ASSESSMENT OF THE POPULATION STRUCTURE AND REGENERATION POTENTIAL OF *Ocotea usambarensis* IN RESPONSE TO RECENT SELECTIVE LOGGING ON THE SOUTHERN SLOPES OF MT. KILIMANJARO, TANZANIA

Stephen Bartholomew Moshy

A Dissertation Submitted in Partial Fulfillment of the Requirement for the Degree of Master of Science in Biodiversity and Ecosystem Management of the Nelson Mandela African Institution of Science and Technology

Arusha, Tanzania

January, 2025

ABSTRACT

East African Camphorwood (*Ocotea usambarensis*) population in montane forests of East Africa has been declining at alarming rates. The decline is attributed to the historical legal commercial harvesting of the species sanctioned by colonial governments and later on illegal selective logging due to its high timber value. *O. usambarensis* is a vital component of the Mt. Kilimanjaro catchment forest and plays an important role in its hydro-ecological functions, making its population worth conserving. This study assessed the population structure, relative abundance and regeneration status of *O. usambarensis* in its range areas with different historical logging intensity and along elevation gradient on the southern slopes of Mt. Kilimanjaro. The age structure varied along the elevation gradient and across different blocks with high and low logging intensities blocks. However, a healthy regeneration status of *O. usambarensis* was observed, with a higher density compared to other tree species, as indicated by a reverse *J*-shaped population structure. Relative abundance of *O. usambarensis* decreased with increased logging intensity and increased along the elevation gradient. Stem density and basal area of seedlings, saplings and adults were compared using Wilcoxon signed-rank test. The comparison between blocks with different historical logging intensity showed no significant difference; adults ($W = 67, p = 0.33$), saplings ($W = 101.50, p = 0.72$), and seedlings ($W = 102, p = 0.90$); however, adults stem density (stems ha^{-1}; $W = 41, p = 0.002$) and basal area (m^2 ha^{-1}; $W = 34, p = 0.001$) varied significantly along the elevation gradient. Moreover, I computed tree species Importance Value Index (IVI) in both blocks and along the elevation gradient. The IVI in both blocks and along the elevation gradient showed *O. usambarensis* is still the most important tree species with higher IVI compared to other tree species found in the study plots. The findings suggests that logging targets mainly adults which are located close to the park boundary. Thus, calling for more enforcement efforts in areas adjacent to park boundaries and participatory approaches towards sustainable management of the species in range areas. Also, more efforts should be put on supporting local communities to plant *O. usambarensis* and other timber trees in their village lands and farms in areas with favourable climate and at the required altitudes. This will help to reduce pressure in the protected forest resources.

DECLARATION

I, Stephen Bartholomew Moshy, do hereby declare to the Senate of the Nelson Mandela African In-stitution of Science and Technology that this dissertation is my original work and that it has neither been presented nor submitted for the award of degree in any University or Institu-tion.

Stephen Bartholomew Moshy Date

The above declaration is hereunder confirmed:

Dr. Francis Moyo Date

Prof. Linus Munishi Date

COPYRIGHT

CERTIFICATION

The undersigned certify that, they have read and hereby recommend for acceptance by the Senate of the Nelson Mandela African Institution of Science and Technology a dissertation titled *"Assessment of the population structure and regeneration potential of Ocotea usambarensis in response to recent selective logging on the southern slopes of Mt. Kilimanjaro in Tanzania"* in partial fulfilment of the requirements for the degree of Master of Science in Biodiversity and Ecosystem Management of the Nelson Mandela African Institution of Science and Technology.

Dr. Francis Moyo Date

Prof. Linus Munishi Date

ACKNOWLEDGEMENTS

I would like to sincerely thank the Almighty God for making all this possible, as through Him, all things are possible. Additionally, I extend my heartfelt gratitude and appreciation to my supervisors, Dr. Francis Moyo and Prof. Linus Munishi of the Nelson Mandela African Institution of Science and Technology, for their steadfast guidance and encouraging feedback, which made the completion of this research and the writing of this dissertation possible.

I am also deeply grateful to my employer, Tanzania National Parks (TANAPA), for granting me a study leave and for permitting this research to be conducted at Kilimanjaro National Park.

I would also like to extend my heartfelt thanks to my entire family for their tireless support, especially my lovely wife, Ms. Silvania I. Kullaya, for standing by my side throughout my journey of studies at the Nelson Mandela African Institution of Science and Technology.

DEDICATION

To my beloved wife, Ms. Silvania I. Kullaya, my lovely daughters, Ivana Stephen and Briana Stephen, and my dear sons, Ethan Stephen and Nathan Stephen—this is for you. May it inspire you to achieve greater things and excel in all your endeavors.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYSMBOLS

HLI	High Logging Intensity
LLI	Low Logging Intensity
LMF	Low Montane Forest
MMF	Middle Montane forest
IVI	Importance Value Index
DBH	Diameter at Breast Height
NTFPs	Non Timber Forest Products
EAMs	Eastern Arc Mountains
TANAPA	Tanzania National Parks
KINAPA	Kilimanjaro National Park
TAFORI	Tanzania Forestry Research Institute
TAWA	Tanzania Wildlife Management Authority
TAWIRI	Tanzania Wildlife Research Institute
TFS	Tanzania Forest Services Agency

CHAPTER ONE

INTRODUCTION

1.1 Background of the problem

Trees provide invaluable ecosystems services and products including food, timber, protection of fresh water systems, medicines and recreation for humans (Percy *et al.,* 2005), and habitats for other species (Mohammed, 2021; Percy *et al.,* 2005). Forests also play key role in flood regulation, soil erosion prevention, carbon sequestration and climate regulation (Percy *et al.,* 2005). In East Africa, Mount Kilimanjaro forest belt (Mt. Kilimanjaro) is a vital source of water and in Kenya and Tanzania (Lambrechts, 2002). About 59% of Mt. Kilimanjaro's area is covered by the forest belt which ranges from dry succulent forests on the mountain foothills (800 meters) to tropical montane rain forests (Hemp, 2006b). The forest belt is characterized by different vegetation zones including alpine, sub-alpine and forest zones.

Mount Kilimanjaro forest belt comprise of more than 900 plant species, and approximately 130 are tree species including *Xymalos monospora, O. usambarensis, Podocarpus latifolius, Ilex mitis* and *Rapanea melanophloeos* (Lambrechts, 2002). Despite the Mt. Kilimanjaro forest belt being among the most diverse habitat in the world, human activities has led to degradation and deforestation of forest belt (Morris, 2010). Selective logging for example, has been widely reported among the other ecosystem goods and services to communities living in East African region mainly major human exploitation of forest resources in the moist East Africa Mountains including the Mt. Kilimanjaro forest belt (Lambrechts, 2002). During colonial era, the Mt. Kilimanjaro forest belt was subjected to immense pressure of legal selective logging for commercial timber (Kleinschroth *et al.,* 2013). The legal harvesting of natural trees along the montane forest belt continued until 1984 when a presidential order was issued to ban all the harvesting activities within the forest belt (Agrawala *et al.,* 2003).

The *O. usambarensis* which is one of the dominant and key species in moist forests below 2500 m above sea level (Kleinschroth *et al.,* 2013; Willan, 1965) has remained a target for illicit loggers around Mt. Kilimanjaro (Richard *et al.,* 2014). An aerial survey conducted in 2002 revealed presence of about 2100 stumps of recently-logged *O. usambarensis* trees (Lambrechts, 2002). This illegal logging pressure compelled the Tanzanian government to therefore annex the Mt. Kilimanjaro forest belt to Kilimanjaro National Park in 2005 so as to reinforce its protection. Twenty years later, information about *O. usambarensis* population structure, relative abundance and regeneration status has never been systematically studied. The lack of information about population status of the Mt. Kilimanjaro's flagship forest tree species jeopardies effort to manage the forest belt as a source of water, tourists' attraction and for carbon sequestration and climate regulation.

Previous studies on Mount Kilimanjaro and other moist mountains in East Africa provide valuable insights into the regeneration dynamics of woody species like *O. usambarensis* in response to elevation and disturbance gradients. Kleinschroth *et al.* (2013) study in Mt. Kenya on *O. usambarensis* regeneration patterns following historical logging sheds light on its adaptability to disturbances. The research revealed that selective logging impacts both the population structure and regeneration of *O. usambarensis*. Despite the species' tolerance to shading, post-logging recovery is still influenced by additional factor such as soil compaction and root damage. Rutten *et al.* (2015) study on vegetation structure across different habitats on Mt. Kilimanjaro also contributes to our understanding of *O. usambarensis* regeneration under varied circumstances. Their findings showed that selective logging exerts long-lasting effects on forest structure and composition, particularly in terms of stem density. The study underscored the significance of considering factors beyond logging, such as elevation, human influence, and non-timber forest product (NTFP) harvesting, in comprehending forest dynamics.

The hypothesis examines the stability of the *O. usambarensis* population despite human disturbances, specifically logging. Historical logging serves as the first blocking criterion in this study, with elevation as the second criterion. Plots within the range of 1800 m to 2200 m are categorized as Low Montane Forest (LMF), while those between 2200 m and 2500 m are classified as Middle Montane Forest (MMF) (Hemp, 2006; Rutten *et al.,* 2015). To test the hypothesis, the present study focused on the following objectives: (a) Determining the stem density and basal area of *O. usambarensis* seedlings, saplings, and adult individuals across blocks with varying logging intensity and elevation gradients; (b) Comparing stem density, basal area of *O. usambarensis* between blocks with high and low logging intensity, as well as along the elevation gradient. The results from this study are essential for assessing the forest's health and its role in sustaining the mountain and other tropical forest ecosystems.

