indigenous trees. *Warburgia ugandensis* is highly valued for its medicinal properties, timber, poles, and fuel wood. Consequently its population and distribution has been declining due to environmental and human factors and it is listed as a medicinal plant at risk from commercial exploitation in East Africa. The objectives of the study were to determine the present distribution and population structure of *W. ugandensis* in Mt. Kenya forests. To establish the plant species associated to potential natural vegetation types where *W. ugandensis* occurs and to investigate the threat of *W. ugandensis* in Mt. Kenya forests.

This study was conducted in several forests around Mount (Mt) Kenya (5,199 m asl, 0° 9' 00'' S and 37° 18' 00'' E in Central Kenya, about 150 Km North East of Nairobi). The study was carried out from September 2009 to march 2010.The study area was stratified into four blocks based on potential natural vegetation types: moist montane, moist intermediate, dry montane and dry intermediate natural vegetation type. Dry montane was the only vegetation type with *W. ugandensis* and therefore four forest blocks were selected for this study; Kangaita, Kahurura, Ontulili and Gathioro forests.

Belt transects measuring 25m wide and 500m long were marked and subdivided into twenty sub-plots of 25m by 25m from which four sub-plots were systematically selected for sampling. Rainfall data for all the sampled blocks were obtained from metrological records in Nanyuki and Nairobi while altitude data was obtained by use of GPS and topographical maps of the area. Data was analyzed by general linear models (GLM) using SPSS 11.0 (2001) statistical software. Soil was analyzed for texture, nitrogen, phosphorus, potassium, organic carbon.

W. ugandensis tree height differed significantly in different forest. There was significant negative correlation between rainfall and canopy diameter, tree height, and diameter at breast height which was consistent with the abundance of the species in dry montane forests. There was negative but significant correlation between altitude, soils and *W. ugandensis* trees sizes. Thus smaller trees were at higher altitudes. All the forests were dominated by mature trees, very few saplings while seedlings were rare. However plenty of shoots sprouted from the tree stumps. The species associated to *W. ugandensis* in the forest were *Mystroxylon aethiopica* with about 18% of the studied species, followed by *Podocarpus latifolius* 14.3%, *Olea africana* and *Olinia rochetiana* with 11.9% and 11.7% respectively. The main threat to *W. ugandensis* was human impact with 86% of damages while other factors contributed 14%. The major form of damage was debarking which threatens trees' survival. *Warburgia ugandensis* distribution and population is mainly determined by climatic factors like rainfall and also human factor through its exploitation for herbal medicine.

Key word: Distribution, Threats, Population, Structure, *Warburgia ugandensis*, Mt. Kenya, potential natural vegetation type (PNVT).

CHAPTER ONE: INTRODUCTION

1.1 Background information

Forests play a vital role in water catchment, improve soil fertility, regulate local climate and are also vital carbon sinks and reservoirs. They are a source of food, a habitat for wildlife and a source of income to the country (Muthike, 2004). Over the years forests have been degraded due to poor legislative framework, politics, encroachment, illegal cultivation, logging, charcoal burning and poor understanding of the benefits of forests by local communities. By 2008 forest cover in Kenya was 2-3% of the land area (Muthike, 2004). Today this figure may have gone down to about 1.5% against the recommended national average of 10%. Assessing the distribution and structure of a particular forest type forms an important part of forest conservation. Tropical montane and tropical dry forests are considered as threatened and are therefore a high priority for conservation (Newton, 2007).

Climate change effects on forests are likely to include changes in forest health, productivity and changes in the geographic range of certain tree species. Fire events are changing for worse and are expected to continue changing due to human activities. According to Intergovernmental Panel on Climate Change (IPCC) 2007, there may be significant transitions associated with shifts in forest locations and composition due to climate change.

Forests vegetation in Kenya is changing due to influence of fire, grazing, cultivation and timber extraction (Kindt *et al.*, 2007). The ecology and distribution of most tree species in Kenya is poorly understood as most biogeographical maps offer spatial surrogate information for analysis of biodiversity patterns. Greater demands on forests and their products require that more information be readily available for decision makers (Kindt *et* *al.*, 2008). The indigenous species are found mainly in the natural forests. *Warburgia ugandensis* being one of the indigenous tree species provides insight into the ecology of other indigenous species on how they are responding to environmental change and human utilization impacts (Kindt *et al.*, 2008). This study collected data on population structure and distribution of *W. ugandesis* in Mt. Kenya forests in Kenya from September 2009 up to January 2010. The species associated with vegetation type in the study areas where *W. ugandensis* were found were identified, enumerated and recorded.

W. ugandensis is one of priority species in herbal medicine in Kenya (Hamilton, 2008) and it has been over-exploited through extraction of herbal medicine, feeding to livestock, cutting for timber, poles and charcoal burning (Bekele-Tesemma *et al.*, 1993). Currently, there is a growing demand for the products from *W. ugandensis* and there are fears that this may lead to its over-exploitation. With such growing attention, experts are sounding the alarm, saying the tree could become extinct soon unless measures are taken to stem over-exploitation.

Unsustainable harvesting for medicinal purpose through ring barking and indiscriminate felling for timber and agricultural expansion is threatening the genetic diversity present in wild plant populations (Muchugi *et al.*, 2008). This species is almost exterminated due to ring barking in forests. Though a lot of research has been done on genetic diversity (Muchugi *et al.*, 2007, 2008), genomics (Muge *et al.*, 2009), phytochemical activities (Kioy *et al.*, 1990; Olila *et al.*, 2001) and survey on uses (Kariuki and Simiyu, 2005; Maundu and Tengnas, 2005), none has focused on *W. ugandensis* current distribution and population structure in Mt. Kenya forests to find out if its distribution and structure has changed due to environmental and anthropogenic pressures. Effective management of this threatened tree species requires updated data and information presented in a user-friendly database that can support in-situ and ex-situ conservation of the species (Martin *et al.*, 2001) in Mount Kenya region, where the species was abundant.

This study was intended to provide information on the current distribution and population structure of *W. ugandensis* in Mt. Kenya forests based on environmental gradients and Potential Natural Vegetation Types (PNVT). The results can be used to plan how species levels can be increased by reintroducing suitable indigenous tree species in anthropogenic landscapes using PNVT as a criterion for ecological suitability (Mueller-Dombois and Ellenberg, 1974).

1.2 Objectives of the Study

1.2.1 Major objective

To assess the distribution and population structure of *W. ugandensis* in Mt. Kenya forest along physical and environmental gradients.

1.2.2 Specific objectives

1. To determine the distribution and population structure of *W. ugandensis.*
2. To establish the relative abundance of plant species associated with potential natural vegetation types where *W. ugandensis* occurs.
3. To determine the threats to *W. ugandensis* in Mt. Kenya forests.

1.3 Research Hypotheses

i) There is gradual change in distribution and population structure of *W. ugandensis* along environmental gradient in Mt. Kenya forests.

ii) The relative abundance of plant species associated with *W. ugandensis* varies with potential natural vegatation type.

iii) Anthropogenic factors have negatively affected the population structure and distribution of *W. ugandensis.*

CHAPTER TWO: LITERATURE REVIEW

2.1 Taxonomic status and distribution of *W. ugandensis* in Africa.

W. ugandensis is named after a German botanist Otto Warburg who named six species (*W. breyeri, W. elongate, W. salutaris, W. stuhlmanii, W. ugandensis* and *W. ugandensis longifolia*) of the genus *Warburgia* (Tomlinson, 1980). *Warburgia* is a genus belonging to the family Canellaceae which is restricted mainly to the South and Eastern regions of Africa. The species occurs in Kenya, Uganda, Ethiopia, Tanzania, Zaire and parts of South Africa (Iwu, 1993). *Warburgia* contains four species that are of valuable medicinal importance and all are found in Africa (Muchugi *et al.*, 2008). According to Kokwaro (1976), there are two species of Warburgia (*Warburgia stahlmanii* and *W. ugandensis*) distributed in East Africa, in lowland rainforests, upland dry evergreen forests and its relics in the secondary bushlands, grasslands and also on termites hills in swamp forest. *W. ugandensis* is endemic to East Africa and it is widely distributed in lower rain forests and drier highland forest (Maundu & Tengnas, 2005).

The species is found in the lower portion of the Harenna forest of Ethiopian highlands where it forms a distinct woodland community, with open canopy together with other species (Beentje, 1993). In Uganda, the plant species is common in Mabira forest while in Kenya the species is commonly found around Nairobi, Masai Mara, Londian, Kitale, Sotik, Kericho, Tugen Hills and South West of Mount Kenya (Beentje, 1993).
Distribution of vegetation types provides information on distribution of indigenous species. Vegetation maps provide the information on potential sources that match the planting sites (Kindt *et al.*, 2011).

2.2 Biology and environmental requirements for *W. ugandensis*

W. ugandensis is an erect tree or a prostrate shrub, evergreen, single stem aromatic perennial plant whose height ranges between 4.5 and 30 m with diameter of up to 70 cm or more. The bark is smooth pale green or brown when young but becomes scaly black when mature; (Orwa *et al*., 2009) Plate 1.

Plate 1: A section of the stem of *W. ugandensis* showing scaly bark

The bark has a pepper taste and it is used by local people for medicine (Bentje, 1994). Crown is rounded, bole is short and clear of branches for about 3 m high.The plant has simple leaves which are glossy dark green, paler green to dull green with entire margin and a midrib off the centre. Flowers are bisexual, solitary or in small 3-4 flowered cymes. Bracts are ovate only covering the buds, sepals are pale green while petals overlap and are yellow green in colour and dotted with glands. It has ten stamens, united to form a tube enveloping the ovary (which is oblong and elongate) and most of the style. Fruit is berry, green and ellipse-like when young and sub-spherical then turns purplish later, with a leathery skin that is glandular with two or more seeds which have an oily endosperm and produce a sticky sap (Beentje, 1993). It requires optimal temperature of between 14 and 28°C and optimum rainfall of 1000-1500mm per annum (Orwa *et al.*, 2009). The species thrives well in altitudes of 100-2200m above sea level and latitudes of 30-35°. It requires moderate to fertile soils with a low salinity of less than 4ds/m and pH of 5.5 to 6.5. The tree grows in tropical wet and tropical dry climatic zones (Orwa *et al.*, 2009).

Natural regeneration is primarily from seed, which germinates easily in natural forests (Albrecht, 1993). Artificially, *W. ugandensis* can be regenerated from cuttings, seedlings and direct sowing. The ripe fruit is collected directly from the tree or shaken off the branches and collected from the ground immediately after falling (Albrecht, 1993). Fruit that has fallen to the ground rots easily.

The plant is classified as recalcitrant in that its seeds cannot resist the effects of drying or low temperatures less than 10°C (< 10°C) thus, they cannot be stored for long period as they lose their viability (Orwa *et al.*, 2009). However, dry seeds' viability can be maintained for six months at cool temperatures. Hence the seeds are said to be at intermediate between orthodox (seeds that retain their viability for long period) and recalcitrant seeds.

2.3 Ecological and socio-economic values of *W. ugandensis*

W. ugandensis fulfills certain ecological functions which include soil conservation, siltation and flood control downstream, a habitat for wildlife, microclimate modulation and aesthetic beauty (Franks and Reeves, 1988). However there has been unsustainable harvesting for medicinal use and indiscriminate felling for timber and agricultural expansion.

A research conducted by Kariuki and Simiyu, (2005) show that the species is rated second highest priority medicinal plant in Kenya after *Prunus africana*. Its extracts have been established to elicit anti-bacterial activities against both *Escherichia coli* and *Staphylococcus aureus* (Olila *et al.*, 2001). The extract also has anti-fungal activity against *Candida albicans* (Wube *et al.*, 2005). Further studies have shown microbial activity against *Mycobacterium aurum*, *M. fortuitum*, *M. phlei* and *M. smegmatus* and the active constituents showed minimum inhibitory concentration (MIC) values ranging from 4 to 128μg/ml compared to antibiotic drugs (Wube *et al.*, 2005). A study by Stampf *et al.*, (1982) showed that sesquiterpene (turpenes consisting of three isoprenes $C_{15}H_{24}$) is used as antiseptic, antibacterial and anti-inflammatory. *W. ugandensis* new sesquiterpenoids are outlined in Table 2.1.

Table 2.1: Sesquiterpenoids of *W. ugandensis*

1	Bemadienolide
2	Cinnamide
3	Drimenol
4	Muzigadial
5	Polygodial
6	Warburganal
7	Warburgiadione
8	Warburgin
9	Ugandensidial
10	Ugandensolide

These extracts from *W. ugandensis* elicit allergic contact dermatitis in guinea pigs. In the local communities, its leaves and bark are used in the treatment of asthma, bronchitis, tooth decay, tuberculosis, rheumatism, general body pains and diarrhea (Kokwaro, 1976). Besides the medicinal value, it is also used as firewood, timber, fodder, tool handles, food seasoning, mulch for soil conservation, ornamental, shade and resin (Maundu and Tengnas, 2005).

The fruit is inedible, all parts have a hot peppery taste, leaves and seeds are used to add flavour to curries (Dharani, 2002). The leaves, pods and seeds are fed to livestock. The wood is yellow or greenish, becoming brown on exposure; very fragrant when freshly cut, the scent somewhat resembling that of sandalwood. The wood also has high oil content and burns well with an incense-like smell. The tree has good timber for building and furniture, but not termite resistant (Dharani, 2002). It planes well and takes a high polish, but it is not durable and is liable to split on nailing. The wood produces fragrance that persists over 4 years of storage. The tree also produces resin that is used locally as glue to fix tool handles (Orwa *et al.*, 2009).

Warburganal and muzigadial are two compounds belonging to the strongest group of anti-feedants and exhibit the anti-feedant activity against armyworm (*Spodoptera littoralis* and *S. exempta*), which are widely occurring African crop pests. In addition, the two compounds exhibit very potent antifungal, anti-yeast and plant-growth regulating activity (Jonassohn, 1996).

W. ugandensis is a common plant that has been used traditionally to treat many disease conditions. Herbal medicine extracted from bark, roots, young twigs, leaves and fruits are used by the traditional healers (Maundu and Tengnas, 2005). Activity of *W. ugandensis* purified Mukaadial and Cinnamolide compounds against trypanosome has been demonstrated (Kioy *et al.*, 1990; Olila *et al.*, 2001). Muzigadial has been isolated from *W. ugandensis* against trypanosomiasis. Various uses of *W. ugandensis* to remedy various illnesses are indicated in Table 2.2.

Though Kenya is yet to set up its own factory to manufacture the tree products, in the western part of Kenya, trees from Mount Elgon are used to provide raw material for processors in nearby Uganda. Some of the products manufactured from the species according to Muchugi (http://allafrica.com/stories/201008300329.html) research include herbal chicken product in Trans-Nzoia, Kenya, Warburgia tea in Ruiri Meru, Bioharmony products in South Africa and Africa Red Tea Imports in South Africa. In Kenya, there is a growing interest in commercial exploitation of this tree. In addition to threats from stripping its bark for sale to herbalists and processors, the species is also used as a source of firewood and charcoal. This has put pressure on *W. ugandensis* populations in the natural forests.

Table 2.2: Traditional uses of *W. ugandensis* as a herbal medicine (ICRAF-International Centre for Research in Agriculture and Forestry; http://www.cgiar.org/icraf)

Plant part	Extraction method	Remedy
Bark dried or in powder form	Chewed to extract juice	Stomachache, toothache, constipation, cough, muscle pains, weak joints.
Fresh roots	Boiled and mixed with soup	Cures diarrhoea
Leaves	Decoction	Cures unspecified skin diseases
Inner bark	Powder snuffed, chewed or its smoke inhaled.	Common colds, sinuses, and chest pains.
Leaves, bark or roots	Boil and decoction used	Treat malaria, asthma, bronchitis, tooth decay, tuberculosis and rheumatism.

2.4 Threats, trends and current conservation efforts

W. ugandensis is a highly valuable species; however it is being destroyed due to the high demand for herbal medicine. Due to their high pharmaceutical value for both human and veterinary health services there is great threat to the genetic diversity in wild plant populations (Muchugi *et al.*, 2008).

The population of *W. ugandensis* has diminished around Nairobi where it used to grow extensively (Miththapala, 2004) due to urban expansion. In their research work, Kinyamario *et al.*, (2008) showed that the seedlings of this species do well under shade, indicating that it is shade tolerant. Indiscriminate destruction of forests through selective logging has exposed the seedlings to excessive sunlight hence reducing its propagation. According to his document on medicinal plants in conservation and development, Hamilton (2008) listed this species among the medicinal plants at risk from commercial trade in East Africa.

In the study by Muchugi *et al.*, (2008), it is stated that as the wild populations of *W. ugandensis* diminishes, planted stands of the species will in future be used as the source of medicinal products as well as germplasm. In their study they showed that the species is predominantly out-crossing at a rate of 89% with significant levels of selfing indicating mating between relatives i.e. parental breeding. This also implies that with proper sampling, the population being established for conservation will retain high genetic diversity found in the wild populations. *W. ugandensis* is among the species whose seeds are collected, dried and preserved by the Kenya Forestry Seeds Centre (Albrecht and Omondi, 1993). It is also one of the trees planted in individual or community group nurseries as a way of conserving it (Lengkeek, 2003). Its conservation is also promoted by tree planting program of Green Belt Movement for its use in furniture and glue resin (Greenbelt Movement Annual Report, 2003).