1.2 Statement of the problem

Various studies have reported poor regeneration of *O. usambarensis* in some moist forests in East Africa including Mt. Kenya (Kleinschroth *et al.,* 2013) and Chome Nature Reserve on the Eastern Arc Mountains (Richard *et al.,* 2014). Mount Kilimanjaro offers a wide range of both ecological functions and services yet its forest belt is degraded and affected by illegal selective logging of native trees mostly broadleaved species in the areas below 2500 meters on the western, southern and eastern slopes (Lambrechts, 2002). Stands of *O. usambarensis* forests which are the dominant species on the southern slopes of Mt. Kilimanjaro are highly targeted by illicit camphor loggers (Richard *et al.,* 2014). However, there is lack of empirical information about the regeneration status, population structure and abundance of *O. usambarensis* on the southern slopes of Mt Kilimanjaro. This lack of information hinders park authority to make informed decisions to protect the only remaining forest belt of *O. usambarensis* on the southern slopes of Mt. Kilimanjaro (Hemp, 2006b).

1.3 Rationale of the study

Forests play key role in ecosystems services and products like food, timber, protection of fresh water systems, medicines and recreation for humans. In addition, forests regulate floods, soil erosion, carbon sequestration and climate. Mount Kilimanjaro forest belt fosters provision of ecosystem goods such as water and services to communities living in East African region such as Kenya and Tanzania population (Lambrechts, 2002). Mount Kilimanjaro forest belt comprise of more than 900 plant species, and approximately 130 are tree species including *Xymalos monospora, O. usambarensis, Podocarpus latifolius, Ilex mitis and Rapanea melanophloeos* (Lambrechts, 2002). Despite the Mt. Kilimanjaro forest belt being among the most diverse habitat in the world, human activities has led to degradation and deforestation of forest belt (Morris, 2010). Selective logging for example, has been widely reported as major human exploitation of forest resources around Kilimanjaro forest belt (Lambrechts, 2002). The *O. usambarensis* which is one of the dominant and key species in moist forests below 2500 m above sea level (Kleinschroth *et al.,* 2013; Willan, 1965) has remained a target for illicit loggers around Mt. Kilimanjaro (Richard *et al.,* 2014). An aerial survey conducted in 2002 revealed presence of about 2100 stumps of recently-logged *O. usambarensis* trees (Lambrechts, 2002). This illegal logging pressure compelled the Tanzanian government to therefore annex the Mt. Kilimanjaro forest belt to Kilimanjaro National Park in 2005 so as to reinforce its protection.

Therefore, this study aimed to examine the stability of the *O. usambarensis* population despite human disturbances, specifically logging.

1.4 Research objectives

1.4.1 Main objective

The main objective of this study was to determine the effects of selective logging on the abundance and population structure of *O. usambarensis* on the southern slopes of Mt. Kilimanjaro.

1.4.2 Specific objectives

(i) To determine the population structure of *O. usambarensis* on the southern slopes of Mt. Kilimanjaro.

(ii) To determine the relative abundance of *O. usambarensis* on the southern slopes of Mt. Kilimanjaro.

(iii) To determine regeneration status of *O. usambarensis* on the southern slopes of Mt. Kilimanjaro.

1.5 Research questions

(i) What is the population structure of *O. usambarensis* on the southern slopes of Mt. Kilimanjaro.

(ii) What is the relative abundance of *O. usambarensis* on the southern slopes of Mt. Kilimanjaro.

(iii) What is the regeneration status of *O. usambarensis* on the southern slopes of Mt. Kilimanjaro.

1.6 Significance of the study

This study is going to provide a baseline on the status on population structure, relative abundance and regeneration status of *O. usambarensis* on the southern slopes of Mt. Kilimanjaro to provide empirical evidence that informs *O. usambarensis* conservation and management strategies on the slopes of Mt. Kilimanjaro.

1.7 Delineation of the study

This study focused on assessing the population structure, relative abundance and regeneration status of *O. usambarensis* on the southern slopes of Mt. Kilimanjaro to provide empirical evidence that informs *O. usambarensis* conservation and management strategies on the slopes of Mt. Kilimanjaro.

CHAPTER TWO

LITERATURE REVIEW

2.1 Tropical forests

Tropical forests are the main biodiversity reserves in the world (Bonnell *et al.,* 2011), yet subjected to a number of disturbances and exploitation which varies in intensity, frequency and duration (Chazdon, 2003). These disturbances range from natural to human induced. In 2000, about 60% of the global tropical forests were categorized as degraded forests with different classes depending on the level of degradation (Wright & Muller-landau, 2006). In Tanzania, tropical montane forests forms about 5% equivalent to about 1.7 million hectares of its highly precious ecosystems (Richard *et al.,* 2014) with Eastern Arc Mountains (EAMs) covering 50% of the said area. Because of their elevation, montane forests provide a wide range of species which are found within certain altitudinal range (Hall *et al.,* 2009). The Mt. Kilimanjaro is home to one of Tanzania's most significant tropical montane forests, straddling 101 008 hectares, which constitutes 5.94% of the country's total montane forest area. This forest zone supports approximately 900 species, with the entire mountain harboring a total of 2500 species (Lambrechts, 2002).

However, due to their rich biodiversity, tropical forests often attract exploitation from individuals living in their proximity (Woldie & Tadesse, 2020) as they can easily navigate to and from the forest unlike those living far away (Mushi *et al.,* 2020). The rapid human population growth in areas hosting tropical forest has led to a loss of about 8 to 12 million square kilometres of closed canopy forest worldwide by the year 1999 (Wright & Muller-landau, 2006). In 1990, the total tropical forest loss rate was about 50 000 to 120 000 km^2/year (Wright & Muller-landau, 2006). In 2000, 80% of the paleo ecological forest of the EAMs in Tanzania was lost due to illegal logging (timber and poles), fuel wood collection, encroachment for agriculture and forest fires (Richard *et al.,* 2014). The loss of forest cover lead to the alteration of local environment and conditions (Hall *et al.,* 2003), causing habitat fragmentation and degradation (Hall *et al.,* 2009) and consequently, poor tree species regeneration due to changes in the local ecological conditions required for their regeneration and establishment (Makana & Thomas, 2005).

A wide range of species extinction may be expected should this loss of tropical forests left unabated (Wright & Muller-landau, 2006). According to Pimm (1995), about half of the species that are unique to a habitat are predicted to go extinct as a direct result of loss of about 90% of suitable habitat for the species. The *O.usambarensis* for example, was once a dominant tree species on both the eastern and southern slopes of Mt. Kilimanjaro (Hemp, 2006b). However, overexploitation has led to the complete loss of all adult *O. usambarensis* on the eastern slopes (Hemp, 2006b), significantly affecting the species' natural regeneration (Maua *et al.,* 2020). Currently, the only remaining adult population of *O. usambarensis* on Mt. Kilimanjaro is found on the southern slopes (Hemp, 2006b).

2.2 The biology of *Ocotea usambarensis*

The *O. usambarensis* also known as East African Camphorwood or Mkulo in Tanzania, Maida in Uganda and Umutake in Rwanda belongs to the family Lauraceae (Richard, 2016). It is a large evergreen tree growing to about 35 m (exceptionally up to 45 m) tall with a branchless trunk of up to 20 m (Plate 1), with a growth of 4 feet or 1.3 m/year for the first five years (Willan, 1965). It is a slope and ridge top species as most of O. *usambarensis* forests are always found on sharp slopes (Hermansen, 1985). Moreover, in Mt. Kilimanjaro a growth rate of up to 3 feet yearly has been observed with girth growth of up to 1 feet in ten years when rainfall is about 60 inches/year (Willan, 1965). Deep and fertile soils with good drainage favors the flourishment of *O. usambarensis* (Okeyo, 2008).

Plate 1: Adult *O. usambarensis* showing crown (A) and bole (B) as observed during field survey January - February 2022

The leaves are opposite, elliptic to oval, 4-16 cm long and 2.5-9 cm wide, dark green above and pale below, with an entire border and an acuminate apex (sometimes alternating on stems with rapid growth) (Okeyo, 2008). The camphor scent is clearly detectable in the leaf. Unnoticeable greenish-yellow blooms cover the plant, and the fruit is a tiny drupe that is 1 cm long (Okeyo, 2008). It yields large number of fruits, but normally only once every five to seven years, particularly in what is known as mast year (Bussman, 2001). The fruits and seeds of *O. usambarensis* are commonly attacked by insects leading to low germination rates of about 45% and takes up to 90 days to germinate (Okeyo, 2008). This makes *O. usambarensis* to have a very difficult and rare sexual regeneration (Bussman, 2001). Also, *O. usambarensis* frequently produce root suckers which are consumed by big animals such as elephants (Bussman, 2001). The species however, have high rates of regeneration after logging/clear cutting through suckering (Plate 3B) and coppicing (Okeyo, 2008).

Plate 2: Coppices of *O. usambarensis* emerging from stumps as observed during field survey January - February 2022

Plate 3: Seedling (A) and root suckers (B) of *O. usambarensis* as observed during field survey January - February 2022

2.3 Distribution of *Ocotea usambarensis*

The *O. usambarensis* is native to Eastern and Southern African countries including Tanzania, Northern Malawi, Rwanda, Northern Zambia, Kenya, and Uganda (Fig. 1). It is one of the dominant tree species in most of montane forests (Kleinschroth *et al.,* 2013) with an average rainfall between 1200-2400 mm and 2-3 dry months (Okeyo, 2008). In Tanzania the largest population of *O. usambarensis* are found in Mt Kilimanjaro and Eastern Arc Mountains (EAMs) while very few exists in mountain areas of Mbulu (Richard, 2016).

Figure 1: Distribution of *O. usambarensis* in Eastern and South Africa (*shaded grey*) (Plant Resources of Tropical Africa [PROTA], 2012)

2.4 Uses of *Ocotea usambarensis*

Ocotea usambarensis, is a hardwood tree species which is over exploited because of its high quality timber (Bussmann & Lange, 2000) and its resistance to fungal damage (Rutten *et al.,* 2015a). The species is sometimes traded under the name "camphor", whereby mature trees are used for making sliced veneer window frames, shutters, furniture, joinery, paneling, doors, cabinet work, and car bodies (Hermansen, 1985). The young trees which are not attacked by heart rot are used to make plywood (Hermansen, 1985). The *O. usambarensis* is also utilized as flooring in residential houses and for making tools. It is also used for making pulpwood, boxes, crates, vats and ships (Okeyo, 2008). However, due to its strong camphor scent, the species is less ideal for draining boards or kitchen equipment. Traditionally, *O. usambarensis* roots and bark are used as medicine to treat swellings, boils, and wounds (Fischer *et al.,* 2008). Also the bark of roots, bole, and branches can be powdered to treat measles and whooping cough (Okeyo, 2008). Its roots juice that has been soaked in water is used to treat back pain and malaria (Fischer *et al.,* 2008). The bark powder can also be used to relive stomach discomfort and for enhancing appetite, additionally, it is used to make charcoal and as firewood.

2.5 Impacts of disturbances on the population of *Ocotea usambarensis*

The population of *O. usambarensis* along the forest belt of Mt Kilimanjaro has been shrinking as it has been a target by many loggers (Rutten *et al.,* 2015a). The gaps created as a result of logging are dominated by early successional tree species *Macaranga kilimandscharica* (Bussman, 2001) which in turn affects the natural regeneration and growth of *O. usambarensis* (Kleinschroth, 2011). Ecologically, recruitment and establishment of early successional tree species is higher in disturbed forests as the species profits from the conditions brought on by removal of the native species (Connell & Slatyer, 1977). It is anticipated that, after a considerable amount of time, the density of this early successional tree species would gradually decrease and be replaced by mid and late successional tree species (Richard, 2016) which may result into forest type change. Moreover, logging results into the reduction of forest cover and tree density by 20-40%, it also leads to accumulation of wood debris up to three times more compared to unlogged sites which increases the risks of wildfires outbreak (Gerwing, 2002). This study focused on selective illegal logging as the main disturbance with highlights on wildfire as these two types of disturbances complement one another, whereby logging sites are always susceptible to wildfires.

2.5.1 Illegal logging

Selective logging involves cutting of limited number of commercially valuable tree species and producing timber out of their logs (Asner *et al.,* 2005). It turns to be illegal when done in a reserve or any protected area without permission previously sworn and obtained from the responsible authority (Mohammed, 2021). Usually illegal logging poses threats to the existence of the forest as it is done without management plan and trees below accepted diameter are harvested (Piabuo *et al.,* 2021). Selective illegal logging is mainly done in poor or developing countries as many communities depends on it as a source of income (Hall *et al.,* 2003) since other options to grow economically are limited (Plouvier, 1998).

Mount Kilimanjaro has been exploited through both legal and illegal logging which has impacted the forest belt below 2500 m resulting to a loss of about 450 km^2 of the belt since 1929 (Hemp, 2006b). Logging in Mt. Kilimanjaro was and is still selective, targeting only some tree species of interest. *O. usambarensis* which is a dominant species on the southern and eastern slopes of the mountain is highly targeted (Rutten *et al.,* 2015b). As a result, *O. usambarensis* has been over-exploited and its population reduced immensely (Lambrechts, 2002) on the southern slopes while the eastern slopes have been left without any adult or mature

O. usambarensis (Hemp, 2006b). As a result of selective logging one third of the potential Ocotea forest area (about 110 km2) in Mt. Kilimanjaro has been depleted (Hemp, 2006b). Nonetheless, selective logging in Mt. Kilimanjaro did not only target *O. usambarensis*. Other tree species were also targeted and exploited by loggers. For instance, about 66.67% of the cedar forest which was dominated by *Juniperus procera* was logged out by 1980 (Hemp, 2006b).

2.5.2 Wild fire regimes

The incidences of wild fires on Mt. Kilimanjaro have increased as a result of climate change and changes of forest cover especially on the lower montane forests. In 1996 it was found that incidences of wild fires were high on disturbed forests mainly by illegal logging in the plots located below 1900 meters a.s.l (Wieser, 2007). Most of the fires were started by poachers and honey collectors inadvertently (Hemp, 2005). Logging plays an important role in the intensity and spread of wild fires within the forest belt (Cochrane & Schulze, 1999). It increases the amount of woody debris and fine fuels at the logging site. Consecutively, it leads to microclimate changes, decreased canopy cover, increased moisture deficits and wind speeds. All these impacts leads to an increased fuel-dry rates thus increasing fire susceptibility in those forest patches (Cochrane & Schulze, 1999). Otherwise, in rain forests wild fires are very rare or even new kind of natural disturbances (Lindenmayer *et al.,* 2009).

On Mt. Kilimanjaro, wildfires have resulted in a 15% loss of forest cover since 1976. This loss has subsequently allowed the flourishing of several other species (Hemp, 2005). For instance, Erica forest has increased from 32 km^2 in 1976 to 187 Km^2 in 2000 due to loss of previous forest cover (Hemp, 2005). But also it has led to severe loss of water which is estimated to be about 20 million cubic meters as a result of loss of fog reception (Hemp, 2005). Wild fires lead to change of forest structure and density of live stems while provide a room for establishment of pioneer tree species (Cochrane & Schulze, 1999) and other species which previously were not established in those areas. In 1996-1997 fire outbreak in Mt. Kilimanjaro's *Agauria-Ocotea* forests lead to proliferation of *Pteridium aquilinum* and covered about 80% of the forest floor by 1998 which had a coverage of about 1% before the fire outbreak (Plate 4) (Wieser, 2007).

Plate 4: **Areas previously disturbed by fire dominated by *Pteridium aquilinum* as observed during field survey January- February 2022**

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was conducted in the montane forest belt on the southern slope of Mt. Kilimanjaro, located in Northern Tanzania. The forest belt which was previously managed by forest division was annexed to Kilimanjaro National Park in 2005. The Mt. Kilimanjaro is found about 300 km south of the Equator just on the border between Tanzania and Kenya. It lies between latitude 2º45' and 3º25' South and longitude 37º00' and 37º43' East (Fig. 2) (Lambrechts, 2002). The area has a bimodal climate which is characterized by two rainy seasons annually: Long rains from March to June and short rains between November and December. The mountain's northern lee slopes receive significantly less annual rainfall when compared with the southern slopes. Moreover, the amount of rainfall also varies significantly along the elevation gradient leading to different ecological zones (Kikoti & Mligo, 2015). The area has experienced selective logging of *O. usambarensis* with different intensities on its southern slopes (Lambrechts, 2002).

It is an important source of water for both Tanzania and Kenya, a service rendered possible by high rainfalls and a widespread forest belt accounting for more than 96% of water originating from Mt. Kilimanjaro (Lambrechts, 2002). Being 1300 meters above sea level, the catchment forests receive about 1600 million m^3 of water per year, 95% of which comes from rainfall and 5% from fog interception (Agrawala *et al.,* 2003). About 500 million m^3 (30%) of water in these forests' percolates into underground water or into streams and rivers making Mount Kilimanjaro of higher hydrological value. It also plays important socio-economic roles in hydropower generation (Nyumba ya Mungu, Hale and Pangani falls) and irrigation agriculture among others (Agrawala *et al.,* 2003).