According to Emerton (1999), forest conservation plans include, on farm tree planting, formation of registered local forest enterprises (Plate 2), support to agriculture intensification, and provision of credit and training for micro-enterprise development. This would make available and strengthen the non forest resources as an alternative source of subsistence, income and employment, in order to conserve local forest resources (Comifor, 1994).

Plate 2: Nursery bed planted with seedlings of *W. ugandensis* in a farm at Kangaita.

2.5 Summary of knowledge gaps

1. Many aspects of the biology of *W. ugandensis* have not been studied in details.

2. The factors influencing the population structure and distribution are not yet known.

3. The impacts of browsing by domestic and wild animals have not been evaluated.

4. *W. ugandensis* is a popular medicinal plant that is exploited by communities but the effects of the various methods of utelisation on the growth and survival of the plant are not known.

5. There were no detailed studies about the ecology of *W. ugandensis* in Mount Kenya ecosystem.

These gaps formed the basis upon which this study was conceptualized and research proposal developed.

CHAPTER THREE: STUDY AREA, MATERIALS AND METHODS

3.1 Study Area

3.1.1. Geographical features

This study was conducted in several forests around Mount (Mt.) Kenya. The mountain is 5,199 m above sea level and lies on latitude 0^{o} 9' 00'' S and longitude 37^{o} 18' 00'' E. It is in the Central Kenya, South of equator about 150 Km North East of Nairobi. Mt. Kenya is one of Kenya's major water towers whose water drains into two major basins: River Ewaso Ngiro basin to the North and River Tana basin to the South East (Emerton, 1999). The slopes of the mountain are covered by different vegetation types from base to the summit. The lower slopes are covered by indigenous and exotic plantation forests, pastures and crops. Some common tree species are camphor found in the wetter parts of South and East and cedar which are found in the drier North and West that are endemic to the region.

Mt. Kenya forest which is 2800 square kilometres is a composite of many forests among which the following forests were selected for study: Chogoria and Ruthumbi forests, on the East and South East of Mt. Kenya, Kithima and Kabakia forests to the East of Mt Kenya, Lower Nchoroiburu and lower Kithooka in Imenti forest and in the North West side was Kangaita, Ontulili, Gathioro and Kahurura forests (Plate. 3). These forests represented the four potential natural vegetation types.

3.1.2 Soils and geology

Most regions of Central Kenya are covered with tertiary to recent lavas and tuffs (Baker, 1967). The soils of the plains consist mainly of vertisols, regosols, lithosols and cambisols. The mountain slopes are covered with humic, nitisols and acrisols in case of the basement formations and the lower volcanic areas and deep humic andosols above 2,700m (Bussmann, 2002).

3.1.3 Climate

Mount Kenya experiences a bimodal type of rainfall; a long wet period from March to June and a short season from December to February (UNEP, 2009). The amount of rainfall ranges from 900 millimeters (mm) in the North to 2,300 mm in the South Eastern slopes. A stratiform cloud deck tends to persist between 2,800m and 3,800m asl. Above 4,500m most of the annual precipitation falls as snow.

The annual temperature range is about 2 degrees Celsius (2°C), with the lowest values in March-April and the highest of 25°C in July-August (UNEP, 2009). The diurnal temperature range is large amounting to about 20°C in January-February and about 12°C in July-August. Diurnal circulations are vigorously developed with wind blowing down the mountain from evening throughout the night into the middle of the morning, and a reversal to upslope till afternoon. Very strong winds are quite regularly encountered in the peak area in the early morning with speeds decreasing gradually with sunrise (UNEP, 2009).

3.1.4 Natural vegetation

Vegetation varies with altitude and rainfall (Kindt *et al.,* 2007) (Table 3.1), with a rich alpine and sub-alpine flora, *Juniperus procera* and *Podocarpus* species which are predominant in the drier parts of the lower zone (below 2,500m). *Cassipourea malosana* predominates in wetter areas in the South-West and North-East (over 2,200 mm/year)

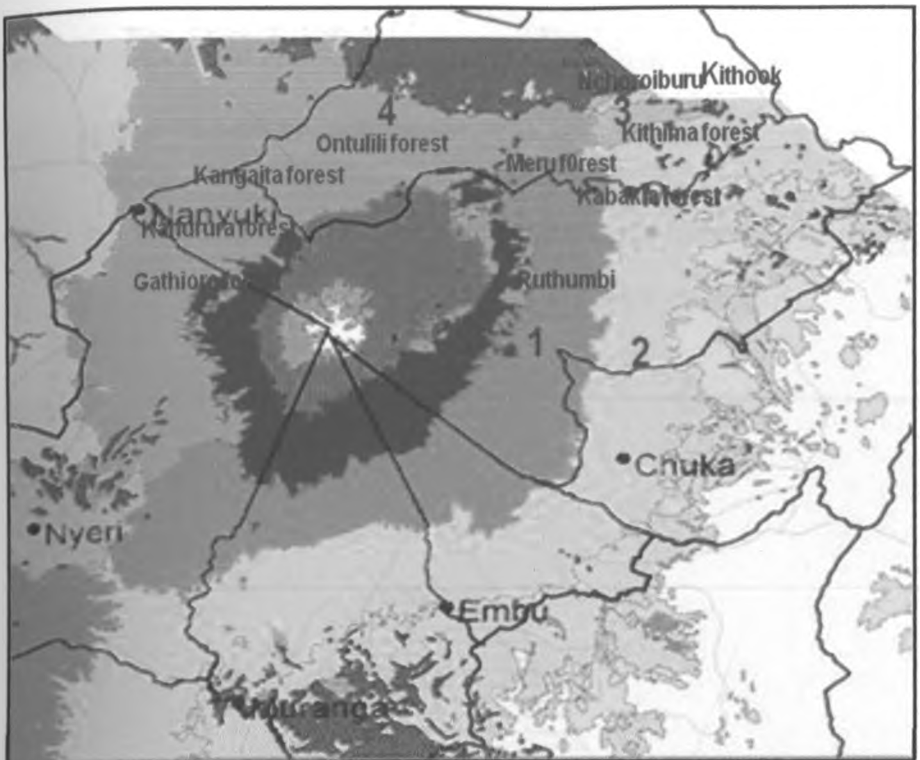

Plate 3: Mt. Kenya potential natural vegetation types adopted from Directorate of Overseas Survey (L.R.) 3006, Kenyan Government 1976. The lines on the map show road network.

Key: Symbol	Vegetation type	Symbol	Vegetation type
1	Moist montane	2	Moist intermediate
3	Dry intermediate	4	Dry montane

However, most of this lower altitude zone is not within the reserve area and is now used for growing crops. Higher altitudes (2,500 - 3,000m) 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 (2,600m-2,800 m), and *Podocarpus* at higher (2,800 - 3,000m) and lower elevations (2500-2600m) (Kindt *et al.*, 2007).

Towards the West and North of the mountain, at altitude of 2,000m-3,500m bamboo becomes progressively smaller and less dominant (Fig. 3.1).

Hagenia abyssinica and *H. revolutum* predominate in areas of maximum rainfall of 2,400 mm per year. Above 3,000m, cold becomes an important factor.

Tree stature declines and *Podocarpus* are replaced by *Hypericum* species. A more open canopy results in a more developed understorey (UNEP, 2009).

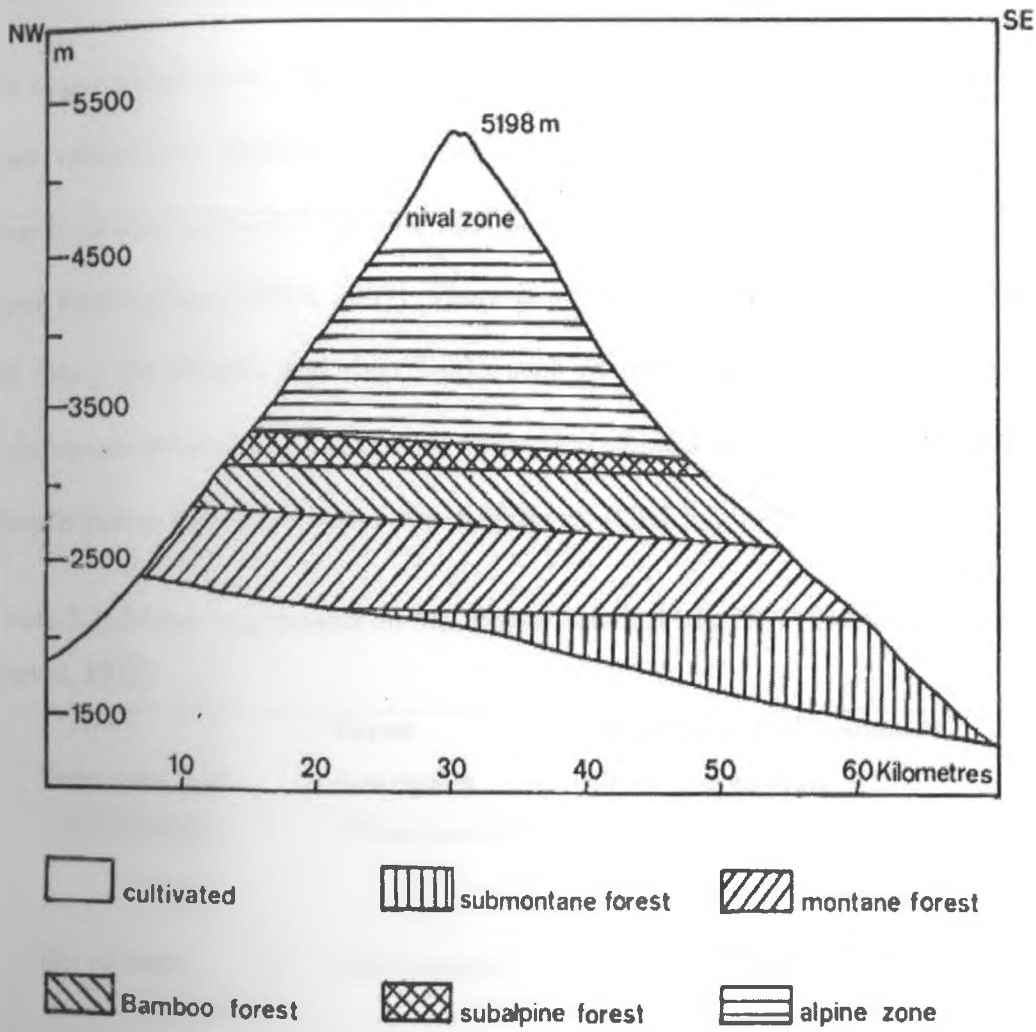

Figure 3.1: Schematic illustration of the zonation of the vegetation of Mt. Kenya from North West to South West (Adopted from Bussmann R. and Beck E., 1995)

Grassy glades are common especially on ridges. The lower alpine or moorland zone (3,400 m-3,800 m) is characterized by high rainfall, a thick humus layer, low topographic diversity, and low species richness. Tussock grasses *Festuca pilgeri* and sedges *Carex* spp. predominates (UNEP, 2009). Between the tussocks, there are *Alchemilla cyclophylla*, *A. johnstonii*, and *Geranium vagans*.

The upper alpine zone (3,800 - 4,500 m) is more topographically diverse, and contains a more varied flora, including the giant rosette plants *Lobelia telekii* and *L. keniensis*, *Senecio keniodendron* and *Carduus* spp. *Senecio brassica* is found in both the lower and upper alpine zone (UNEP, 2009). There is 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 over 5,000m asl (UNEP, 2009).

Table 3.1: Major vegetations on Mt. Kenya (Kindt *et al.,* 2007: Trapnell and Langdale-Brown, 1972)

Vegetation type	Forest description	Biophysical limits obtained from GIS analysis
Moist montane	Wetter montane	Altitude: Above 1800m rainfall of 1400 – 2000 mm
Dry montane	Drier montane	Altitude: Above 1800m rainfall 750 – 1400 mm
Moist intermediate	Wetter intermediate	Altitude: Below 1800m rainfall of 1000 – 1900 mm
Dry intermediate	Drier intermediate	Altitude: Below 1800m rainfall of 900 – 1000 mm

3.1.5 Conservation of Mount Kenya forest

Mt. Kenya forest is a natural world heritage site declared in 1997. It is designated as a biosphere reserve under UNESCO man and biosphere programme (UNESCO, 2004). It is an ecotourism destination and a sacred site to the communities of Kikuyu, Embu and Meru. Local communities are involved in the conservation and management of the forest; to improve beekeeping methods, setting up an eco-resource centre and tree planting on degraded slopes (UNESCO, 2004).

Plantation establishment and livelihood improvement scheme (PELIS) system of forest farming is practiced where tree plantations are grown with annual crops. The programme provides significant food, income and employment opportunities to the local communities (Dorward and Witcomb, 2009).

3.2 Materials and methods

3.2.1 Research Design

The study area was stratified into four blocks based on potential natural vegetation types (Kindt *et al.,* 2007); moist montane, moist intermediate, dry montane and dry intermediate natural vegetation type. Selection of these blocks was based on potential natural vegetation type (PNVT) map from Directorate of Overseas Survey (L.R.) 3006, Kenyan Government 1976 (Plate 3). Potential natural vegetation is the vegetation structure that would become established if all successional processes were completed under the present or future climatic and edaphic conditions (Kindt *et al.,* 2011). According to Kindt *et al.,* (2011), PNVT were classified according to physiognomy which was based on their structure, such as percentage aerial cover and height while a secondary classification scheme was based on floristic characteristics like dominant or typical species. Other differences between PNVT were based on interpretation of climatic conditions as described by Kindt *et al.,* (2011).

Mapping of all the roads and foot paths used within Mt. Kenya forests was done by use of Global Positioning System (GPS) together with vegetation and climatic maps (Trapnell *et al.,* 1966). In each vegetation type a minimum of two forests were investigated for presence of *W. ugandensis*. Hence, in moist montane, Ruthumbi and Meru forests were selected while Kabakia and Kithima forests were selected in moist intermediate forests. In dry intermediate PNVT lower Kithooka and lower Nchoroiburu forests were selected. However, dry montane was the only vegetation type with *W. ugandensis* and therefore four forest blocks were selected for this study; Kangaita, Kahurura, Ontulili and Gathioro forests. In each forest, a base transect was selected. The base transect was laid parallel to the base transect in the other forest with similar environmental condition. Base transects were either an established road, foot path or animal track cutting across altitudinal gradient as described by Caratti *et al.*, (2006). At each sampling site, data was collected at a distance of 50m from the forest edge into the forest to reduce edge effects from neighbouring farms. Length of base transects varied depending on the terrain. In relatively gentle slope a long base transect was established in order to get to the 2300m above sea level or until no more *W. ugandensis* species was seen. In areas with steep slopes shorter base transects were established.

Belt transects measuring 25m wide and 500m long were marked with the starting points being 50m from the base transect. Direction of the first belt transect was determined randomly by tossing a coin, where a head represented the left hand side of the base transect and the tail represented the right hand side. The rest of the belts were selected systematically by alternating left and right sides of base transect (Fig. 3.2) spaced at an altitudinal intervals of 100m above sea level.

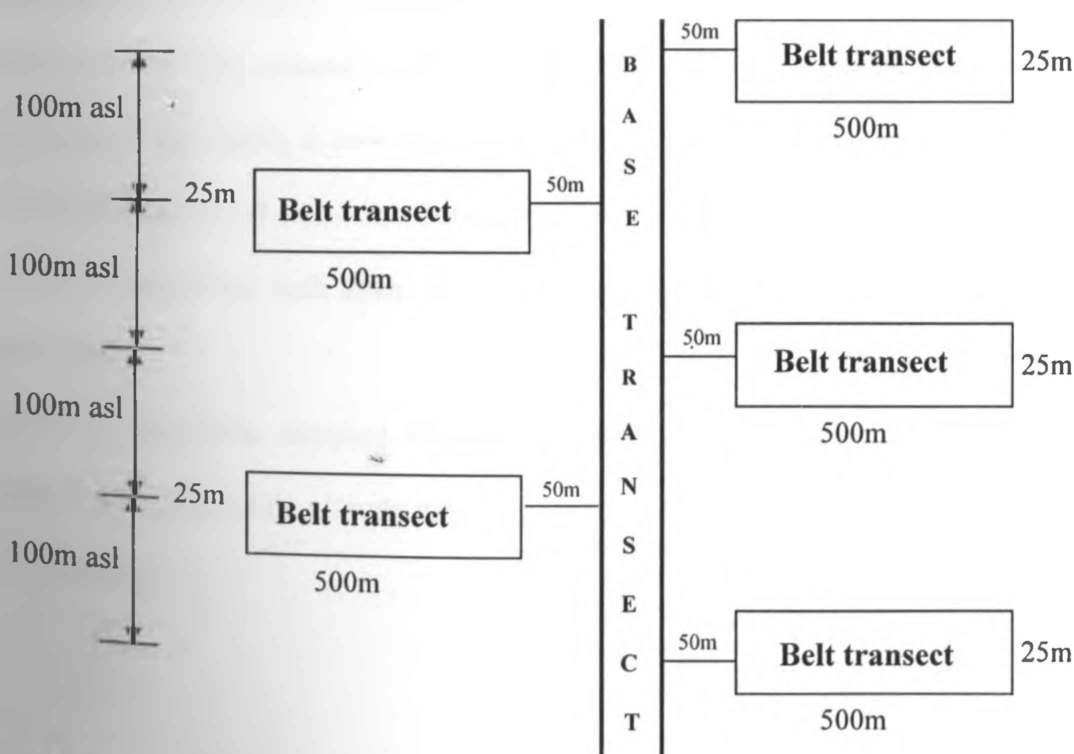

Figure 3.2: A sketch map of the study design: Base transect with side belt transects

The belt transect was subdivided into twenty plots of 25m by 25m (Fig. 3.3) from which four sub-plots were systematically selected for sampling starting from the 2nd sub-plot and then the others after a distance of every 100m.

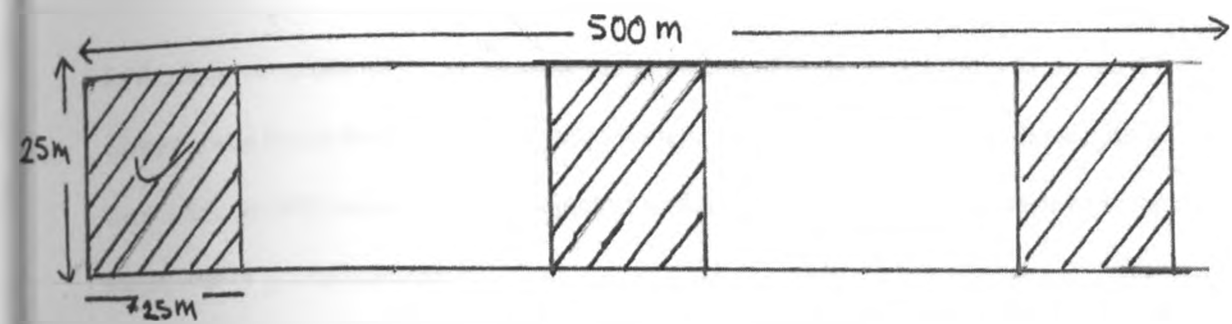

Figure 3.3: Belt transect indicating the sub-plots of 25x25m

The entire sub-plot was used in sampling the mature trees and regenerates of *W. ugandensis,* identifying and enumerating associated species (Kindt *et al.*, 2007) as well as assessing threat indicators.

In the farm lands, base transect were set along a major road or footpath. The first belt transect was set by tossing a coin where tails represented the right side of base transect and the head represented left side. Subsequent belts were at intervals of one kilometer horizontal distance from each other. Belt transects covered farmland with crops, pasture and woodlots.

Rainfall data for all the sampled blocks were obtained from meteological records in Nanyuki and Nairobi while altitude data was obtained by use of GPS and topographical maps of the area.

3.2.2 Plant sampling strategies

In each plot, data on the number of trees, saplings, seedlings and threat indicators were recorded. Tree DBH, height, canopy diameter as well as anthropogenic and wildlife impacts data were collected along changes in altitude, rainfall and the soil types.

In the four sub-plots, all *W. ugandensis* with a height of more than 1.5m was sampled for diametre at a breast height (1.3m) by use of a tape measure (Plate 4) while those with less than 1.5m no DBH measured. The height of saplings and seedlings was measured using a metre rule or graduated pole.

Plate 4: Measurement of the circumference of *W. ugandensis* tree trunk with a tape measure at breast height (1.3m) in Gathioro forest, Mt. Kenya (Diameter = circumference/3.14(π))

If a tree was forked below 1.3 m, DBH of each of the branched trunks were measured and their diameters were averaged to obtain the actual measure of DBH. DBH is important aspect in determining the structure of plants. In this case a tree was considered as woody plant if it had a height of above 1.5 m. The height of the seedlings, saplings and trees was measured from the root collar, where roots join the stem to the shoot tip as described by Adrian, (2007).

For trees on the slopes DBH was measured on the uphill side of the trunk and lower side of the trunk, and averaged so as to avoid bias caused by the differences in the slope of the land at the tree base.

For leaning trees the DBH was measured along the top and underside of the trunk and the DBH was also obtained as an average of the two planes. Some of the parts that were ignored when taking DBH were the dead branches or forks, stems and sprouts. In case of obstruction at 1.3m by a bump, burl, branch or other obstructions, the circumference above and below the obstruction was measured and their average values recorded. However, a buttress was not considered an obstruction.

Seedlings were the small plants of the species in question originating from seeds and of less than 20 cm height as described by Walker, (2000). Sprouts were shoots that originated from a stump, an uprooted plant or root. Saplings were the young trees that had not attained a height of one and a half metres (Husch *et al.*, 2003) but were more than 20cm in height.

Tree height was taken as the vertical distance between the ground line and the tallest part of live crown. The tree height was determined by use of Suunto clinometer. This is an instrument with a trade mark of Suunto Tandem Compass Clinometer that uses both percentages and degrees to measure angle of slope. (http://www.wikipedia.org/wiki/file:clinometer_commonlyusedbyforesters).

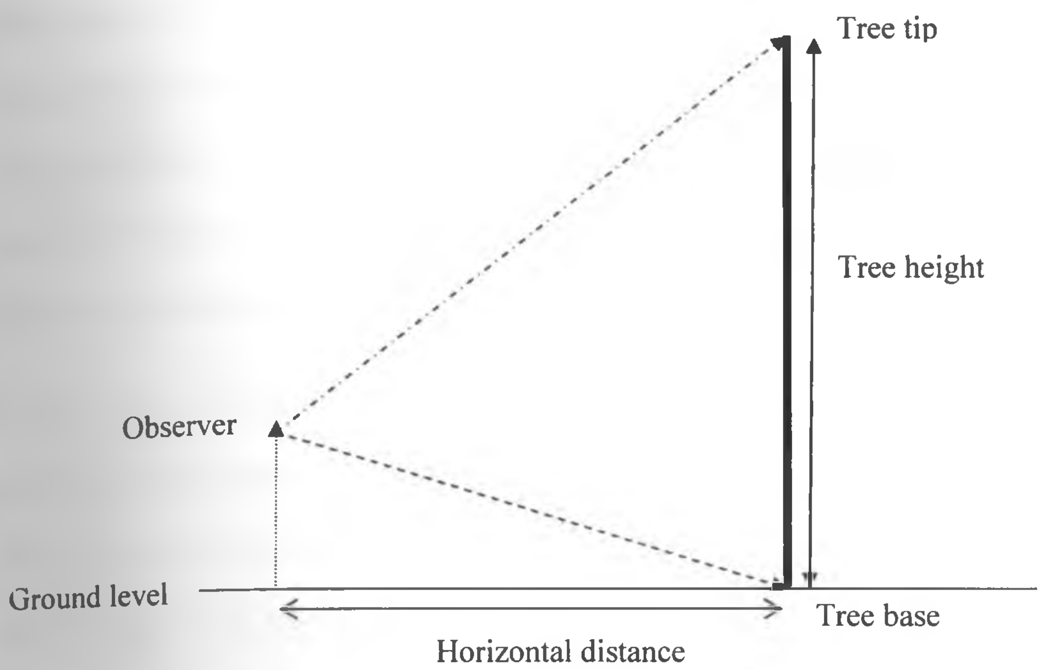

Figure 3.4: Measurement of tree height using suunto clinometer

Horizontal distance from the base of vertical tree was measured to a location where the tree tip could be seen. This was the baseline or horizontal distance. Standing at a baseline distance point, the Suunto scale readings at tree tip were recorded. The bottom of the tree was also sighted and the Suunto scale readings recorded (Fig. 3.4). The height of the tree was obtained by adding the two scale readings multiplying their total with the baseline distance as indicated in the following formula.

$Ht = (S_1 + S_2) \times b$

Where Ht = tree height in metres

S_1 = Suunto scale reading at the tree tip

S_2 = Suunto scale reading at the tree base

b = horizontal distance to the target tree

Sapling and seedling height was determined by use of a meter rule or graduated pole.

Within each sub-plot, spot soil collection was done up to a depth of 15 cm from the soil surface using soil auger size $3_{1/4}$" (with an extension of three feet). The soil samples from the same belt were later combined to come up with a composite sample. The composite sample was later used to determine the soil pH, total nitrogen, total organic carbon, phosphorous, potassium and soil texture of the site.

The tree stumps, debarked and uprooted plants were enumerated stating cause of debarking as either human or animals. Human debarking had shapely signs of matchet cuttings, sometimes extending into the woody part of the tree (see Plate 4 on page 23 and Plate 8 on page 45 in this thesis) while animal debarking lacked regular shape and had teeth scratch signs on the wood. Other forms of damage recorded include damages by browsing and foraging wildlife and livestock, leaves plucked off, branches and twigs cut off.

Identification of plant species was done in the field, however species difficult to identify were picked, pressed and taken to the University of Nairobi Herbarium for identification. The species associated with the vegetation type were selected from a special-purpose excel sheet called species selector.xls as provided by Kindt *et al.,* (2007).

3.3 Data analysis

Data was analyzed by general linear models (GLM) using SPSS 11.0 (2001) statistical software. Correlation analysis was used to test for relationships between a set of several variables (Appendix 3). The variables were the diameter at breast height, tree height and canopy diameter, forests, altitude, rainfall and soil. Also used were graphical presentations and descriptive statistics (mean, standard error and frequencies and percentages). Mean differences were tested using Student Newman Keuls (S-N-K) at 5%

significance level. Soil texture was analysed using hydrometer method which involves dispersing soil in water into its primary particles for analysis. It uses the hydrometer to measure the density of soil particles based on settling time of various particle sizes. Nitrogen, phosphorus and potassium were analysed according to physical and chemical methods of soil analysis by Hinga *et al.*, (1980). Organic carbon was analysed by using dichromate oxidation reduction method (Anderson and Ingram, 1993).

CHAPTER FOUR: RESULTS

4.1 Major features of Mt. Kenya forest

Mount Kenya consists of several separate forest blocks of different sizes and varying in altitude. This research was conducted within an altitude range of 2056m to 2275m asl. Kangaita forest had the highest altitudinal range of 2080m to 2275m asl.

Of the four forests with *W. ugandensis,* Gathioro forest was the largest covering 66.9% of the total area covered by the four forest blocks. Kangaita forest covered 21.2% while Ontulili forest and Kahurura forest covered 6.9% and 4.9% respectively. Gathioro forest had the highest density of 25.6 trees per hectare. Kangaita forest had 14.7 trees per hectare, Ontulili forest had 18.8 while Kahurura forest had 13 trees per hectare (Table 4.1).

W. ugandensis population per forest block was estimated by using density and forest block size. Gathioro forest had the highest population estimate of 383,616 mature *W. ugandensis* while Kahurura had the lowest population estimate of 14,431 trees (Table 4.1).

Rainfall per month ranged between 72 to 79.5mm per forest block with variations between different altitudes, with Gathioro receiving the highest rainfall of 79.5mm while Ontulili had the lowest of 72mm per month (Table 4.1).

There was no *W. ugandensis* recorded in forests within the moist montane, dry intermediate and moist intermediate PNV. Hence all the sampled *W. ugandensis* were obtained from dry montane type of forests, particularly in the North West of Mount Kenya. The average density of *W. ugandensis* in dry montane forests was 18.025 trees per hectare.

Table 4.1: Density and population estimates of *W. ugandensis* in different forests and environments

Forest	Size(ha)/ forest	No. of *W. ugandensis* in belts	Density (no./ha)per forest block	Popn estimate	Rainfall/ Month	Vegetation type
Gathioro	14,985	64	25.6	383,616	79.5	D.M.
Kahurura	1,110.1	49	13	14,431	75	D.M.
Kangaita	4,737.15	55	14.7	69,636	74.5	D.M.
Ontulili	1,565.4	47	18.8	73,574	72	D.M.

D.M = dry montane forests

4.2 Population structure

4.2.1 Population structure based on diameter at breast height (DBH) in different forests

The sizes of *W. ugandensis* trees varied in different forests in Mount Kenya ecosystem. *W. ugandensis* tree species in Kangaita forest had a mean DBH of 0.23m and was therefore larger than the trees of the same species in other forests. However trees found in the high altitude Ontulili forest were slightly smaller (mean DBH of 0.21m) than those found in Kangaita forest but higher than that of Kahurura (mean DBH 0.14m) and Gathioro (mean DBH 0.17m) forests. There was no significant difference in DBH of this species among the four forests ($F_{[3, 214]} = 6.67$, $p=0.077$).

4.2.2 *W. ugandensis* height in different forests

Ontulili and Kangaita forest recorded the tallest *W. ugandensis* trees with mean heights of 12.6m and 12.2m respectively. Kahurura and Gathioro forests had shorter trees with mean heights of 7.3 m and 6.025m respectively (Plate 5 and Table 4.2). There was significant difference in height of trees of this species among different forests ($F_{[3, 214]} = 9.92$, $p= 0.046$).

Plate 5: Varying heights of *W. ugandensis* (pointed by an arrow) in Gathioro forest

4.2.3 Canopy diameters of *W. ugandensis* in different forest reserves

Canopy diameter of *W. ugandensis* averaged between 2.5m to 4.5m in all the forests. Kangaita recorded the greatest canopy diameter of 4.5m, Ontulili 3.9m, Kahurura 3.1m and Gathioro 2.5m (Table. 4.2). The third belt in Kangaita had only two individual trees and therefore not included in the analysis since they were not representative of the real situation (Appendix 4). Ontulili and Gathioro's belt three lacked the species. There was no significant difference in canopy diameter of this species among different forests ($F_{[3, 214]}$ = 5.932, p= 0.089). The canopy diameter appeared to have been influenced by the location of the tree among other associated forest tree species. *W. ugandensis* trees located in open areas tended to have larger canopies than those with tree neighbours of other species.

Table 4.2: Mean DBH, height and canopy diameter in different forests, altitudes and rainfall amounts.

Forest	Altitude(m)	Rainfall(mm)	Height (m)	DBH(m)	Canopy(m)
Kangaita	2080	72.9	12.7	0.26	5.1
	2171	74.6	11.7	0.19	3.8
Kahurura	2058	74.8	9.5	0.18	3.9
	2156	74.5	8.2	0.15	2.9
	2234	77.1	4.3	0.10	2.4
Ontulili	2155	71.3	15	0.26	4.3
	2254	72.8	10.1	0.15	3.5
Gathioro	2117	78.1	6.4	0.08	2.3
	2221	81.5	5.65	0.09	2.6

4.2.4 Trends in tree sizes found in different altitudes

The findings of this study revealed that DBH of *W. ugandensis* decreased with increasing altitude in all the forests (Fig. 4.1). The DBH of trees decreased with increasing altitude in Kangaita, Kahurura and Ontulili (Fig. 4.1). However, this trend was reverse for

Gathioro where highest DBH of 0.09m was recorded at a higher altitudes of 2221m and a lower DBH of 0.08m at lower altitude of 2117m asl.

The largest DBH was 0.26m at 2080m and 2155m above sea level (asl) while the lowest was 0.08m at 2117m asl. Data on the third belt in Kangaita was not used in the analysis since only two *W. ugandensis* trees were found. To reduce the variation of the values of height, DBH and canopy diameter, the values were converted into log base ten. The DBH data on Table 4.2 turn negative when converted to log base ten. There was no significant correlation (r = -0.447, n=214, p= 0.228) between DBH and altitude.

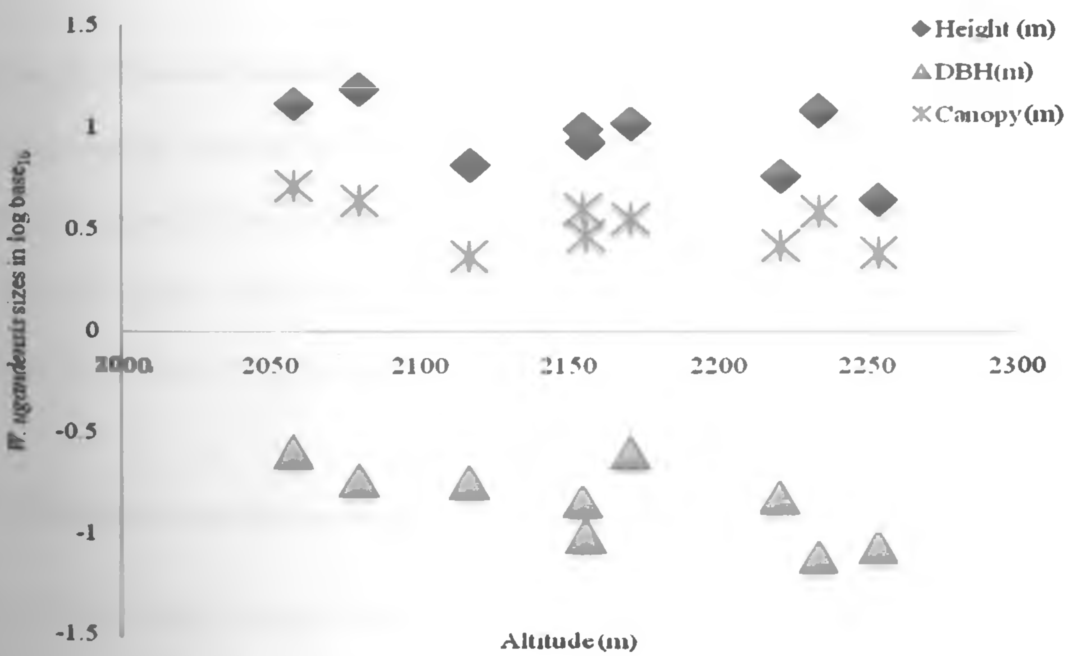

Fig. 4.1 Tree sizes in relation to altitude ranged from about 2000-2300m asl.