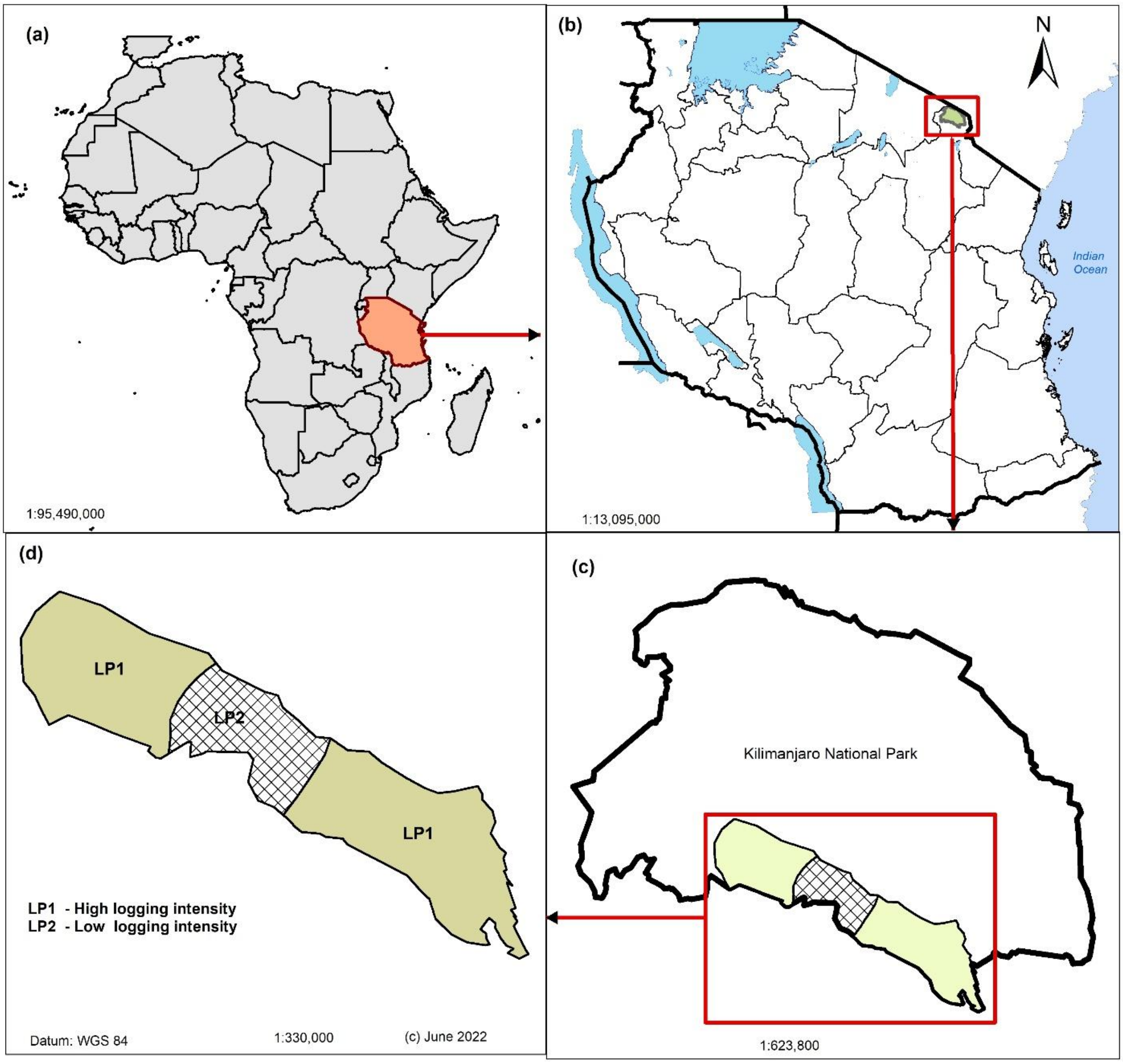

Figure 2: Map of the study area on the southern slopes of Mt. Kilimanjaro

3.2 Sampling strategy and assessment of population structure and relative abundance

The study area was divided into two blocks namely High Logging Intensity (HLI) and Low Logging Intensity (LLI) based on the aerial survey results by Lambrechts (2002). The blocks, were further divided into 143 grid cells with an area of 1 km^2 each. The study used Arc GIS/map software to randomly select 30 grids (Fig. 3).

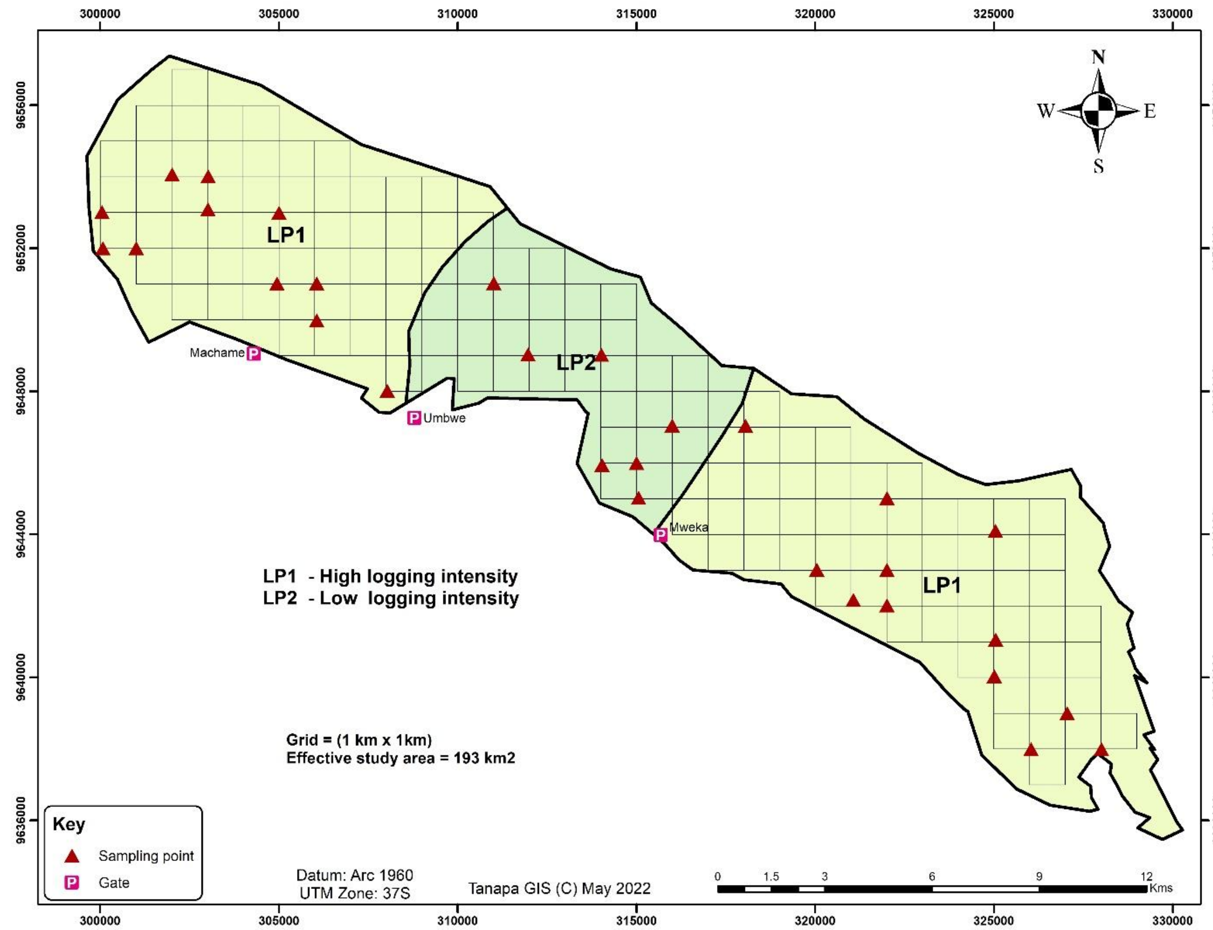

Figure 3: Effective study area and points where data were collected

Thereafter, a total of 90 concentric circular plots (24 plots in LLI block and 66 plots in HLI block) (Fig. 4), each with an area of 500 m^2, 25 m^2 and 1 m^2 were laid for adults, saplings and seedlings, respectively (Mueller-Dombois, 1974; Paudel & Mandal, 2019). Furthermore, sampling plots were grouped based on their location, whereby, those located between altitudes 1800 m and 2200 m were categorised as Low Montane Forest (LMF) totalling 48 plots while those above 2200 m to 2500 m were considered as Middle montane forest (MMF) totalling 42 plots (Hemp, 2006b; Rutten *et al.,* 2015b). In each plot, all trees were marked, enumerated, identified and their heights recorded accordingly.

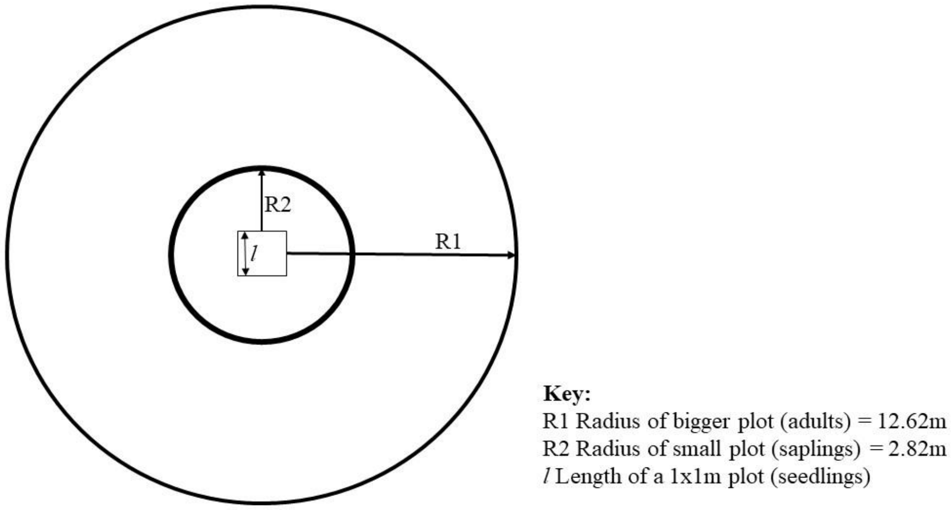

Figure 4: Sampling plot design (Pudel *et al.,* 2019; Mueller-Dombois, 1974)

Trees were categorised following Mwavu and Witkowski (2009) classification which assert that, seedlings are trees with diameter less than 2 cm and height less than 1m, saplings comprise trees with diameter between 2 and 10 cm and adult trees with Diameter at Breast Height (DBH) > 10 cm. The DBH for adult trees was measured at 1.3 m height of a stem from the ground (Plate 5) (Msalilwa *et al.,* 2020). For the purpose of this study, root suckers and coppices were all considered as seedlings given, they fit the above-mentioned criteria. The *O. usambarensis* has poor sexual reproduction, hence its propagation is mainly asexually from roots and stumps (Hermansen, 1985), therefore, the assessment of both sexual and asexual propagation provide clear picture of the species regeneration status.