4.2.5 Mean tree heights in relation to altitude

The findings of this study revealed that height of *W. ugandensis* decreased with increasing altitude in all the forests (Fig. 4.1 and Table 4.2). In Kangaita, the mean heights were 12.7m and 11.7m at altitudes 2,080m and 2,171m respectively. This trend was also reflected in Kahurura where mean heights were 9.5m and 4.3m at altitudes 2,058 m and 2,234 m respectively. Equally for Ontulili the mean heights were 15m and 10.1m at altitudes 2,155 and 2,254m and in Gathioro, mean height were 6.4m at 2,117m and 5.65m at 2,221m asl. There was no significant correlation (r = -0.359, n =214, p=0.343) between height of trees and altitudes.

4.2.6 Canopy diameter in relation to altitude

The highest canopy diameter of 5.1m was recorded at an altitude of 2080m asl while the lowest was 2.3m at 2117m asl (Table. 4.2). Mean canopy diameter for Kangaita's 3rd belt was excluded because there were only two individual trees. However there was no significant correlation (r=-0.49, n=214, p=0.183) between canopy diameter and altitude.

4.2.7 Variation in sizes of trees found in different rainfall regimes

Mean monthly rainfall ranged from 71 to 81mm in all forests where *W. ugandensis* occured (Table 4.2). The findings of this study revealed that DBH of *W. ugandensis* decreased with increasing rainfall in all the forests (Fig. 4.2). Highest DBH was 0.26m at 71.3mm and 72.9mm of rainfall and the lowest was 0.08m at rainfall of 78.1 mm. There was a highly significant negative correlation (r = -0.840, n=214, p= 0.005) between rainfall and tree diameter at breast height. Diameter at breast height was higher in trees in lower rainfall range and as the rainfall increased the DBH decreased (Fig. 4.2). The largest DBH of 0.5m was recorded in Kangaita at 74.5mm of rainfall, however it was a mean of only two trees and was therefore not representative of trees at the site.

4.2.8 Tree height in relation to rainfall

The findings of this study revealed that height of *W. ugandensis* decreased with increasing rainfall in all the forests (Fig. 4.2). The tallest trees averaging 15m were found at 71mm of rainfall while the shortest trees with an average 4.3m occurred at 77mm of rainfall. There was a strong negative correlation (r = -0.84, n=214, p=0.005) between rainfall and tree heights. When the mean DBH, height and canopy diameter were converted to log base ten to reduce their variation, a general trend was noted where all sizes decreased with increasing rainfall (Fig. 4.2).

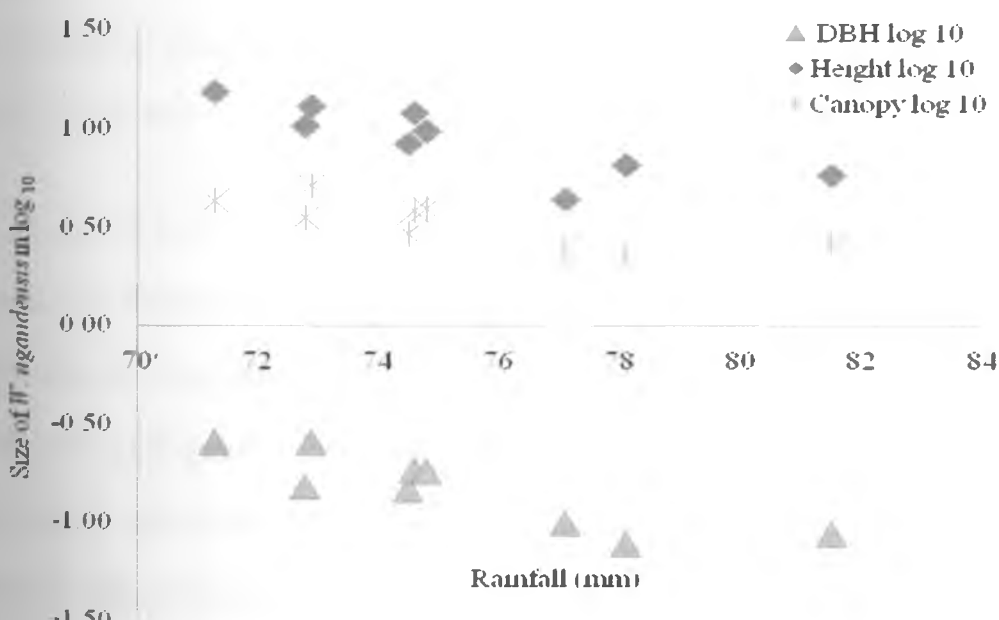

Fig. 4.2: Tree sizes in relation to rainfall

4.2.9 Effect of rainfall on canopy establishment

The largest canopy diameter was 5.1m occurring at 72.9mm of rainfall and the smallest canopy diameter was 2.3m at 81.5mm of rainfall per month (Fig. 4.2). Data collected indicated that areas with higher rainfall had smaller canopy diameter than areas with low rainfall (Fig. 4.2). There was significant negative correlation (r = -0.75, n=214, p=0.02) between canopy diameter and rainfall.

4.2.10 Trends in tree sizes in relation to different soil parametres

Correlation analysis between soil factors and *W. ugandensis* sizes (DBH, tree height and canopy diameter) showed that soil parameters had no significant correlation with *W. ugandensis* sizes (Table 4.3). pH ranged from 6.17 to 7.33 in the forests where *W. ugandensis* was found. Soil pH had no significant correlation with DBH (r= 0.49, n=214, p=0.178), canopy diametre (r= 0.55, n=214, p=0.129) and tree height (r=0.41, n=214, p=0.273) (Table 4.3).

Nitrogen content was 0.10 to 0.18% and correlation analysis showed that plant sizes increased with increase in nitrogen levels. However, there was no significant correlation between nitrogen with DBH (r= 0.28, n=214, p=0.463), canopy diameter (r=0.44, n=214, p=0.23) and tree height (r=0.39, n=214, p=0.299). Phosphorus content ranged from 10.3 to 84 ppm in all the belts with this species. Total phosphorus had no significant correlation with DBH (r= -0.19, n=214, p=0.62), canopy diameter (r=-0.26, n=214, p=0.577) and tree height (r=-0.16, n=214, p=0.680). Plant sizes decreased in soils with high phosphorus. In Gathioro at altitude 2017m asl phosphorus levels were 139ppm and *W. ugandensis* was completely absent.

Organic carbon ranged from 1.02 to 1.76% with highest in Kangaita and lowest in Kahurura. There was no significant correlation between total organic carbon and DBH (r = 0.28, n=214, p=0.465), canopy diameter (r=0.44, n=214, p=0.231) and tree height (r=0.40, n=214, p=0.292). Soils with high organic carbon had bigger DBH, taller trees and wider canopy diameters.

Table 4.3: Correlation analysis matrix for *W. ugandensis* DBH, height and canopy diameter in relation to soil parametres

Soil parameters	DBH	Canopy diametre	Height
pH	0.49	0.55	0.41
Total nitrogen	0.28	0.44	0.39
Organic carbon	0.28	0.44	0.40
Phosphorus	-0.19	-0.26	-0.16
Potassium	0.23	0.14	0.12
Sand	-0.31	-0.28	-0.43
Silt	0.55	0.45	0.48
Clay	-0.16	-0.07	0.05

Potassium (Mili-equivalent %) content ranged between 0.92 to 3.02 with Kangaita having the highest levels and Gathioro the lowest. Potassium had no significant correlation with DBH (r= 0.23, n=214, p=0.557), canopy diameter (r=0.14, n=214, p=0.717) and tree height (r=0.12, n=214, p=0.786). Sand content ranged from 26% to 36% in the collected soil samples. There was no significant correlation between sand with DBH (r= -0.31 n=214, p=0.406), canopy diameter (r=-0.28, n=214, p=0.463) and tree height (r=-0.43, n=214, p=0.245). Silt level ranged from 28 to 36% with highest in Kangaita forest and lowest in Ontulili forest. There was no significant correlation between silt and DBH (r= 0.55, n=214, p=0.125), canopy diameter (r=0.45, n=214, p=0.230) and tree height (r=0.48, n=214, p=0.189).

ay amounts ranged from 30 to 46% with lowest in Kangaita and highest in Ontulili. ere was no significant correlation between soil clay content with DBH ($r= -0.16$, $n=214$, $p=0.686$), canopy diameter ($r=-0.07$, $n=214$, $p=0.858$) and tree height ($r=0.05$, $n=214$, $p=0.906$). Table 4.3 summarises correlation coefficients of soil parameters and DBH, canopy diameter and height of *W. ugandensis.*

.2.11 Population structure of *W. ugandensis* in farmed areas

total of 38 trees and 44 trees of *W. ugandensis* were recorded in the study transects in Nanyuki and Meru respectively. The mean DBH in Nanyuki was 0.27m while Meru had a mean DBH of 0.11m. There was significant difference between DBH of trees in Meru and those recorded in Nanyuki farms ($F_{[1, 81]} = 17.60$, $p<0.01$). The mean tree height in Nanyuki was 12.90m, while in Meru it was 5.95m. There was a high significant difference between height of trees recorded in Meru farms and in Nanyuki farms ($F_{[1, 81]} = 25.98$, $p<0.01$). Mean canopy diameter of *W. ugandensis* was 5.10m and 3.82m in Meru and Nanyuki farms respectively but did not significantly differ ($F_{[1, 81]} = 1.80$, $p>0.05$).

4.2.12 Regeneration in relation to rainfall and forest reserves

Various forms of regeneration were recorded in the different forests where the species was found. The regenerates included seedlings, saplings, sprouts and seeds (Plate 6). *W. ugandensis* produce enormous amount of fruits (Plate 6: b & c) with a lot of seeds. However seedlings were very rare in all the forests except Gathioro forest which had 1.2% seedlings. Saplings (Plate 6: a) were however found in all the sampled forests (Appendix 5). Majority of the regenerates were from sprouts of tree stumps (Plate 7). Other regenerates

Figure 6a: Regenerate of *W. ugandensis*; Sapling growing under shade of other trees

Figure 6b: Fruits of *W. ugandensis* rotting on the ground

Figure 6c: A fruiting *W. ugandensis* tree

Plate 7: Regeneration in form of sprouts from a tree stump

sprouted from exposed *W. ugandensis* roots and the trees that had fallen over but their roots were still attached to the ground. There were more regenerates of *W. ugandensis* in Kangaita and Kahurura forests than in Ontulili and Gathioro forests (Fig. 4.3).

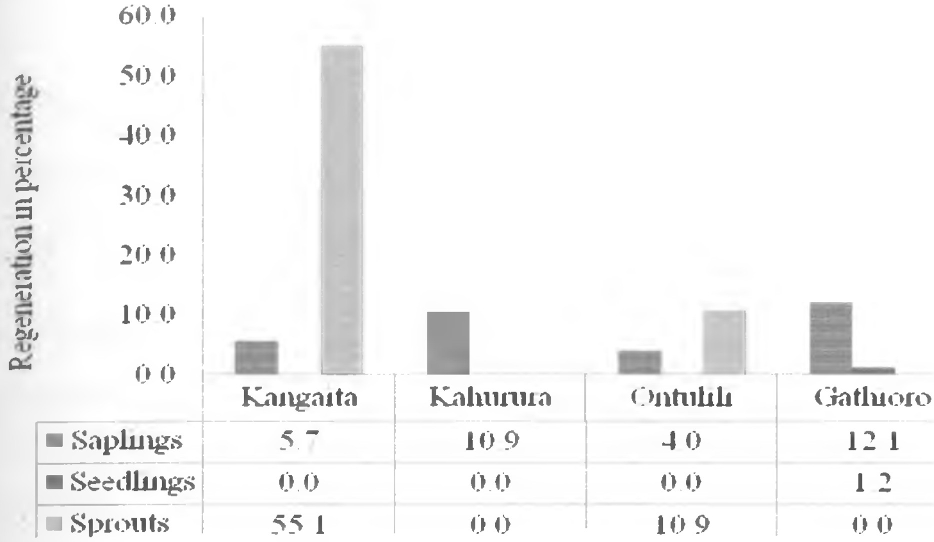

Fig. 4.3: Percentage regeneration in different forests

The highest regeneration was recorded where the rainfall was 74.6mm. Lowest amount of regeneration was 2.3% of total regeneration, recorded at rainfall of 71.3mm. There was a general trend whereby the regeneration decreased with increase in rainfall.

4.2.13 Regeneration at different altitudes

Highest regeneration stage was of 45 plants recorded at middle level altitude of 2100m asl. At a lower altitude of 2000m asl total regeneration was 33 plants while at a higher altitude of 2200m asl there were 14 plants.

4.3 Plant species associated with *W. ugandensis*

Data collected from dry montane forest where *W. ugandensis* was found indicated 28 plant species were found growing in sub-plots with *W.ugandensis* in studied forests. 22 of those species were associated with the dry montane PNV type (Table 4.4).

Table 4.4: The relative abundance of plant species associated with *W. ugandensis* in dry montane type forests in Mt. Kenya.

Species name	Species percentage	Relative abundance
Mystroxylon aethiopica	18.6	0.186
Olinia rochetiana	11.7	0.117
Podocarpus latifolius	14.3	0.143
Euclea divinorum	5.6	0.056
Maytenus undata	1.5	0.015
Dovyalis abyssinica	0.2	0.002
Acokanthera schemperi	0.4	0.004
Dodonae anguistifolia	1.5	0.015
Calodendrum capense	0.2	0.002
Afrocrania volkensii	5.2	0.052
Pittosporum viridiflorum	5.7	0.057
Celtis africana	4.5	0.045
Euclea divinorum	4.2	0.042
Olea africana	11.9	0.119
Sclerebera alata	0.3	0.003
Cassipourea malosana	0.6	0.006
Ekerbergia capense	0.7	0.007
Teclea nobilis	4.8	0.048
Vanguera infausta	3.0	0.03
Rhus natalensis	2.6	0.026
Calodendrum capense	0.7	0.007
Tarchonanthus camphoratus	1.8	0.018

The most prevalent species were *Mystroxylon aethiopica* comprising 18% of all the species, followed by *Podocarpus latifolius* 14.3%, *Olea africana* and *Olinia rochetiana* with 11.9% and 11.7% respectively. While these trees competed for soil nutrients and moisture with *W. ugandensis*, they did not appear to affect its natural regeneration (personal observation). However the trees shaded *W. ugandensis* saplings and sprouts, thereby reducing its growth and establishment.

4.4 Threats to *Warburgia ugandensis*

4.4.1 Comparing threat indicators in different forests

Investigations in different forests revealed indicators that show the plant species is being threatened. The principle threats were overutilization or overexploitation in one form or another by humans, livestock and wildlife. The physical signs of threats are hereby refered to as 'indicators of threats'.

The most frequent threat indicators were the damages on non-pronounced plant parts such as the cut off branches and twigs, removal of terminal twigs in seedlings, saplings and defoliation of leaves by grazers, browsers and elephants, here being reffered to as 'other types of damage' comprising 37.4%. This was followed by debarked plants comprising 32 %, stumps comprising 24% and fallen and uprooted plants comprising 7%. There was significant difference among various indicators of threat ($F_{[3, 99]} = 5.97$, $p<0.05$).

The stumps, debarked plants and other types of damage were encountered in all forests. Out of all the indicators of threats, Ontulili forest had the highest frequency of damages with 34%. Kangaita forest had 28% while Kahurura and Gathioro forests had 25% and 13% respectively (Table 4.5). There was no significant difference among threat indicators in various forest reserves sampled ($F_{[3, 99]} = 2.7$, $p>0.05$).

Table 4.5: Percentage of threat indicators in different forests

Site	Stump (%)	Debarked (%)	Fallen or uprooted trees(%)	Other indicators (broken twigs(%)	Total
Kangaita	8	10	0	10	28
Kahurura	8	7	0	10	25
Ontulili	5	13	7	9	34
Gathioro	3	2	0	8	13
Total	24	32	7	37	100

4.4.2 Comparing threat indicators by human and wildlife

The results showed that humans were the major threats to *W. ugandensis* and this was by debarking, cutting off branches and twigs and felling or cutting of the trees leaving stumps (Fig. 4.4).

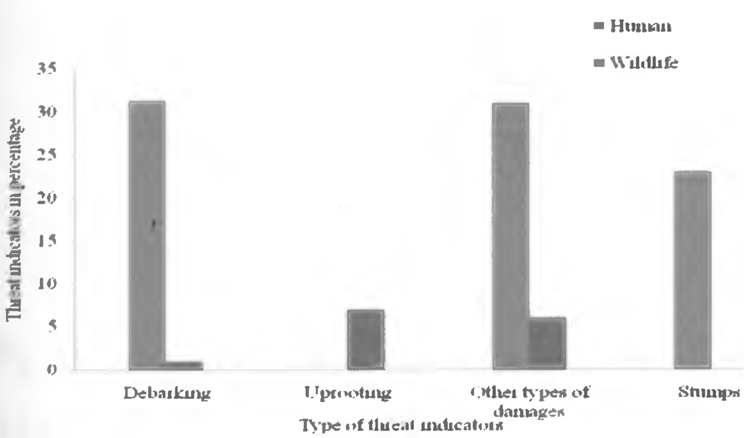

Fig. 4.4: Threat indicators caused by humans and wildlife in Mt. Kenya forest

Human constituted 86% of all the threat indicators while wildlife constituted 14%. Debarking by human constituted 31% and was common in all the forests while debarking by wildlife comprised of 1%. Wildlife impacted on the species by uprooting mature trees (7%) and this was mainly by elephants. Damages impacted by human on leaves, twigs and branches comprised 31% while wildlife impact was 6% of all the threats recorded.