Plate 5: **Field data collection and enumeration at Mt. Kilimnjaro forest January-February 2022**

3.3 Assessment of regeneration status of *Ocotea usambarensis*

The *O. usambarensis* regeneration status in each plot was assessed based on the relative density of seedlings, saplings and adults (Maua *et al.,* 2020). Regeneration status were categorized as follows: (a)"Good" if the number of seedlings are more or fewer than saplings but number of number of saplings are higher than adults; (b) "Fair" if the number of seedlings is greater than or equal to the number saplings and less or equal to the number of adults; (c) "Poor" if species exists only in sapling stage with no seedlings with the saplings number being less than or equal to the number of adults; (d) "None" or not regenerating, if it is absent both in sapling and seedling stages, but only found in adults; and (e) "New", if a species has no adults, but only saplings and/or seedling stages.

3.4 Diameter at breast height class distribution and age prediction

The individual tree stems were categorized into four (4) DBH classes: (a) 1= (1-10 cm), (b) 2= (>10-30) cm, (c) 3=(>30-60 cm), and (d) 4=(>60 cm). The categorization helped in identifying the differences in the age distribution of adults in the study area. Age prediction was done following Willan (1965) where it was indicated that *O. usambarensis* has a girth growth rate of approximately 30 cm (1ft) per ten years and a height growth rate of 90 cm per year. In each DBH class, both mean stem density (stems ha^{-1}) and basal area (m^2/ha) were computed (Table 1 & 2).

3.5 Data analysis

Density of seedlings, saplings and adult stems were calculated by dividing total number of stems by the sampled area (Equation 1). This was then converted to number of individuals in each plot per unit area of 1 ha (stems ha^{-1}) (Woldie & Tadesse, 2020). Then basal area and stem density were computed following Mohammed *et al.* (2021) (Equation 1, and 2). Also, the relative abundance, relative frequency, relative dominance and the important value index were computed following Maua (2020) (Equation 3, 4, 5 and 6).

$$\textbf{Stem density} = \frac{\textbf{Total number of stems}}{\textbf{Area sampled } (\mathbf{m^2})} \quad (1)$$

$$\textbf{Basal area} = \frac{\pi}{4}(\text{DBH})^2 \quad (2)$$

$$\textbf{Relative Abundance (RA)} = \frac{\textbf{Abundance of a species}}{\sum \textbf{All sampled species}} * \mathbf{100} \quad (3)$$

$$\textbf{Relative Frequency (RF)} = \frac{\textbf{Frequency of a species}}{\sum \textbf{All frequencies}} * \mathbf{100} \quad (4)$$

$$\textbf{Relative Dominance (RD)} = \frac{\textbf{Total basal area of a species}}{\sum \textbf{All basal area of all species}} * \mathbf{100} \quad (5)$$

The Importance Value Index (IVI) = RA + RF + RD (6)

Data for each growth stages were initially summarized using descriptive statistics, including means and standard errors. This preliminary summary was conducted using Microsoft Excel before proceeding with further analyses. To compare the mean stem densities and basal areas of seedlings, saplings, and adult trees between the two blocks (HLI & LLI) and along the elevation gradient (LMF & MMF), an unpaired two-sample Wilcoxon signed-rank test was conducted using R (version 4.0.3). Before conducting the Wilcoxon signed-rank test, a normality test was performed in R (version 4.0.3) using the Shapiro-Wilk test, following the approach outlined by Mohammed *et al.* (2021). The comparison of relative abundance was done using Origin Pro 2021 (9.80.200).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Population structure of *Ocotea usambarensis* on the southern slopes of Mt. Kilimanjaro

(i) Growth stages distribution of *O. usambarensis* in blocks with different historical logging intensities

Stem densities

Seedling density was higher in High logging Intensity (HLI) and Low logging Intensity (LLI) blocks as compared to other growth stages. However, the mean stem densities of all growth stages were higher in the LLI block than in the HLI block (Fig. 5).

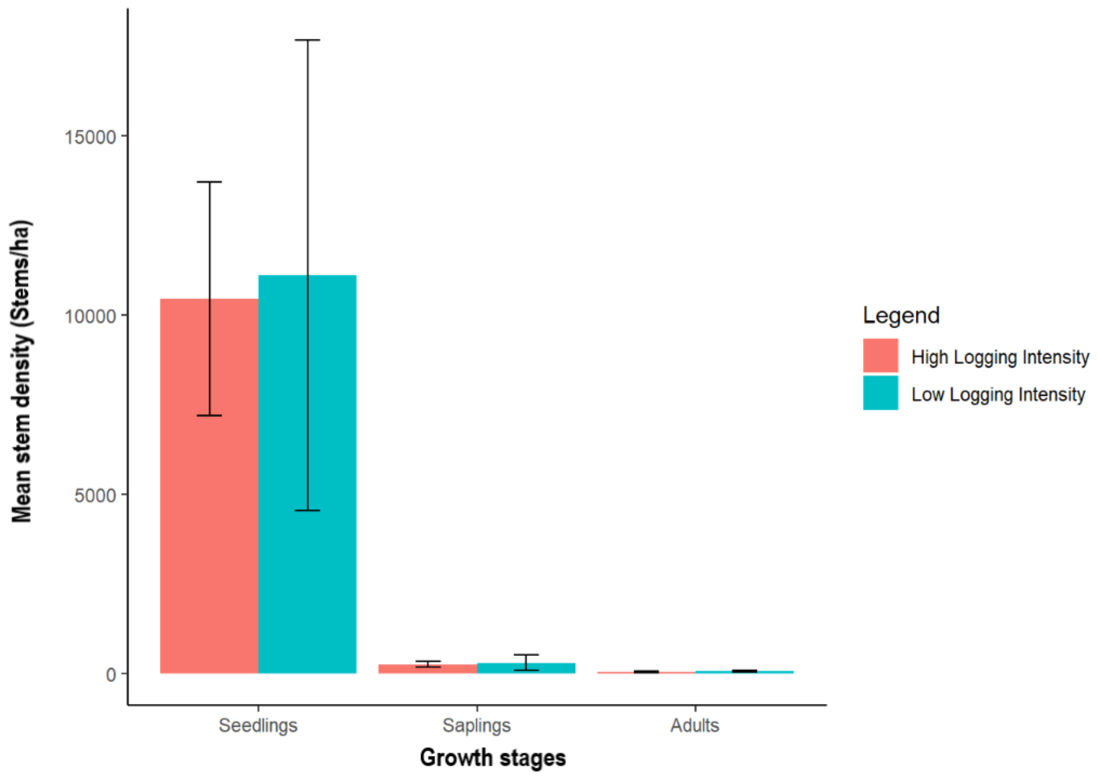

Figure 5: **Variation in the mean stem density (stems/ha) of seedlings, saplings and adults across different logging intensities**

The mean stem densities of adults, saplings and seedlings did not differ significantly between HLI and LLI (*W = 67, p = 0.33; W = 101.50, p = 0.72* and *W = 102, p = 0.90* respectively) (Fig. 6).

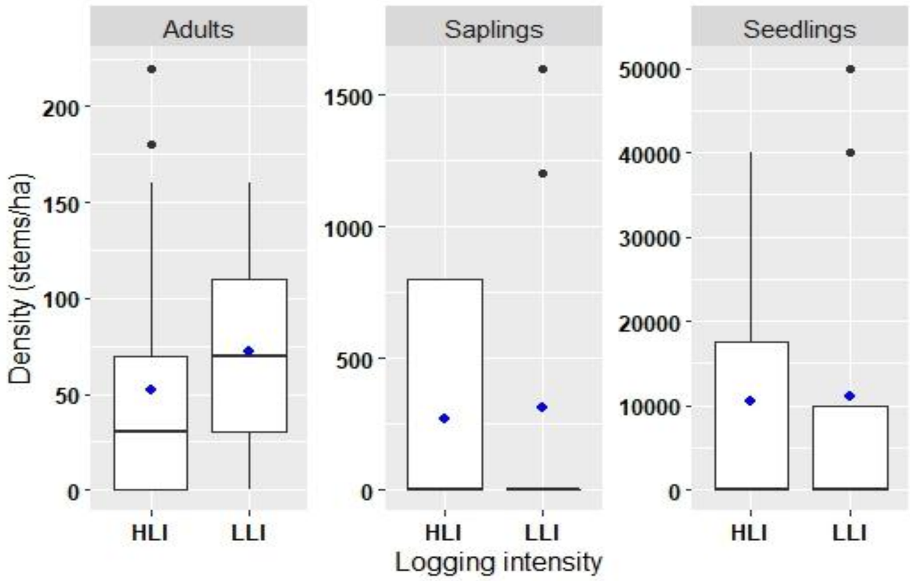

Figure 6: Boxplots showing mean stem densities (stems/ha) in both High and Low logging intensities blocks

Basal area

Basal area results showed that adult trees in the LLI block had higher mean basal area (21.1 m^2/ha) compared to HLI block (9.45 m^2/ha). However, the differences in mean basal area were not significant between the two logging intensities (Adults; *W=58, p = 0.16*; Saplings: *W= 103.5, p = 0.65*; Seedlings: *W = 102.50, p = 0.88*) (Fig. 7).