Tree stumps encountered constituted 24% of all the damages and were caused by human through cutting down of trees.

4.4.3 Percentage stumps in forest reserves.

Stumps were indicators of cut trees and were highest in Kangaita and Kahurura forests where they constituted 33%, compared to Ontulili and Gathioro forests where they constituted 20% and 14% respectively (Fig. 4.5. There was no significant difference between number of stumps in different forests ($F_{[3, 8]} = 0.41$, $p>0.05$). However Ontulili and Gathioro had fewer stumps than the other two forests.

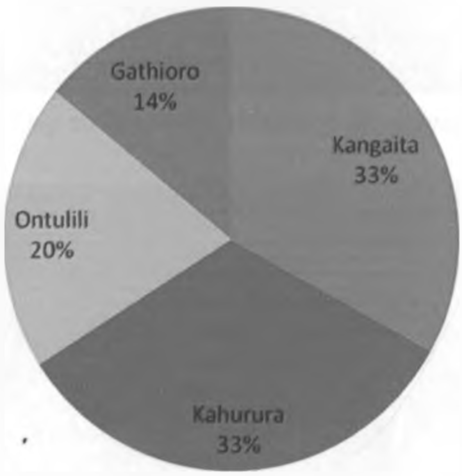

Fig. 4.5 Percentage cut tree stumps in different forests

4.4.4 Debarked *W.ugandensis* plants

Some of the trees had full debarking as shown in Plate 8 (a and b). Dry *W.ugandensis* was common in Ontulili forest due to complete ring debarking and wildlife impacts.

Plate 8: (a); Dry and severely debarked *W. ugandensis* tree

Plate 8:(b), A debarked tree stem regenerating a new bark

Plate 8:(c) A traditional herbalist removing the bark from *W. Ugandensis tree*

Out of the four forests, debarking by wildlife was greatest in three forests (Kangaita, Kahurura and Gathioro) while debarking by human was highest in Ontulili forest. Gathioro had the least human impact on debarking (Fig 4.6).

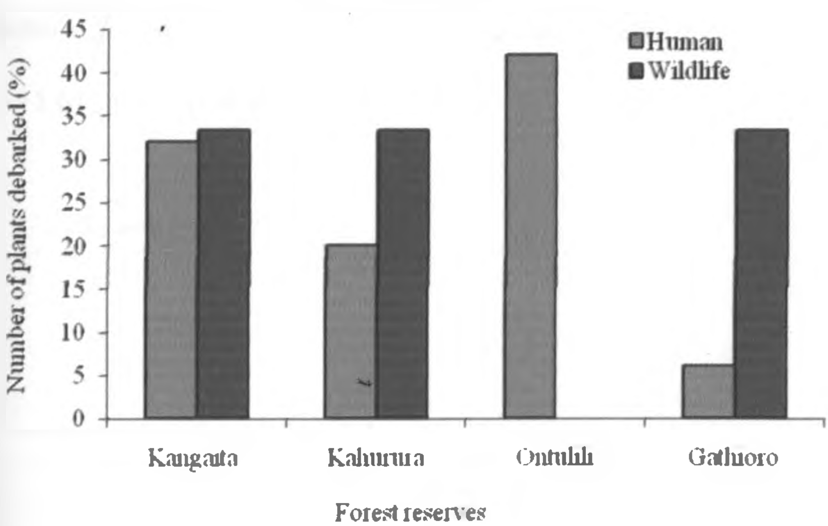

Fig 4.6: Percentage debarked by human and wildlife in different forests

The mean number of trees debarked by animals was 0.30 while mean number of trees debarked by humans was 6.30. There was a significant difference between the debarking incidences caused by wildlife and those caused by human beings Mann-whitney ($U_4 = 60$, $n_1=4$, $n_2=18$, $p<0.05$). This means that the real threat to *W. ugandensis* is human being who destroys the species through debarking, cutting it down and removal of brances and twigs.

4.4.5 Other forms of damages

The major form of damage to *W. ugandensis* in Mt. Kenya forests were attributed to human, wildlife, wild fires, landslides and small animals foraging on fruits, flowers and seeds on the ground. These included monkeys, baboons, duikers and squirrels. Birds, ants and termites also consumed the fruits and seeds of *W. ugandensis.*

Overall humans contributed 60% of the damage, while elephants contributed 17.5%, livestock 14.5% and other agents 8% of the total damage (Fig. 4.7). There was a highly significant difference between the various causes of debarking in the four forest blocks ($F_{[3, 61]} = 11.61$, n=62, p=0.00)

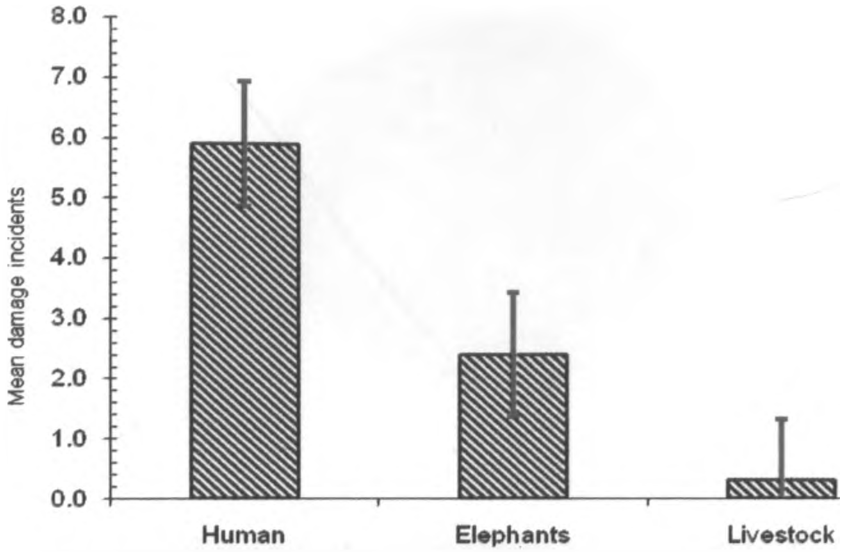

Figure 4.7: Causes of threat and their incidences of damages

W. ugandensis fruits and seeds were heavily infested with fruit fly larvae which dama the fruit by feeding on the pulp and boring holes in the seeds (Plate 9c) hence destroy their viability and regeneration in the forest (Plates 9a and 9b).

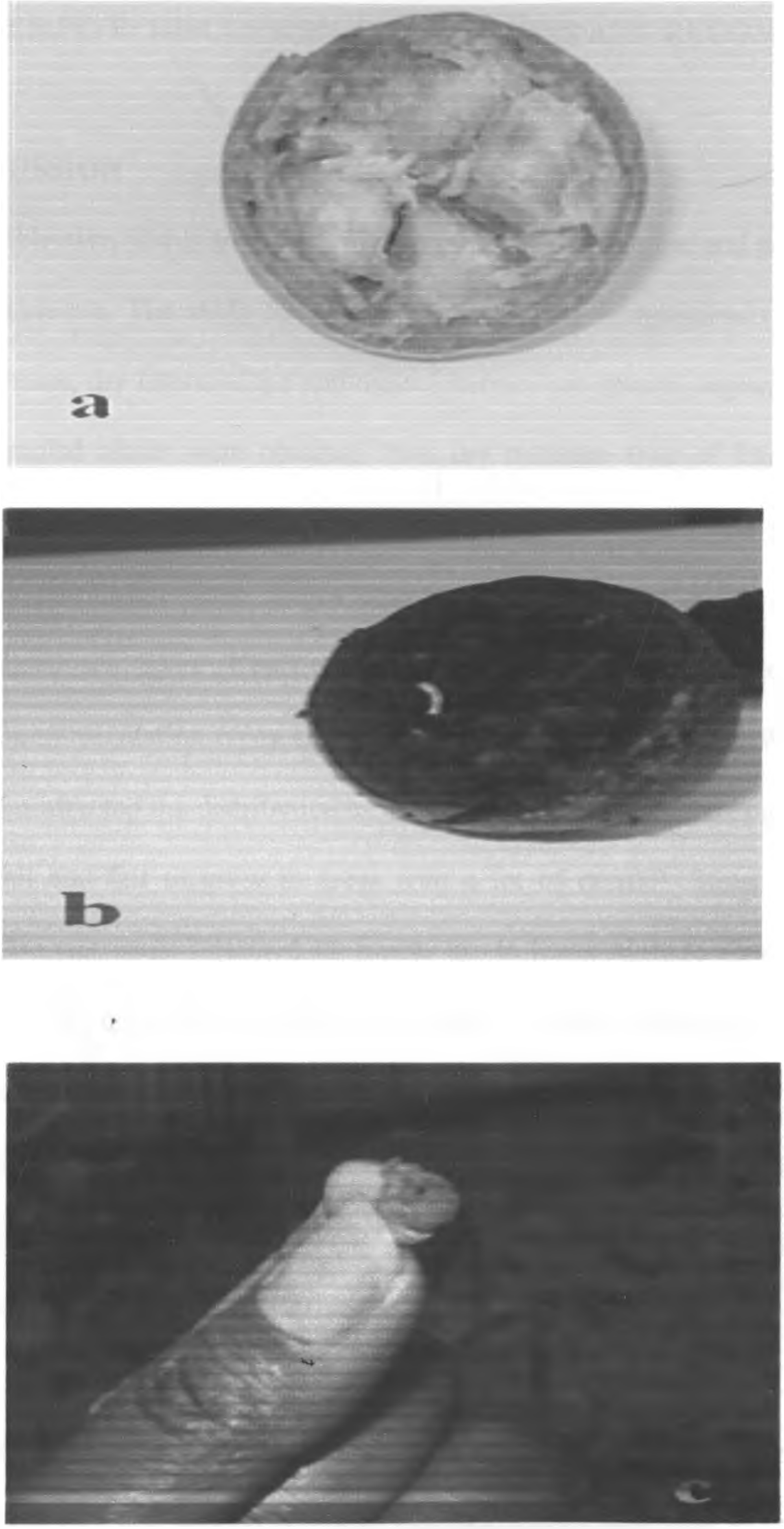

Plate 9: *W.ugandensis* fruits infested with fruitfly larvae (a, b) and a seed damaged by the same larvae

CHAPTER FIVE: DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 DISCUSSION

The first objective of this study was to determine the distribution and population structure of *W. ugandensis.* The study found that distribution of *W.ugandensis* does not occur in moist montane, dry intermediate and moist intermediate natural vegetation types and that all the sampled plants were obtained from dry montane type of forest, particularly in North West of Mount Kenya. This may be attributed to the uniqueness of dry montane's type of annual rainfall which ranges from 650mm to 1500mm and in altitude of 1800 to 2500m above sea level (Kindt *et al.,* 2007). Climate is the major control on the distribution of vegetation types and plants in the world as stated by Woodward, (1987). Rainfall has affected the distribution of this species in that the species grows in areas with less rainfall and fail to grow in areas with a lot of rainfall. Moist montane forest is probably too wet while intermediate forests are in lower altitude zones where the forest has already been oonverted into agricultural land. This has affected the distribution of *W. ugandensis* by limiting it only to the forest reserves where its distribution is also limited by altitude up to about 2200m asl. The variation in distribution of *W. ugandensis* in different forests may be due to variations in rainfall amount, however soil type and human activities may have also influenced the distribution of this species.

W. ugandensis structure has been described in relation to diametre at a breast height, height of the tree and canopy diameter (Ogden, 1970). Kangaita forest had the largest trees. The large size of trees could be contributed by the relatively neutral pH levels that range between 6.8-7.3 which provide good conditions for high breakdown of organic matter into organic carbon and total nitrogen which are released into the soil for plant use.

According to Anderson *et al.*, (2000) pH affects organic carbon solubility. Areas with small sized plant structures like Gathioro had low pH levels of 6.17 to 6.7. The presence of less phosphorus, clay, sand and moderate silt in Kangaita forest as compared to more of those in Gathioro forest may be responsible for promoting larger trees in Kangaita.

There was a trend with the tree DBH decreasing as the altitude increased in Kangaita, Kahurura and Ontulili. This may be attributed to decrease in temperature and water holding capacity of air and decrease in soil nutrients which decline with increase in altitude. This concurs with the work of Kapelle *et al.*, (1995) which showed stem diameter of the different species of trees decreased with increase in altitudinal zonation of Quercus montane forest. The results of the current study again concurred with the findings of Kitayama and Aiba (1994) and Priceton, (1997) who reported that plant stature declined with increase in altitude but no significant correlation between DBH and altitude.

From the results of the current study it was found that the tree DBH tended to increase with increase in some soil factors such as pH, total nitrogen levels and total organic carbon which noticeably declined with increasing altitude. Probably certain limits of nutrients limit the growth of plant stem diameter. Rainfall, soil water and temperature are important in determining DBH increment (Chidumayo, 2005). These factors varied in different forests hence causing differences in DBH in different forests.

Studies by Chidumayo (2005) showed that optimum rainfall, soil moisture and temperature were important in determining DBH increment. According to his findings, there was a correlation between rainfall and diameter at breast height. In this study, the

DBH declined with increase in rainfall. The possible cause of decline of DBH size with increase in rainfall in the current study could be attributed to high levels of leaching and erosion of essential nutrients like nitrate and organic compounds from the soil by the heavy rainfall experienced in Mt. Kenya. High levels of leaching and water logging reduce soil pH as describe by Macintire *et al.,* (1938). In the current study, most transects where this species was found had clay soils which has poor drainage. Impeded drainage causes waterlogging which influences plant structure development (Frankham *et al.,* 1996) due to reduced aeration limiting the microbial activities and reducing nutrients availability. These results are consistent with findings by Soethe *et al.,* (2008) who found that plant growth, correlates with nutrients availability which is determined by parental substrate, weathering intensity, cation exchange capacity, rate of litter decomposition or extracellular phosphatase activity.

In the converse, the mean tree height decreased with increase in altitude in the current study. This decline was possibly caused by low soil nutrients and low temperatures which cause decreased rate of microbial decomposition and nutrients release for plant use. The reduced microbial activity could be linked to the decreasing temperatures as altitude increased. Decrease in tree height with increasing altitude was also reported by Kofidis and Bosabalidis (2008) whose work on *Nepeta nuda* L. found that height decreased with altitude. The decrease in tree height could be explained by the shortening of tree stems at high elevations as reported by Smith (1980) who found that stem height decreases with increase in altitude in plant species occurring above tree line (ecotone containing upright trees with more than 3m tall). Decrease in plant height may also be associated with decreased solar radiation and sunshine which decreases the photosynthetic rate

(Frankham *et al*, 1996). Shorter plants are able to obtain warmth from the ground for the purpose of photosynthesis.

Similarly, tree height decreased with increasing rainfall amount. There was a strong negative correlation between rainfall and tree heights. These findings are supported by Longino (1986), in their study on tropical liana which indicated a negative correlation between rainfall and height of shoot. This may be attributed to waterlogging of the soils which limit availability of nitrogen compounds, enhances accumulation of phosphorus, loss of organic matter through erosion and low levels of pH (Longino, 1986).

The mean canopy diameter had a negative correlation with altitude. Higher altitudes had trees with smaller canopy diameter. Decrease in canopy diameter with increasing altitude is linked to decrease in nutrients and increase of phosphate compounds which tie up micronutrients like iron, copper and zinc (Busman *et al.,* 2002).

There was strong significant negative correlation between canopy diameter and rainfall. Canopy diameter was also found to correlate with DBH and plant height. According to Chidumayo (2005), if DBH decreases with increase in rainfall, then canopy diameter would also decrease with rainfall increase. However, the possible cause of decline of canopy size with increase in rainfall amount may also be linked to the leaching, waterlogging, unavailability of nutrients and eroding levels of essential nutrients. Moreover, impeded drainage has negative influence on canopy development (Frankham *et al.,* 1996). This may be due to poor root hair development and hence low absorption of essential nutrients causing reduced growth.

The study found out that there were very few seedlings observed growing in the forests even though the trees produced a large number of fruits and seeds. This may be attributed to the high rate of attack of the *W. ugandensis* fruits and seeds by fruit flies, birds and mammals while still growing on the trees. Livestock especially cattle and goats as well as wildlife also damage the young seedlings, saplings and sprouts.

Seedlings and saplings were found thriving well under shade of other trees, probably because of their ability to survive under shade (Kinyamario *et al.,* 2008) in habitats that are relatively wet compared to the open habitats. Other factors affecting regeneration included faster loss of viability by the seeds since they are reculcitrants (ICRAF, 1992) and high mortality of transplanted seedlings.

Comparison of the tree structure in farm lands in Nanyuki and Meru revealed that larger trees were found in Nanyuki than those of Meru. This could be explained by the fact that most of trees found in Nanyuki were the original trees that existed in the natural forests. This was confirnmed by farmers who reported that they had not uprooted the original *W. ugandensis* trees they had found in their farmlands. However, in Meru there were no original forest trees in the farms and that the *W. ugandensis* that was sampled in Meru farms had been planted by the farmers and hence the small size of the trees.

The second objective was to establish the relative abundance of plant species associated with potential natural vegetation types where *W. ugandensis* occurs.
Presence of different species of trees growing within the dry montane vegetation type may be attributed to the rainfall and altitudes' characteristics of dry montane forests as

well as soils and temperature (Woodward, 1997). The occurrence of such a large number of species associated with *W. ugandensis* suggests that competition for water, light and nutrients was high.

The third objective in this study was to to determine threats to *W. ugandensis* in Mt. Kenya forests. *W. ugandensis* is a valuable plant for humans, livestock and wildlife use hence the greatest threat to the species under study was human being. This threat is attributed to the high use of herbal products from such species for treating diseases for human and livestock use. The threats are actualized through breaking off twigs, branches and debarking for use in herbal medicine. Bark stripping was also highlighted by Wass (1995) in his book on Kenya's indigenous forests. Today many people are shifting away from over the counter medicine due their high cost and side effects to herbal remedies as reported by Canningham (1988), who stated that massive trade was in existence in South Africa for herbal medicine

5.2 CONCLUSIONS

1. In concludion the present study found that *W. ugandensis* exist in dry montane forests and that the population structure was mainly dependent on the amount of rainfall. However, generally, the changes observed in relation to soil parameters and altitude did not correlate with population structure. Changes in rainfall and corresponding changes in temperature, which are also linked to altitude variation, appeared to limit the distribution of *W. ugandensis* in Mt. Kenya. Soil phosphorus could also be limiting the growth of this species.

2. The study also found that there were twenty two prevalent plant species that closely associate with *W. ugandensis* in the dry montane forest.

3. Though the tree is exploited by human and wildlife, it has been able to adjust to wildlife impacts as opposed to human impacts. Human beings are the greatest threat to this species.

It was found that some farmers grow the plant in their farms. This will reduce the exploitation pressure of the species in the forest. The findings of this study are important for management and conservation of the remnants of *W. ugandensis* in the forest and farm lands.

5.3 RECOMMENDATIONS

5.3.1 Further research

1. Studies should be conducted to investigate the impacts of fruit flies on the propagation of *W. ugandensis*.
2. Further studies should be carried out on the availability of pollinators and their role in sustaining the population of *W. ugandensis* in protected forest areas.
3. An exhaustive investigation on the impact of soil on the distribution and population structure should be conducted.
4. A study on regeneration rate and survival of saplings.
5. Studies should be conducted to investigate on the role of fruit eating animals in the
6. dispersal of the species.

5.3.2 Conservation actions

1. Community groups should be supported in production of *W.ugandensis* seedlings from seeds to enhance conservation of those growing naturally in the forest.

2. Regeneration should be facilitated by reducing livestock grazing in the forests.

3. Replanting should be done in areas where the tree has been logged out.

4. Farmers should be encouraged to grow more trees in their farms.

5. People be trained on sustainable harvesting of the bark while preserving the tree.

6. Analysis the active ingradients of the different parts of the plant to reduce the reliance on tree bark. Usage of other plant parts other than the bark should be encouraged.

5.3.3 Policy interventions

1. There should be breeding of the species to make it shorter for ease of harvesting and faster growth. More factories for processing the products should be constructed to enhance easy marketing of the species' products.
2. Draw a national conservation and management plan for the species.Emphasis on government's input in enhancing tree planting by the inhabitants of Mt. Kenya area.
3. Due to the high demand of the species products, all *W. ugandensis* in the forest should be identified so that they are monitored by the Kenya Forest Service (KFS). Such areas should be restricted from public to encourage regeneration to occur.
4. The species should be declared an endangered species in Kenya and globally to facilitate its conservation and management.
5. Ban the exploitation of the species in the existing forest reserves.
6. Map out the distribution of *W. ugandensis* in the whole country to know where it is abundant for conservation and management.

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APPENDIX

Appendix 1

Summary of soil parameters, in different forests, rainfall amounts and altitudes with *W. ugandensis* sizes

Location	Alt.	Rain fall	pH	Total N	O.C	P	K	DBH	Height	Canopy
Kangaita	2080	72.9	7.33	0.18	1.76	10.3	2.08	25.8	12.7	5.1
	2171	74.6	6.84	0.16	1.62	25	2.62	18.76	11.7	3.8
Kahurura	2058	74.8	6.74	0.13	1.25	84	1.6	18.4	9.5	3.9
	2156	74.5	7.06	0.13	1.27	17.8	3.02	14.9	8.2	2.9
	2234	77.1	6.38	0.1	1.02	64	2.12	10.1	4.3	2.4
Ontulili	2155	71.3	6.43	0.14	1.36	73	1.57	25.7	15	4.3
	2254	72.8	6.69	0.15	1.52	62	1.61	15.5	10.1	3.5
Gathioro	2117	78.1	6.7	0.15	1.45	47	0.92	7.97	6.4	2.3
	2221	81.5	6.17	0.17	1.65	62	1.57	8.9	5.65	2.6

Appendix 2

Regeneration in different forests

Location	Altitude	Rainfall	pH	N	O. C	P	K	Saplings	Seedlings	Sprouts
Kangaita	2080	72.9	7.33	0.18	1.76	10.3	2.08	7	0	42
	2171	74.6	6.84	0.16	1.62	25	2.62	3	0	54
	2275	74.5	6.9	0.13	1.3	73	2.44	0	0	0
Kahurura	2058	74.8	6.74	0.13	1.25	84	1.6	11	0	0
	2156	74.5	7.06	0.13	1.27	17.8	3.02	8	0	0
	2234	77.1	6.38	0.1	1.02	64	2.12	0	0	0
Ontulili	2155	71.3	6.43	0.14	1.36	73	1.57	1	0	3
	2254	72.8	6.69	0.15	1.52	62	1.61	6	0	16
Gathioro	2117	78.1	6.7	0.15	1.45	47	0.92	13	0	0
	2221	81.5	6.17	0.17	1.65	62	1.57	8	2	0

Appendix 3

Correlation matrix of plant sizes and environmental factors

	Variables	**DBH**	**Canopy**	**Height**
A. Plant sizes	Dbh	1.00	.961**	.939**
	Canopy	.961**	1.00	.890**
	Height	.939**	.890**	1.00
B. Soil characteristics	pH	0.49	0.54	0.41
	Total nitrogen	0.28	0.44	0.39
	Organic carbon	0.28	0.44	0.40
	Phosphorus	-0.19	-0.22	-0.16
	Potassium	0.23	0.14	0.11
	Sand	-0.32	-0.28	-0.43
	Silt	0.55	0.45	0.48
	Clay	-0.16	-0.07	0.05
C. Altitudinal gradient	Altitude	-0.45	-0.49	-0.36
D. Climatic factor	Rainfall	-.840**	-.750*	-.835**

Appendix 4

Raw data of mature *Warburgia ugandensis* in the forest

Transect	Rainfall	Alt.	Number	DBH(cm)	Height(m)	Canopy(m)
Kangaita	72.875	2080	1	24.84	12	4
Kangaita	72.875	2080	0	3.82	4	1
Kangaita	72.875	2080	0	9.87	2	1.5
Kangaita	72.875	2080	1	22.61	13	5
Kangaita	72.875	2080	0	0.00	0	0
Kangaita	72.875	2080	0	0.00	0	0
Kangaita	72.875	2080	1	39.81	20	5.5
Kangaita	72.875	2080	1	13.06	10	3.5
Kangaita	72.875	2080	1	15.92	11	4.5

Kangaita	72.875	2080	1	65.92	15	11
Kangaita	72.875	2080	1	15.92	15	3
Kangaita	72.875	2080	1	39.49	30	6
Kangaita	72.875	2080	0	0.00	0	0
Kangaita	72.875	2080	1	24.20	12	5.5
Kangaita	72.875	2080	0	0.00	0	0
Kangaita	72.875	2080	1	63.69	30	12.5
Kangaita	72.875	2080	1	0.00	7.4	3.5
Kangaita	74.583	2171	1	13.06	10	2.5
Kangaita	74.583	2171	1	17.83	10	5.5
Kangaita	74.583	2171	1	7.32	5	0.75
Kangaita	74.583	2171	1	4.14	3.5	0.5
Kangaita	74.583	2171	0	0.00	0	0
Kangaita	74.583	2171	0	0.00	0	0
Kangaita	74.583	2171	1	10.19	6	1
Kangaita	74.583	2171	0	0.00	0	0
Kangaita	74.583	2171	0	0.00	0	0
Kangaita	74.583	2171	1	20.06	15	3.5
Kangaita	74.583	2171	0	0.00	0	0
Kangaita	74.583	2171	1	29.62	15	6
Kangaita	74.583	2171	1	22.61	13	3.5
Kangaita	74.583	2171	1	29.94	17	3.5
Kangaita	74.583	2171	1	17.52	11	3
Kangaita	74.583	2171	1	22.93	12	4
Kangaita	74.583	2171	1	22.61	16	5.5
Kangaita	74.583	2171	1	14.97	12	2.5
Kangaita	74.583	2171	1	3.82	2.5	0.75
Kangaita	74.583	2171	1	23.09	14	6.5
Kangaita	74.583	2171	1	20.70	15	5.5
Kangaita	74.583	2171	1	26.75	15	4.5
Kangaita	74.583	2171	1	26.43	13	3.5
Kangaita	74.583	2171	1	28.03	18	6

Kangaita	74.583	2171	0	0.00	0	0
Kangaita	74.583	2171	0	0.00	0	0
Kangaita	74.583	2171	0	0.00	0	0
Kangaita	74.583	2171	1	18.47	15	2.5
Kangaita	74.583	2171	1	29.30	15	5.5
Kangaita	74.583	2171	1	21.50	15	5
Kangaita	74.583	2171	1	16.56	13	2.5
Kangaita	74.583	2171	1	11.62	10	2.5
Kangaita	74.583	2171	1	7.64	11	2
Kangaita	74.583	2171	1	39.17	16	8
Kangaita	74.583	2171	1	27.07	15	7.5
Kangaita	74.583	2171	1	20.70	14	5.5
Kangaita	74.583	2171	1	15.29	12	3.5
Kangaita	74.583	2171	1	3.18	3.5	0.75
Kangaita	74.583	2171	0	0.00	0	0
Kangaita	74.583	2171	1	15.29	12	4.5
Kangaita	74.583	2171	1	11.78	1.3	3.5
Kangaita	76.458	2275	1	17.20	15	3
Kangaita	76.458	2275	1	82.80	25	7.5
Kangaita	76.458	2275	0	0.00	0	0
Kahurura	74.75	2058	1	35.03	18	11.5
Kahurura	74.75	2058	1	22.61	13	7.5
Kahurura	74.75	2058	1	41.40	20	5.5
Kahurura	74.75	2058	1	40.13	21	5
Kahurura	74.75	2058	1	4.00	4.4	1
Kahurura	74.75	2058	1	2.55	2.5	1
Kahurura	74.75	2058	1	7.64	5.5	1
Kahurura	74.75	2058	1	29.62	8	5.5
Kahurura	74.75	2058	0	0.00	0	0
Kahurura	74.75	2058	1	36.94	20	8.5
Kahurura	74.75	2058	1	4.36	3.26	1.5
Kahurura	74.75	2058	1	5.41	3.5	1

Kahurura	74.75	2058	0	0.00	0	0
Kahurura	74.75	2058	1	4.78	1.6	30
Kahurura	74.75	2058	0	0.00	0	0
Kahurura	74.75	2058	1	5.10	3	2
Kahurura	74.75	2058	0	0.00	0	0
Kahurura	74.479	2156	1	27.71	13	6.5
Kahurura	74.479	2156	1	15.29	7	3.5
Kahurura	74.479	2156	0	0.00	0	0
Kahurura	74.479	2156	0	0.00	0	0
Kahurura	74.479	2156	0	0.00	0	0
Kahurura	74.479	2156	1	19.27	12	4.5
Kahurura	74.479	2156	1	12.74	5	2.5
Kahurura	74.479	2156	1	20.70	13	5
Kahurura	74.479	2156	0	0.00	0	0
Kahurura	74.479	2156	0	0.00	0	0
Kahurura	74.479	2156	0	0.00	0	0
Kahurura	74.479	2156	1	5.41	5	1
Kahurura	74.479	2156	1	3.82	3	1
Kahurura	74.479	2156	0	0.00	0	0
Kahurura	74.479	2156	0	0.00	0	0
Kahurura	74.479	2156	0	0.00	0	0
Kahurura	74.479	2156	1	22.29	13	7
Kahurura	74.479	2156	1	12.10	13	5.5
Kahurura	74.479	2156	1	20.70	18	3.5
Kahurura	74.479	2156	1	21.02	14	3.5
Kahurura	74.479	2156	0	0.00	0	0
Kahurura	74.479	2156	1	9.55	1.5	1
Kahurura	74.479	2156	0	0.00	0	0
Kahurura	74.479	2156	0	0.00	0	0
Kahurura	74.479	2156	1	3.18	1.5	0.5
Kahurura	77.083	2234	1	15.92	1.7	1
Kahurura	77.083	2234	1	3.22	2.7	0.7

Kahurura	77.083	2234	1	8.92	3	1.5
Kahurura	77.083	2234	1	32.48	23	8
Ontulili	71.333	2155	1	25.48	13.5	5
Ontulili	71.333	2155	1	19.75	14	5.5
Ontulili	71.333	2155	1	28.03	15	5.5
Ontulili	71.333	2155	1	13.69	13	3
Ontulili	71.333	2155	1	17.83	12	3.5
Ontulili	71.333	2155	1	25.16	14.5	3
Ontulili	71.333	2155	1	16.56	11	2.5
Ontulili	71.333	2155	1	11.15	8	1
Ontulili	71.333	2155	1	12.42	7	1
Ontulili	71.333	2155	1	28.66	15	4.5
Ontulili	71.333	2155	1	17.36	17	6
Ontulili	71.333	2155	1	15.29	12	3.5
Ontulili	71.333	2155	1	23.89	18	6
Ontulili	71.333	2155	1	18.15	16	4
Ontulili	71.333	2155	0	0.00	0	0
Ontulili	71.333	2155	1	19.11	23.5	5.5
Ontulili	71.333	2155	1	19.75	20	5.5
Ontulili	71.333	2155	1	23.89	18	4.5
Ontulili	71.333	2155	1	23.41	20	5.5
Ontulili	71.333	2155	1	27.39	17.5	6
Ontulili	71.333	2155	1	11.78	15	4
Ontulili	71.333	2155	0	0.00	0	0
Ontulili	71.333	2155	1	16.24	11	2
Ontulili	71.333	2155	1	12.42	12	2.5
Ontulili	71.333	2155	0	0.00	0	0
Ontulili	71.333	2155	0	0.00	0	0
Ontulili	71.333	2155	1	32.80	18	6
Ontulili	71.333	2155	1	21.18	18	7.5
Ontulili	72.833	2254	1	25.80	12	5
Ontulili	72.833	2254	T	18.15	14	4.5

Ontulili	72.833	2254	0	0.00	0	0
Ontulili	72.833	2254	1	18.15	10	3.5
Ontulili	72.833	2254	0	0.00	0	0
Ontulili	72.833	2254	1	13.22	9	3.5
Ontulili	72.833	2254	1	24.84	15	4.5
Ontulili	72.833	2254	1	19.75	15	5
Ontulili	72.833	2254	1	10.19	15	2.5
Ontulili	72.833	2254	1	11.15	10	4.5
Ontulili	72.833	2254	1	19.11	13	4.5
Ontulili	72.833	2254	0	0.00	0	0
Ontulili	72.833	2254	0	0.00	0	0
Ontulili	72.833	2254	0	0.00	0	0
Ontulili	72.833	2254	1	4.87	3.03	1.37
Ontulili	72.833	2254	1	7.32	5	2
Ontulili	72.833	2254	0	0.00	0	0
Ontulili	72.833	2254	1	22.29	15.5	6
Ontulili	72.833	2254	1	11.15	7	3
Ontulili	72.833	2254	1	3.25	2.4	0.8
Ontulili	72.833	2254	1	26.75	13	5
Ontulili	72.833	2254	1	19.43	14	5.6
Ontulili	72.833	2254	1	11.46	2.5	1
Ontulili	72.833	2254	1	8.60	3	1
Ontulili	72.833	2254	1	20.70	15	4.5
Gathioro(caves)		2017	0	0	0	0
Gathioro(caves)		2017	0	0	0	0
Gathioro(caves)		2017	0	0	0	0
Gathioro(caves)		2017	0	0	0	0
Gathioru forest (caves)	78.083	2117	1	2.87	2	1
Gathioru forest (caves)	78.083	2117	1	1.59	1.8	0.75
Gathioru forest	78.083	2117	1	3.50	3	1

(caves)						
Gathioru forest (caves)	78.083	2117	1	3.18	2	0.5
Gathioru forest (caves)	78.083	2117	1	3.82	4	2.5
Gathioru forest (caves)	78.083	2117	1	2.55	2	1
Gathioru forest (caves)	78.083	2117	1	2.55	2	1
Gathioru forest (caves)	78.083	2117	1	2.87	2	0.75
Gathioru forest (caves)	78.083	2117	1	6.85	6	2
Gathioru forest (caves)	78.083	2117	1	4.14	2	1
Gathioru forest (caves)	78.083	2117	1	7.32	4	1.25
Gathioru forest (caves)	78.083	2117	1	10.67	12	2.5
Gathioru forest (caves)	78.083	2117	1	12.42	8	3
Gathioru forest (caves)	78.083	2117	1	5.41	6	2
Gathioru forest (caves)	78.083	2117	1	4.14	3.5	2.5
Gathioru forest (caves)	78.083	2117	0	0.00	0	0
Gathioru forest (caves)	78.083	2117	1	7.64	2.5	3
Gathioru forest (caves)	78.083	2117	1	6.05	12	2.5
Gathioru forest	78.083	2117	1	3.82	2	1