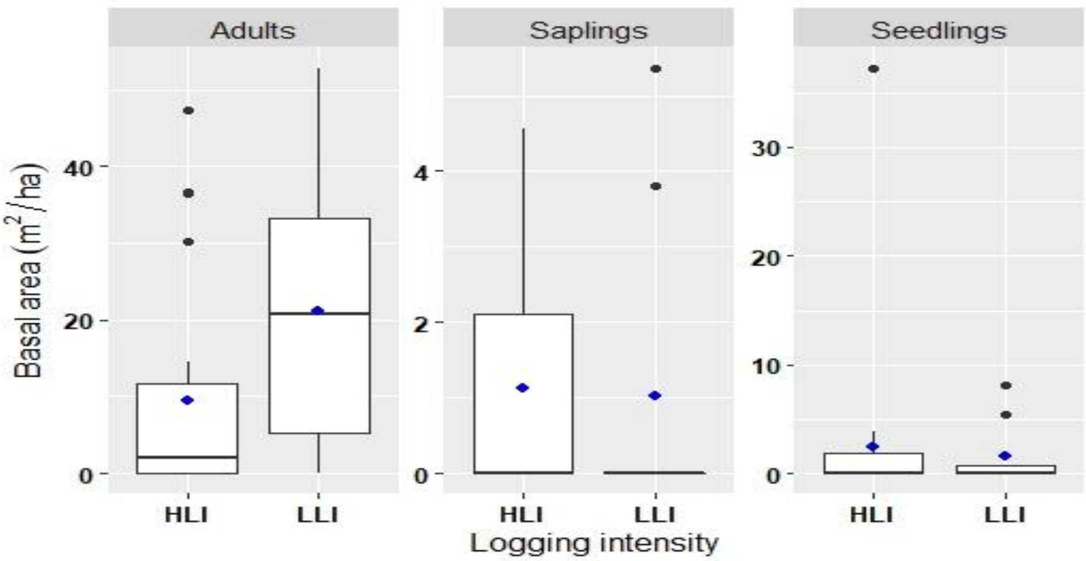

Figure 7: **Boxplots showing mean basal area (m^2h^{-1}) of the three live forms (adults, saplings and seedlings) between high and low logging intensity blocks**

Diameter at breast height class distribution and age prediction in blocks with different logging intensity

Stem density and basal area were analyzed across different diameter at breast height (DBH) classes under high and low logging intensities. The data reveal variations in both stem density (stems ha^{-1}) and basal area (m^2 ha^{-1}) (Table 1) across four DBH classes: (a) 1= (1-10 cm), (b) 2= (>10-30) cm, (c) 3=(>30-60 cm), and (d) 4=(>60 cm), with differences observed between blocks subjected to high versus low logging intensities.

Table 1: Stem density and basal area in relation to DBH classes along different logging intensities blocks

Blocks	Approximated age	High logging intensity		Low logging intensity	
DBH Classes	**Years**	**Density (stems ha^{-1})**	**Basal Area (m^2h^{-1})**	**Density (stems ha^{-1})**	**Basal Area (m^2h^{-1})**
1-10	3<	12 072.73	3.76	16 600	3.28
11-30	3-10	17.27	0.61	2.5	0.02
31-60	10-20	22.73	3.17	20	4.52
>60	>20	11.82	5.67	45	16.55

(ii) Growth stages distribution of *Ocotea usambarensis* across elevation gradient

Stem densities

The mean stem densities for all growth stages were found to be higher in the Middle montane forest (MMF) than in the Lower montane forest (LMF) with seedlings having the highest mean densities (Fig. 8). Only the adults mean stem density (stems ha-1) varied significantly along the elevation gradient (*W=41, p=0.002*). However, this was not the case for other growth stages, as the differences were not significant for saplings (*W = 99, p = 0.53*) and seedlings (*W = 111, p = 0.70*) (Fig. 9).

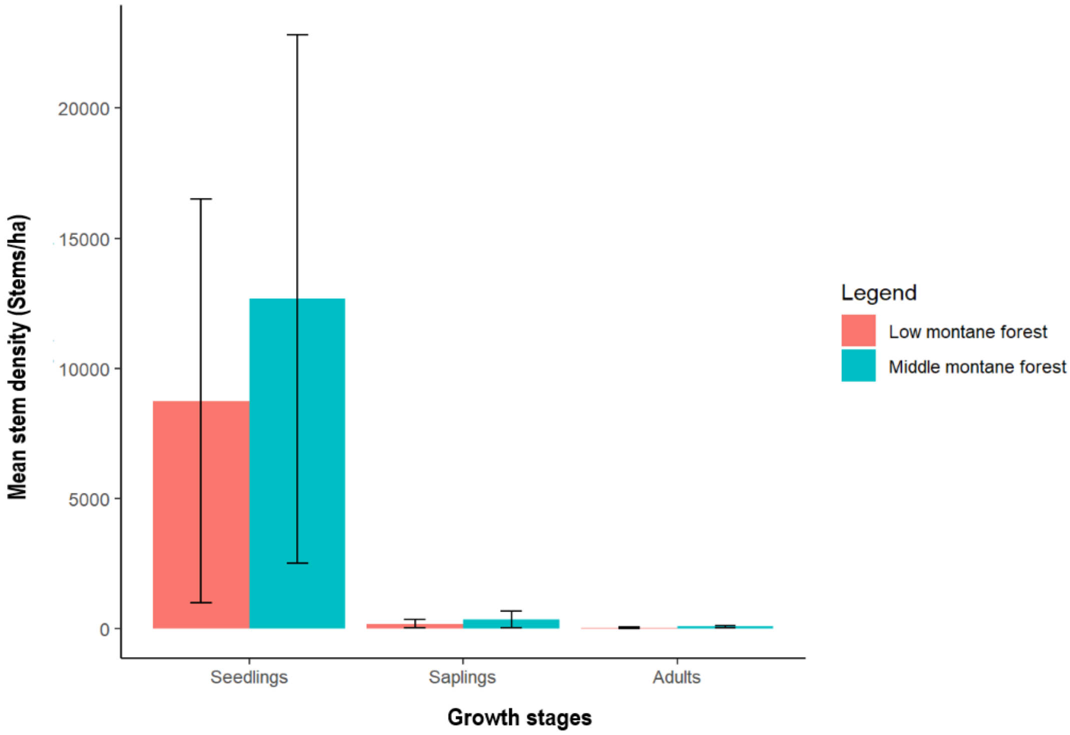

Figure 8: **Variation in the mean stem density (stems ha^{-1}) of seedlings, saplings and adults along the elevation gradient**

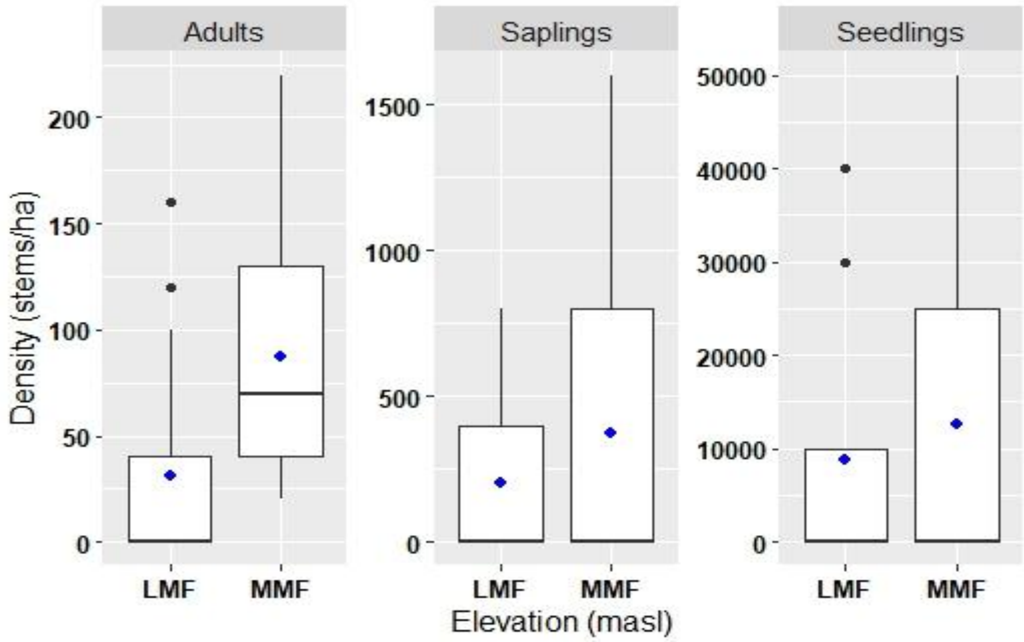

Figure 9: **Boxplots showing mean stem densities (stems ha^{-1}) in Middle montane forest (MMF) and Lower montane forest (LMF) zones**

Basal area

The mean basal area (m^2h^{-1}) for adults was higher in the MMF (19.63 m^2h^{-1}) as compared to LMF (6.37 m^2h^{-1}). Further, the mean basal area (m^2h^{-1}) for adults had a significant difference along the elevation gradient ($t = -2.41$, $P = 0.02$), while mean basal area (m^2h^{-1}) for seedlings

($t = -0.38$, $P = 0.71$) and saplings ($t = -0.97$, $P = 0.34$) did not vary significantly (Fig. 10).