(caves)						
Gathioru forest (caves)	78.083	2117	1	15.61	14	3.5
Gathioru forest (caves)	78.083	2117	1	4.78	5	1.5
Gathioru forest (caves)	78.083	2117	1	10.19	20	6.5
Gathioru forest (caves)	78.083	2117	1	16.88	20	6.5
Gathioru forest (caves)	78.083	2117	1	29.94	23	9
Gathioru forest (caves)	78.083	2117	1	17.68	15	5.5
Gathioru forest (caves)	78.083	2117	1	10.51	6	1.5
Gathioru forest (caves)	78.083	2117	1	7.01	4	1.25
Gathioru forest (caves)	78.083	2117	1	4.46	4	1.25
Gathioru forest (caves)	78.083	2117	1	7.96	3.5	2
Gathioru forest (caves)	78.083	2117	0	0.00	0	0
Gathioru forest (caves)	78.083	2117	1	2.01	1.8	0.46
Gathioru forest (caves)	78.083	2117	1	13.69	4	2.5
Gathioru forest (caves)	78.083	2117	1	15.29	3	2
Gathioru(njoguini)	81.458	2221	1	11.15	10	5.5
Gathioru(njoguini)	81.458	2221	1	39.33	20	11.5
Gathioru(njoguini)	81.458	2221	1	2.55	2	0.5

Gathioru(njoguini)	81.458	2221	0	0.00	0	0
Gathioru(njoguini)	81.458	2221	1	6.69	3	2.5
Gathioru(njoguini)	81.458	2221	1	3.18	2.5	2
Gathioru(njoguini)	81.458	2221	0	0.00	0	0
Gathioru(njoguini)	81.458	2221	1	7.64	4.5	0.5
Gathioru(njoguini)	81.458	2221	0	0.00	0	0
Gathioru(njoguini)	81.458	2221	1	7.64	4.5	0.5
Gathioru(njoguini)	81.458	2221	1	4.46	5	1
Gathioru(njoguini)	81.458	2221	0	0.00	0	0
Gathioru(njoguini)	81.458	2221	1	2.55	2	0.5
Gathioru(njoguini)	81.458	2221	0	0.00	0	0
Gathioru(njoguini)	81.458	2221	1	3.41	3	1.5
Meru	150.58	1761	1	3.18	2	1

Appendix 5

Regeneration of *Warburgia ugandensis* in the forests

Study area	Average monthly rainfall	Altitude	Height(m)	No.of: saplings	Seedlings	Sprouts
Kangaita	72.875	2080	2.4	0	0	12
Kangaita	72.875	2080	1.4	4	0	0
Kangaita	72.875	2080	1	3	0	0
Kangaita	72.875	2080	2	0	0	20
Kangaita	72.875	2080	0.5	0	0	1
Kangaita	72.875	2080	1.5	0	0	3
Kangaita	72.875	2080	2.5	0	0	1
Kangaita	72.875	2080	2.7	0	0	3
Kangaita	72.875	2080	3.5	0	0	2
Kangaita	74.583	2171	0.6	1	0	0
Kangaita	74.583	2171	1	1	0	0
Kangaita	74.583	2171	0.30	1	0	0
Kangaita	74.583	2171	0.45	0	0	20

Kangaita	74.583	2171	1.3	0	0	16
Kangaita	74.583	2171	1.4	0	0	10
Kangaita	74.583	2171	2.8	0	0	8
Kangaita	76.458	2275	0	0	0	0
Kangaita	76.458	2275	0	0	0	0
Kangaita	76.458	2275	0	0	0	0
Kangaita	74.75	2275	0	0	0	0
Kahurura	74.75	2058	1.4	1	0	0
Kahurura	74.75	2058	1.2	1	0	0
Kahurura	74.75	2058	1.3	1	0	0
Kahurura	74.75	2058	1.2	5	0	0
Kahurura	74.75	2058	1.3	3	0	0
Kahurura	74.479	2156	0.6	1	0	0
Kahurura	74.479	2156	1	1	0	0
Kahurura	74.479	2156	1.3	1	0	0
Kahurura	74.479	2156	1.2	3	0	0
Kahurura	74.479	2156	0.9	1	0	0
Kahurura	74.479	2156	1.45	1	0	0
Kahurura	77.083	2234	0	0	0	0
Kahurura	77.083	2234	0	0	0	0
Kahurura	77.083	2234	0	0	0	0
Kahurura	77.083	2234	0	0	0	0
Ontulili	71.333	2155	1	0	0	1
Ontulili	71.333	2155	1.5	0	0	2
Ontulili	71.333	2155	0.8	1	0	0
Ontulili	71.333	2155	0	0	0	0
Ontulili	71.333	2155	0	0	0	0
Ontulili	72.833	2254	0	0	0	0
Ontulili	72.833	2254	1.5	0	0	15
Ontulili	72.833	2254	1.3	0	0	1
Ontulili	72.833	2254	1.5	1	0	0
Ontulili	72.833	2254	1.5	3	0	0
Gathioro(caves)		2017	0	0	0	0
Gathioro(caves)		2017	0	0	0	0
Gathioro(caves)		2017	0	0	0	0

Gathioro(caves)		2017	0	0	0	0
Gathioro(caves)	78.083	2117	1.2	1	0	0
Gathioro(caves)	78.083	2117	1.4	1	0	0
Gathioro(caves)	78.083	2117	0	0	0	0
Gathioro(caves)	78.083	2117	0.6	1	0	0
Gathioro(caves)	78.083	2117	1.5	1	0	0
Gathioro(caves)	78.083	2117	0.72	1	0	0
Gathioro(caves)	78.083	2117	1	1	0	0
Gathioro(caves)	78.083	2117	1.3	1	0	0
Gathioro(caves)	78.083	2117	0.3	1	0	0
Gathioro(caves)	78.083	2117	1.5	1	0	0
Gathioro(caves)	78.083	2117	0.2	0	1	0
Gathioro(caves)	78.083	2117	0.6	1	0	0
Gathioro(caves)	78.083	2117	1.45	1	0	0
Gathioro(caves)	78.083	2117	0.8	1	0	0
Gathioro(caves)	78.083	2117	0.18	1	0	0
Gathioro(caves)	78.083	2117	0.2	0	1	0
Gathioro(njoguini)	81.458	2221	0.6	1	0	0
Gathioro(njoguini)	81.458	2221	1.3	1	0	0
Gathioro(njoguini)	81.458	2221	0.24	2	0	0
Gathioro(njoguini)	81.458	2221	1	1	0	0
Gathioro(njoguini)	81.458	2221	0	0	0	0
Gathioro(njoguini)	81.458	2221	1	1	0	0
Gathioro(njoguini)	81.458	2221	1.5	2	0	0

Appendix 6

Anthropogenic impacts on *W. ugandensis* in forests

Transect	Rainfall	Alt	Plot	Stumps	Debarked	Cause Human	Animal	Broken branches Human	Elephant	L /stock	Uprooted by elephants
Kangaita	72.875	2080	1	0	1	1	0	0	0	0	0
Kangaita	72.875	2080	1	1	0	0	0	1	0	0	0
Kangaita	72.875	2080	1	0	0	0	0	0	1	0	0
Kangaita	72.875	2080	2	0	1	1	0	0	0	0	0
Kangaita	72.875	2080	2	1	0	0	0	0	1	0	0
Kangaita	72.875	2080	2	1	1	0	1	0	0	0	0

Kangaita	72.875	2080	2	0	1	1	0	0	0	0	0
Kangaita	72.875	2080	2	0	0	0	0	1	0	0	0
Kangaita	72.875	2080	3	0	0	0	0	0	0	0	0
Kangaita	72.875	2080	3	0	1	1	0	1	0	0	0
Kangaita	72.875	2080	3	0	1	1	0	0	0	0	0
Kangaita	72.875	2080	4	0	1	1	0	0	0	0	0
Kangaita	72.875	2080	4	1	0	0	0	0	0	0	0
Kangaita	72.875	2080	4	0	1	1	0	1	0	0	0
Kangaita	72.875	2080	4	1	0	0	0	1	0	0	0
Kangaita	72.875	2080	4	0	1	1	0	0	0	0	0
Kangaita	72.875	2080	4	0	1	1	0	0	0	0	0
Kangaita	74.583	2171	1	0	1	1	0	0	0	0	0
Kangaita	74.583	2171	1	0	1	1	0	0	0	0	0
Kangaita	74.583	2171	1	0	0	0	0	1	0	0	0
Kangaita	74.583	2171	1	0	0	0	0	1	0	0	0
Kangaita	74.583	2171	1	1	0	0	0	1	0	0	0
Kangaita	74.583	2171	1	1	0	0	0	1	0	0	0
Kangaita	74.583	2171	1	0	0	0	0	0	0	0	0
Kangaita	74.583	2171	1	1	0	0	0	0	0	0	0
Kangaita	74.583	2171	1	1	0	0	0	0	0	0	0
Kangaita	74.583	2171	1	0	1	1	0	0	0	0	0
Kangaita	74.583	2171	1	1	0	0	0	0	0	0	0
Kangaita	74.583	2171	1	0	0	0	0	1	0	0	0
Kangaita	74.583	2171	1	0	1	1	0	0	0	0	0
Kangaita	74.583	2171	1	0	0	0	0	0	0	0	0
Kangaita	74.583	2171	1	0	0	0	0	0	0	0	0
Kangaita	74.583	2171	1	0	0	0	0	0	0	0	0
Kangaita	74.583	2171	1	0	1	1	0	0	0	0	0
Kangaita	74.583	2171	2	0	0	0	0	1	0	0	0
Kangaita	74.583	2171	2	0	0	0	0	1	0	0	0
Kangaita	74.583	2171	2	0	1	1	0	0	0	0	0
Kangaita	74.583	2171	2	0	0	0	0	0	1	0	0
Kangaita	74.583	2171	2	0	1	1	0	0	1	0	0
Kangaita	74.583	2171	2	0	1	1	0	0	0	0	0
Kangaita	74.583	2171	3	0	1	1	0	0	0	0	0
Kangaita	74.583	2171	3	1	0	0	0	0	0	0	0
Kangaita	74.583	2171	3	1	0	0	0	0	0	0	0
Kangaita	74.583	2171	3	1	0	0	0	0	0	0	0
Kangaita	74.583	2171	3	0	0	0	0	0	1	0	0
Kangaita	74.583	2171	3	0	0	0	0	0	0	0	0
Kangaita	74.583	2171	3	0	0	0	0	0	0	0	0
Kangaita	74.583	2171	3	0	0	0	0	0	0	0	0
Kangaita	74.583	2171	3	0	1	1	0	1	0	0	0
Kangaita	74.583	2171	3	0	0	0	0	0	0	0	0
Kangaita	74.583	2171	4	0	1	1	0	0	0	0	0

Kangaita	74.583	2171	4	0	0	0	0	0	0	0	0
Kangaita	74.583	2171	4	0	0	0	0	0	0	0	0
Kangaita	74.583	2171	4	0	0	0	0	0	0	0	0
Kangaita	74.583	2171	4	0	0	0	0	0	0	0	0
Kangaita	74.583	2171	4	1	0	0	0	0	0	0	0
Kangaita	74.583	2171	4	0	0	0	0	0	0	0	0
Kangaita	74.583	2171	4	0	0	0	0	0	0	0	0
Kangaita	76.458	2275	4	0	1	1	0	1	0	0	0
Kangaita	76.458	2275	4	0	1	1	0	0	1	0	0
Kangaita	76.458	2275	4	1	0	0	0	0	1	0	0
Kahurura	74.75	2058	1	0	1	1	0	1	0	0	0
Kahurura	74.75	2058		0	1	1	0	0	0	0	0
Kahurura	74.75	2058	2	0	1	1	0	0	0	0	0
Kahurura	74.75	2058	2	0	1	1	0	0	0	0	0
Kahurura	74.75	2058	1	0	0	0	0	1	0	0	0
Kahurura	74.75	2058	2	0	0	0	0	1	0	0	0
Kahurura	74.75	2058	2	0	0	0	0	1	0	0	0
Kahurura	74.75	2058	3	0	1	1	0	1	0	0	0
Kahurura	74.75	2058	3	1	0	0	0	0	0	0	0
Kahurura	74.75	2058	3	0	1	1	0	1	0	0	0
Kahurura	74.75	2058	3	0	1	1	0	1	0	0	0
Kahurura	74.75	2058	4	0	0	0	0	0	0	0	0
Kahurura	74.75	2058	4	1	0	0	0	0	0	0	0
Kahurura	74.75	2058	4	0	0	0	0	0	0	0	0
Kahurura	74.75	2058	4	1	0	0	0	0	0	0	0
Kahurura	74.75	2058	4	0	0	0	0	1	0	0	0
Kahurura	74.75	2058	4	1	0	0	0	0	0	0	0
Kahurura	74.479	2156	1	0	1	1	0	0	0	0	0
Kahurura	74.479	2156	1	0	1	1	0	0	0	0	0
Kahurura	74.479	2156	1	1	0	0	0	0	0	0	0
Kahurura	74.479	2156	1	1	0	0	0	0	0	0	0
Kahurura	74.479	2156	1	1	0	0	0	0	0	0	0
Kahurura	74.479	2156	1	0	1	1	0	1	0	0	0
Kahurura	74.479	2156	1	0	1	1	0	0	0	0	0
Kahurura	74.479	2156	2	0	0	0	0	1	0	0	0
Kahurura	74.479	2156	2	1	0	0	0	0	0	0	0
Kahurura	74.479	2156	2	1	0	0	0	0	0	0	0
Kahurura	74.479	2156	2	1	0	0	0	0	0	0	0
Kahurura	74.479	2156	2	0	0	0	0	1	0	0	0
Kahurura	74.479	2156	2	0	0	0	0	1	0	0	0
Kahurura	74.479	2156	2	1	0	0	0	0	0	0	0
Kahurura	74.479	2156	2	1	0	0	0	0	0	0	0
Kahurura	74.479	2156	2	1	0	0	0	0	0	0	0
Kahurura	74.479	2156	2	0	0	0	0	1	0	0	0
Kahurura	74.479	2156	2	0	0	0	0	1	0	0	0

Kahurura	74.479	2156	2	0	0	0	0	1	0	0	0
Kahurura	74.479	2156	2	0	1	1	0	0	0	1	0
Kahurura	74.479	2156	2	1	0	0	0	0	0	0	0
Kahurura	74.479	2156	2	0	0	0	0	0	0	1	0
Kahurura	74.479	2156	2	1	0	0	0	0	0	0	0
Kahurura	74.479	2156	2	1	0	0	0	0	0	0	0
Kahurura	74.479	2156	2	0	0	0	0	0	0	1	0
Kahurura	77.083	2234	1	0	0	0	0	0	0	0	0
Kahurura	77.083	2234	1	0	0	0	0	0	0	0	0
Kahurura	77.083	2234	3	0	1	0	1	0	0	0	0
Kahurura	77.083	2234	4	0	1	1	0	0	0	0	0
Ontulili	71.333	2155	1	0	1	1	0	0	0	0	0
Ontulili	71.333	2155	1	0	0	0	0	0	0	0	0
Ontulili	71.333	2155	1	0	1	1	0	1	0	0	0
Ontulili	71.333	2155	1	0	0	0	0	0	0	0	1
Ontulili	71.333	2155	1	0	0	0	0	1	0	0	0
Ontulili	71.333	2155	2	0	1	1	0	0	0	0	0
Ontulili	71.333	2155	2	0	1	1	0	1	0	0	0
Ontulili	71.333	2155	2	0	0	0	0	0	0	0	0
Ontulili	71.333	2155	2	0	0	0	0	1	0	0	0
Ontulili	71.333	2155	2	0	1	1	0	0	0	0	0
Ontulili	71.333	2155	2	0	1	1	0	1	0	0	0
Ontulili	71.333	2155	2	0	1	1	0	1	0	0	0
Ontulili	71.333	2155	2	0	1	1	0	0	0	0	0
Ontulili	71.333	2155	2	0	0	0	0	0	0	0	0
Ontulili	71.333	2155	2	1	0	0	0	1	0	0	0
Ontulili	71.333	2155	3	0	1	1	0	0	0	0	0
Ontulili	71.333	2155	3	0	1	1	0	1	0	0	0
Ontulili	71.333	2155	3	0	1	1	0	1	0	0	0
Ontulili	71.333	2155	3	0	1	1	0	0	0	0	0
Ontulili	71.333	2155	3	0	1	1	0	1	0	0	0
Ontulili	71.333	2155	3	0	0	0	0	0	0	0	1
Ontulili	71.333	2155	3	1	0	0	0	0	0	0	1
Ontulili	71.333	2155	4	0	1	1	0	0	0	0	1
Ontulili	71.333	2155	4	0	0	0	0	0	0	0	1
Ontulili	71.333	2155	4	1	0	0	0	0	0	0	0
Ontulili	71.333	2155	4	1	0	0	0	0	0	0	0
Ontulili	71.333	2155	4	0	1	1	0	0	0	0	0
Ontulili	71.333	2155	4	0	1	1	0	1	0	0	0
Ontulili	72.833	2254	1	0	1	1	0	0	0	0	0
Ontulili	72.833	2254	1	0	1	1	0	0	0	0	0
Ontulili	72.833	2254	1	1	0	0	0	1	0	0	0
Ontulili	72.833	2254	1	0	1	1	0	0	0	0	0
Ontulili	72.833	2254	1	1	0	0	0	1	0	0	0
Ontulili	72.833	2254	2	0	0	0	0	0	0	0	0

Ontulili	72.833	2254	2	0	1	1	0	0	0	0	0
Ontulili	72.833	2254	2	0	1	1	0	1	0	0	0
Ontulili	72.833	2254	2	0	0	0	0	0	0	0	1
Ontulili	72.833	2254	2	0	1	1	0	0	0	0	1
Ontulili	72.833	2254	2	0	1	1	0	0	0	0	1
Ontulili	72.833	2254	2	1	0	0	0	0	0	0	1
Ontulili	72.833	2254	2	1	0	0	0	1	0	0	0
Ontulili	72.833	2254	2	1	0	0	0	1	0	0	0
Ontulili	72.833	2254	2	0	0	0	0	0	0	0	0
Ontulili	72.833	2254	3	0	0	0	0	0	0	0	0
Ontulili	72.833	2254	3	1	0	0	0	1	0	0	0
Ontulili	72.833	2254	3	0	1	1	0	1	0	0	0
Ontulili	72.833	2254	3	0	0	0	0	0	0	0	1
Ontulili	72.833	2254	3	0	0	0	0	0	0	0	0
Ontulili	72.833	2254	4	0	1	1	0	1	0	0	1
Ontulili	72.833	2254	4	0	0	0	0	1	0	0	1
Ontulili	72.833	2254	4	0	0	0	0	0	0	0	0
Ontulili	72.833	2254	4	0	0	0	0	0	0	0	0
Ontulili	72.833	2254	4	0	0	0	0	0	0	0	1
Gathioro(caves)		2017	1	0	0	0	0	0	0	0	0
Gathioro(caves)		2017	2	0	0	0	0	0	0	0	0
Gathioro(caves)		2017	3	0	0	0	0	0	0	0	0
Gathioro(caves)		2017	4	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	1	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	1	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	1	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	1	0	0	0	0	1	0	0	0
Gathioro(caves)	78.083	2117	1	0	0	0	0	1	0	0	0
Gathioro(caves)	78.083	2117	1	0	0	0	0	1	0	0	0
Gathioro(caves)	78.083	2117	1	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	1	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	1	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	1	0	0	0	0	0	1	0	0
Gathioro(caves)	78.083	2117	1	0	0	0	0	0	1	0	0
Gathioro(caves)	78.083	2117	2	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	2	0	1	0	1	1	0	0	0
Gathioro(caves)	78.083	2117	2	0	0	0	0	1	0	0	0
Gathioro(caves)	78.083	2117	2	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	2	1	0	0	0	1	0	0	0

Gathioro(caves)	78.083	2117	2	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	2	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	2	0	0	0	0	1	0	0	0
Gathioro(caves)	78.083	2117	2	0	0	0	0	0	1	0	0
Gathioro(caves)	78.083	2117	2	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	3	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	3	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	3	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	3	0	0	0	0	0	1	0	0
Gathioro(caves)	78.083	2117	3	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	3	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	3	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	3	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	4	1	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	4	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	4	0	0	0	0	0	0	0	0
Gathioro(caves)	78.083	2117	4	0	0	0	0	0	0	0	0
G. (Njoguini)	81.458	2221	1	0	0	0	0	0	0	0	0
G. (Njoguini)	81.458	2221	1	0	1	1	0	0	0	0	0
G. (Njoguini)	81.458	2221	1	0	0	0	0	0	0	0	0
G. (Njoguini)	81.458	2221	2	1	0	0	0	1	0	0	0
G. (Njoguini)	81.458	2221	2	0	0	0	0	0	0	0	0
G. (Njoguini)	81.458	2221	2	0	0	0	0	0	0	0	0
G. (Njoguini)	81.458	2221	2	1	0	0	0	0	0	0	0
G. (Njoguini)	81.458	2221	3	0	1	1	0	0	0	0	0
G. (Njoguini)	81.458	2221	3	1	0	0	0	1	0	0	0
G. (Njoguini)	81.458	2221	3	0	1	1	0	0	0	0	0
G. (Njoguini)	81.458	2221	3	0	0	0	0	0	0	0	0
G. (Njoguini)	81.458	2221	3	1	0	0	0	1	0	0	0
G. (Njoguini)	81.458	2221	4	0	0	0	0	1	0	0	0
G. (Njoguini)	81.458	2221	4	1	0	0	0	1	0	0	0
G. (Njoguini)	81.458	2221	4	0	0	0	0	0	0	0	0
meru staton forest	150.58	1761	1	0	0	0	0	1	0	0	0

Appendix 7

Species associated with dry montane PNV

7 (a) Ontulili forest

Vegetation type	Study area	Altitude	GPS reading	Species name	No. of trees in 25x25m
Dry montane	Ontulili	2165	N001.222E3710.349	*Podocarcus latifolius*	1
Dry montane	Ontulili	2165	N001.222E3710.349	*Calodendrum capense*	1
Dry montane	Ontulili	2168	N001.184E3710.351	*Calodendrum capense*	1
Dry montane	Ontulili	2166	N001.093E3710.214	*Podocarcus latifolius*	7
Dry montane	Ontulili	2166	N001.093E3710.214	*Calodendrum capense*	1
Dry montane	Ontulili	2165	N001.111E3710.196	*Calodendrum capense*	1
Dry montane	Ontulili	2240	N000.292E3710.717	*Podocarcus latifolius*	4
Dry montane	Ontulili	2240	N000.292E3710.717	*Olea africana*	1
Dry montane	Ontulili	2240	N000.292E3710.717	*Nuxia congesta (mwanda)*	1
Dry montane	Ontulili	2240	N000.292E3710.717	*Afrocrania volkensii* (muga nyoni)	1
Dry montane	Ontulili	2239	N000.294E3710.709	*Fever tree, Yellow-barked acacia* (murera)	1
Dry montane	Ontulili	2239	N000.294E3710.709	*Juniperus procera*	1
Dry montane	Ontulili	2239	N000.294E3710.709	*Olinia rochetiana*(muthangira)	1
Dry montane	Ontulili	2239	N000.294E3710.709	*Podocarcus latifolius*	1
Dry montane	Ontulili	2239	N000.294E3710.709	*Afrocrania volkensii* (muga nyoni)	1
Dry montane	Ontulili	2270	N000.329E3710.925	*Podocarcus latifolius*	1
Dry montane	Ontulili	2270	N000.329E3710.925	*Juniperus procera*	1
Dry montane	Ontulili	2270	N000.329E3710.925	*Olea africana*	1
Dry montane	Ontulili	2270	N000.329E3710.925	*Dovyalis abyssinica*(mukambura)	1
Dry montane	Ontulili	2267	N000.352E3710.899	*Podocarcus latifolius*	5
Dry montane	Ontulili	2267	N000.352E3710.899	*Juniperus procera*	1

7 (b) **Species associated with dry montane in Gathioro forest**

Vegetation type	Study area	Altitude	Species name	No.of trees in 25x25m
Dry montane	Gathioru forest(caves)	2137	*Olea africana*	7
Dry montane	Gathioru forest(caves)	2137	*Teclea simplicifolia*	7
Dry montane	Gathioru forest(caves)	2137	*Acokanthera schemperi*	2
Dry montane	Gathioru forest(caves)	2137	*Juniperous procera*	8
Dry montane	Gathioru forest(caves)	2137	*Mystroxylon aethiopica(mukawa)*	7
Dry montane	Gathioru forest(caves)	2137	*Dodonae anguistifolia (mirema ngigi)*	4
Dry montane	Gathioru forest(caves)	2136	*Calodendrum capense (chest nut)*	1
Dry montane	Gathioru forest(caves)	2136	*Olea africana*	10
Dry montane	Gathioru forest(caves)	2136	*Afrocrania volkensii (muga nyoni)*	2
Dry montane	Gathioru forest(caves)	2136	*Podocarcus latifolius*	2
Dry montane	Gathioru forest(caves)	2136	*Juniperus procera*	3
Dry montane	Gathioru forest(caves)	2109	*juniperous procera*	10
Dry montane	Gathioru forest(caves)	2109	*Teclea simplicifolia*	5
Dry montane	Gathioru forest(caves)	2109	*Olea africana*	4
Dry montane	Gathioru forest(caves)	2109	*Teclea simplicifolia*	5
Dry montane	Gathioru forest(caves)	2109	*Tarchonanthus camphoratus (murereshwa)*	10
Dry montane	Gathioru forest(caves)	2109	*Afrocrania volkensii (muga nyoni)*	2
Dry montane	Gathioro(njoguini)	2233	*Anthocleista grandiflora (E. cabbage)*	1
Dry montane	Gathioro(njoguini)	2233	*Teclea simplicifolia*	3
Dry montane	Gathioro(njoguini)	2216	*Afrocrania volkensii (muga nyoni)*	1
Dry montane	Gathioro(njoguini)	2216	*Mystroxylon aethiopica(mukawa)*	3
Dry montane	Gathioro(njoguini)	2216	*Euclea divinorum (mukinyei)*	4
Dry montane	Gathioro(njoguini)	2254	*Juniperus procera*	1
Dry montane	Gathioro(njoguini)	2254	*Podocarcus latifolius*	1
Dry montane	Gathioro(njoguini)	2264	*Juniperus procera*	1
Dry montane	Gathioro(njoguini)	2264	*Dodonae anguistifolia (mirema ngigi)*	4

7 (c) ¡Species associated with dry montane in Kahurura forest

Vegetation type	Study area	Altitude	Species name	No.of trees in 25x25m
Dry montane	kahurura	2518	*Euclea divinorum* (mukinyei)	4
Dry montane	kahurura	2519	*Mystroxylon aethiopica*(mukawa)	6
Dry montane	kahurura	2520	*Olinia rochetiana*(muthangira)	6
Dry montane	kahurura	2521	*Olea africana*	3
Dry montane	kahurura	2522	*Podocarcus latifolius*	5
Dry montane	kahurura	2523	*Juniperus procera*	6
Dry montane	kahurura	2524	*Podocarcus latifolius*	8
Dry montane	kahurura	2512	*Juniperus procera*	1
Dry montane	kahurura	2513	*Juniperus procera*	4
Dry montane	kahurura	2514	*Olinia rochetiana*(muthangira)	4
Dry montane	kahurura	2476	*Juniperus procera*	1
Dry montane	kahurura	2477	*Mystroxylon aethiopica*(mukawa)	4
Dry montane	kahurura	2478	*Olea africana*	3
Dry montane	kahurura	2479	*Blighia unijugata* (muthiama)	2
Dry montane	kahurura	2483	*Juniperus procera*	13
Dry montane	kahurura	2485	*Maytenus undata* (Muthuthi)	8
Dry montane	kahurura	2557	*Rhamnus staddo* (mukukurui)	1
Dry montane	kahurura	2558	*Halleria lucida*	1
Dry montane	kahurura	2559	*Olea africana*	1
Dry montane	kahurura	2560	*Juniperus procera*	6
Dry montane	kahurura	2561	*Teclea nobilis*	3
Dry montane	kahurura	2563	*Mystroxylon aethiopica*(mukawa)	10
Dry montane	kahurura	2565	*Vangueria infausta*	8
Dry montane	kahurura	2566	*Rhus natalensis (muthigio)*	7
Dry montane	kahurura	2567	*Afrocrania volkensii (muga nyoni)*	13
Dry montane	kahurura	2568	*Prunus africanamwiri*	8
Dry montane	kahurura	2555	*Olea africana*	1
Dry montane	kahurura	2558	*Olinia rochetiana*(muthangira)	18
Dry montane	kahurura	2548	*Euclea divinorum* (mukinyei)	12
Dry montane	kahurura	2550	*Podocarcus latifolius*	5
Dry montane	kahurura	2551	Olea africana	5

Dry montane	kahurura	2552	*Juniperus procera*	6
Dry montane	kahurura	2553	*Teclea nobilis*	3
Dry montane	kahurura	2549	*Mystroxylon aethiopica*(mukawa)	7
Dry montane	kahurura	2551	*Vangueria infausta*	8
Dry montane	kahurura	2552	*Rhus natalensis (muthigio)*	7
Dry montane	kahurura	2553	*Olea africana*	9
Dry montane	kahurura	2554	*Juniperus procera*	9
Dry montane	kahurura	2555	*Juniperus procera*	7
Dry montane	kahurura	2663	*Euclea divinorum* (mukinyei)	6
Dry montane	kahurura	2664	*Olinia rochetiana*(muthangira)	6
Dry montane	kahurura	2665	*Olinia rochetiana*(muthangira)	8
Dry montane	kahurura	2635	*Euclea divinorum* (mukinyei)	4
Dry montane	kahurura	2636	*Podocarcus latifolius*	6
Dry montane	kahurura	2637	*Mystroxylon aethiopica*(mukawa)	5
Dry montane	kahurura	2638	*Podocarcus latifolius*	8
Dry montane	kahurura	2643	*Olea africana*	1

7 (d) Species associated with dry montane in Kangaita forest

study area	altitude	***Species name***	No.of trees in 25x25m
Kangaita forest	2090	*Mystroxylon aethiopica*(mukawa)	4
Kangaita forest	2108	*Mystroxylon aethiopica*(mukawa)	3
Kangaita forest	2108	*Euclea divinorum* (mukinyei)	3
Kangaita forest	2086	*Crotom megalocarpus*	3
Kangaita forest	2086	*Juniperus procera*	2
Kangaita forest	2086	*Olinia rochetiana*(muthangira)	4
Kangaita forest	2086	*Euclea divinorum* (mukinyei)	2
Kangaita forest	2086	*Mystroxylon aethiopica*(mukawa)	5
Kangaita forest	2117	*Olea africana*	1
Kangaita forest	2117	*Celtis africana*	1
Kangaita forest	2117	*Olinia rochetiana*(muthangira)	3
Kangaita forest	2117	*Euclea divinorum* (mukinyei)	3

Kangaita forest	2117	*Mystroxylon aethiopica*(mukawa)	3
Kangaita forest	2117	*Schrebela alata*	2
Kangaita forest	2185	*Prunus africana*	3
Kangaita forest	2185	*Olea africana*	9
Kangaita forest	2185	*Afrocrania volkensii* (muga nyoni)	2
Kangaita forest	2185	*Juniperus procera*	5
Kangaita forest	2185	*Mystroxylon aethiopica*(mukawa)	4
Kangaita forest	2187	*Afrocrania volkensii* (muga nyoni)	5
Kangaita forest	2187	*Mystroxylon aethiopica*(mukawa)	6
Kangaita forest	2187	*Podocarpus latifolius*	2
Kangaita forest	2187	*Juniperus procera*	5
Kangaita forest	2187	*Cassipourea malosana* (mucarage)	2
Kangaita forest	2183	*Juniperus procera*	3
Kangaita forest	2183	*Mystroxylon aethiopica*(mukawa)	4
Kangaita forest	2183	*Euclea divinorum* (mukinyei)	2
Kangaita forest	2183	*Olea africana*	2
Kangaita forest	2184	*Afrocrania volkensii* (muga nyoni)	2
Kangaita forest	2184	*Mystroxylon aethiopica*(mukawa)	6
Kangaita forest	2184	*Juniperus procera*	7
Kangaita forest	2184	*Podocarpus latifolius*	2
Kangaita forest	2271	*Podocarpus latifolius*	10
Kangaita forest	2271	*Euclea divinorum* (mukinyei)	9
Kangaita forest	2271	*Ekerbergia capense*	4
Kangaita forest	2271	*Olea africana*	2
Kangaita forest	2271	*Mystroxylon aethiopica*(mukawa)	6
Kangaita forest	2271	*Olinia rochetiana*(muthangira)	3
Kangaita forest	2271	*Juniperas proceras*	2
Kangaita forest	2272	*Podocarpus latifolius*	6

Kangaita forest	2272	*Mystroxylon aethiopica*(mukawa)	12
Kangaita forest	2272	*Juniperus procera*	8
Kangaita forest	2272	*Olinia rochetiana*(muthangira)	7
Kangaita forest	2289	*Cassipourea malosana* (mucarage)	1
Kangaita forest	2289	*Olinia rochetiana*(muthangira)	1
Kangaita forest	2289	*Euclea divinorum* (mukinyei)	1
Kangaita forest	2289	*Mystroxylon aethiopica*(mukawa)	1
Kangaita forest	2289	*Podocarpus latifolius*	4
Kangaita forest	2289	*Olea africana*	2
Kangaita forest	2291	*Podocarpus latifolius*	2
Kangaita forest	2291	*Euclea divinorum* (mukinyei)	3
Kangaita forest	2291	*Afrocrania volkensii* (muga nyoni)	3
Kangaita forest	2291	*Mystroxylon aethiopica*(mukawa)	4
Kangaita forest	2291	*Juniperus procera*	6
Kangaita forest	2291	*Olea africana*	2