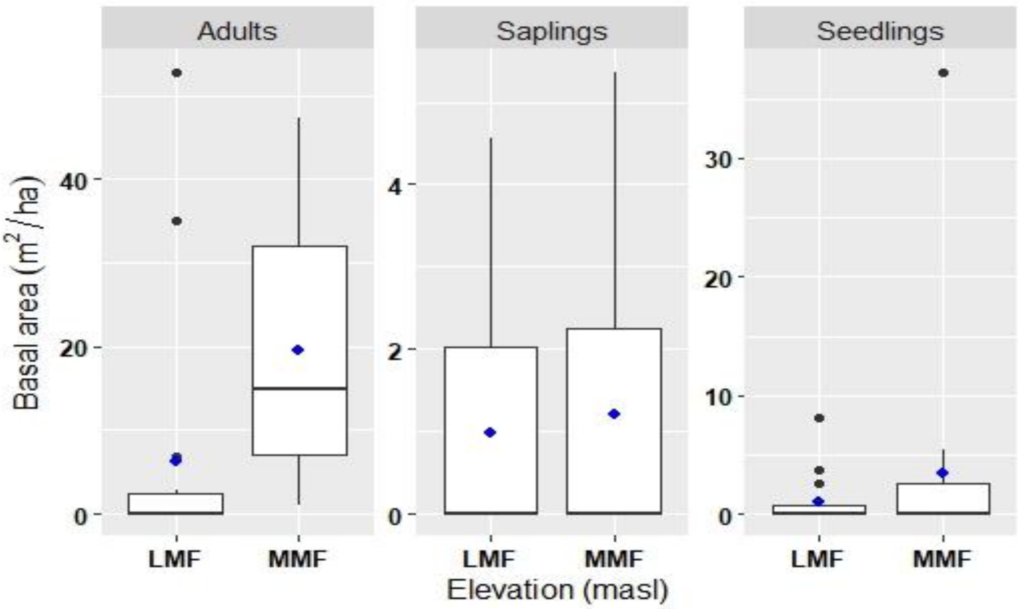

Figure 10: Boxplots showing mean basal area (m^2h^{-1}) in Middle montane forest (MMF) and Lower montane forest (LMF) zones for adults, saplings and seedlings

Diameter at breast height class distribution and age prediction along elevation gradient

The data show stem density and basal (Table 2) area across different DBH classes along elevation gradient, comparing Low Montane Forest (LMF) and Middle Montane Forest (MMF) sites. For each elevation zone, stem density (stems ha^{-1}) and basal area (m^2 ha^{-1}) are presented for four DBH classes: (a) 1= (1-10 cm), (b) 2= (>10-30) cm, (c) 3= (>30-60 cm), and (d) 4= (>60 cm), with corresponding approximate tree ages.

Table 2: Stem density and basal area in relation to DBH classes along elevation gradient

Elevation gradient	Approximated age	Lower montane forest (LMF)		Middle montane forest (MMF)	
DBH Classes	Years	Density (stems ha^{-1})	Basal Area (m^2h^{-1})	Density (stems ha^{-1})	Basal Area (m^2h^{-1})
1-10	3<	8950	2.02	18 228	5.47
11-30	3-10	11.25	0.13	15.71	0.82
31-60	10-20	5	0.82	44.29	6.63
>60	>20	15	5.42	27.14	12.18

4.1.2 Relative abundance of Ocotea usambarensis on the southern slopes of Mt. Kilimanjaro

(i) Relative abundance in blocks with different logging intensity

In both HLI and LLI blocks *O. usambarensis* had higher relative abundance 36% and 44% respectively (Fig. 11). Out of the 30 tree species observed in the study sites, *Macaranga kilimandscharica* was found to be the second most abundant species with higher abundance in HLI than in LLI.

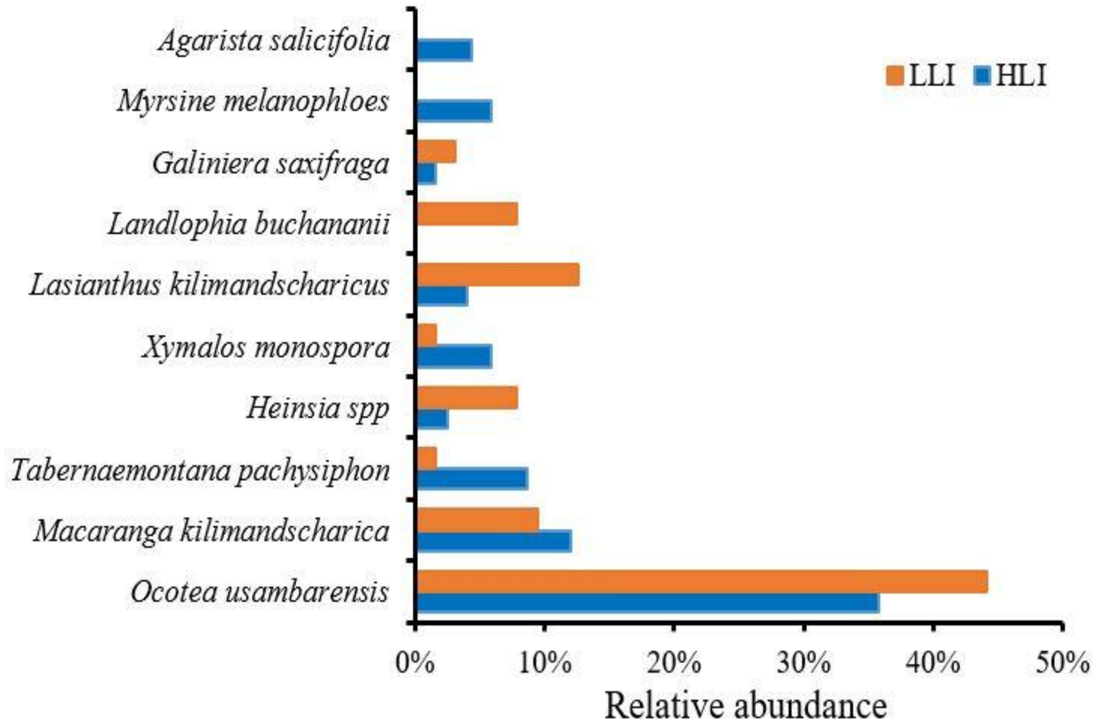

Figure 11: Relative abundancies of different species in blocks with different logging intensity

(ii) Relative abundance along elevation gradient

Along the elevation gradient *O. usambarensis* had significantly higher relative abundance on higher altitude (MMF) than in lower altitudes (LMF) *Macaranga kilimandscharica* and *Tabernaemontana pachysiphon* species were the next most abundant species with 21% and 12 % relative abundance respectively in the LMF and 0% in the MMF (Fig. 12).

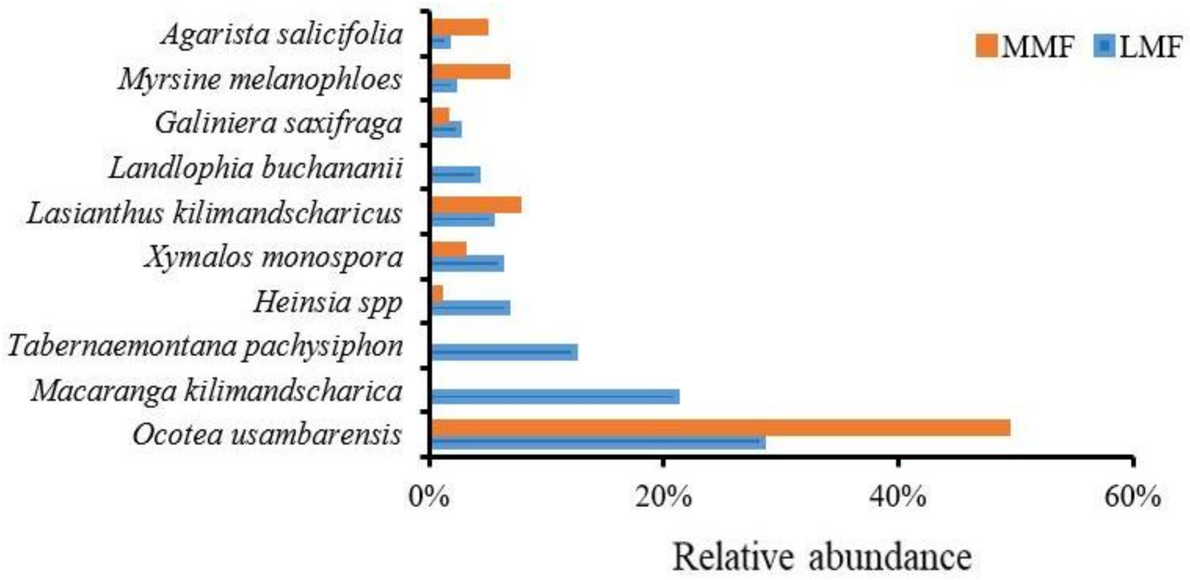

Figure 12: Relative abundance of *O. usambarensis* and other species along the elevation gradient

4.1.3 The Importance value index (IVI)

Both HLI and LLI blocks were dominated by *O. usambarensis* while LMF and MMF forests were dominated by *Macaranga kilimandscharica*. However, *Ocotea usambarensis, Macaranga kilimandscharica* were the most important species in both HLI and LLI (Appendix 3 and Appendix 4). This was also the same in MMF and LMF forests (Appendix 1 and Appendix 2).

4.1.4 Regeneration status of *O. usambarensis* on the southern slopes of Mt. Kilimanjaro

The HLI block showed better regeneration than LLI block. About 13% *O. usambarensis* showed fair and good regeneration while only 7% had fair regeneration and 3% had good regeneration in the LLI. Also, more *O. usambarensis* (17%) showed no regeneration in the LLI than in the HLI block (7%) (Fig. 13).

Along the elevation gradient, about 20% of *O. usambarensis* were not regenerating on the MMF while only 7% were observed in the LMF. Also, in the LMF, 3% of *O. usambarensis* showed a "new" regeneration status which was not the case in the MMF (0%) (Fig. 14).

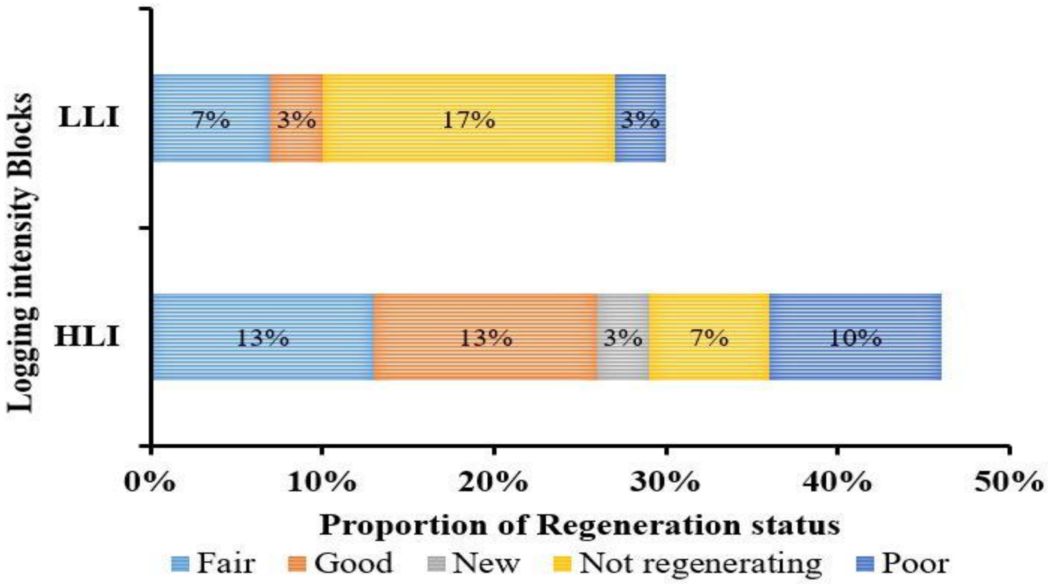

Figure 13: **Regeneration status of *O. usambarensis* in different logging intensities**

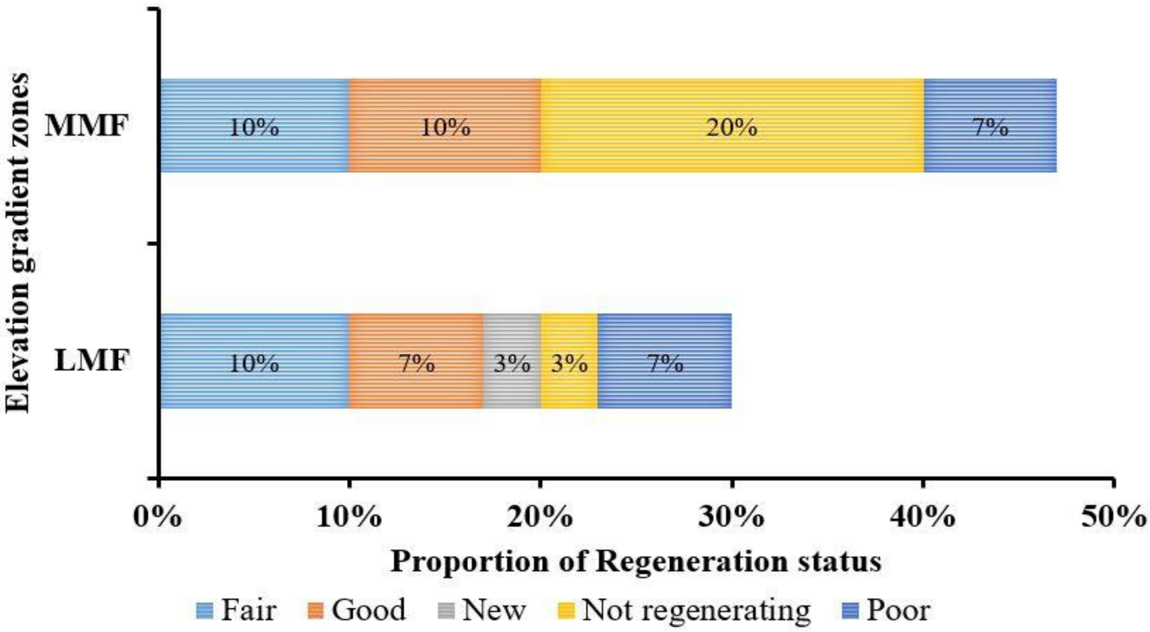

Figure 14: **Regeneration status of *O. usambarensis* along elevation gradient**

4.2 Discussion

4.2.1 Growth stages distribution of *Ocotea usambarensis* in blocks with different historical logging intensities

The growth stages within the blocks with different logging intensity histories exhibited minimal variation with a higher density of junior adults with DBH between 11-30 cm and 31-60 cm. The forest's recovery has been evident despite the logging disturbance, demonstrating a high potential for regeneration and increased recruitment. Under good bio-physical conditions, forest patches with moderate disturbance are expected to have higher regeneration potential a finding which was also observed in studies done by Koirala (2004) and Renner *et al.* (2022). Improved light penetration plays a key role in enhancing seed germination and the development of the understory (Renner *et al.,* 2022). The population structure of *O. usambarensis* was observed to be stable a finding which denotes that the logging impact to the Ocotea forest was not significant because *O. usambarensis* is a long-lived species. Also, in 2005, the Mt. Kilimanjaro forest belt was incorporated into Kilimanjaro National Park, resulting in improved enforcement of conservation laws and more effective protection of natural resources. A decrease in selective illegal logging cases in the Mt. Kilimanjaro forest belt was also reported by Rutten *et al.* (2015). It was observed a higher density of *O. usambarensis* trees 20 years old or younger, a finding which also suggests annexation of the Mt. Kilimanjaro forest belt (approximately 17 years of strict protection) has reduced illegal extraction of *O. usambarensis* thus allowing saplings of the species to grow further. However, more mature adults with DBH equal to or more than 60 cm were observed in blocks with lower logging intensity. This indicates that the block has reached a climax state, where recruitment is expected to be lower due to canopy cover hindering the growth of seedlings and saplings in the understory (Condit *et al.,* 2017).

Nonetheless, the study observed higher densities of *O. usambarensis* seedlings compared to its other growth stages across all study blocks. However, only a few saplings and adults were observed, indicating that very few seedlings survive to reach the adult stage. This could be due to the low survival rates of *O. usambarensis* seedlings, which face competition from the light-demanding pioneer species like *Macaranga kilimandscharica, Hagenia abyssinica,* and *Agarista salicifolia* (Bussman, 2001; Renner *et al.,* 2022). In particular, *Macaranga kilimandscharica*, as an early successional species, exhibits a growth rate 50% higher (Bussman, 2001) than that of *Ocotea usambarensis*, failing *Ocotea usambarensis* seedlings and saplings to survive due to limited/low light intensity (Koirala, 2004).

4.2.2 Growth stages distribution of *Ocotea usambarensis* along the elevation gradient

The mean stem density and basal area of adult *O. usambarensis* varied significantly between the plots found in lower and higher altitudes. This indicates that selective illegal logging decreases as the elevation increases, with more logging activity concentrated at lower altitudes. Similar findings were reported by Richard *et al.* (2014), who observed a higher presence of anthropogenic disturbances near or along the boundaries of forest reserves compared to higher altitudes located further away. Forest patches in proximity to human settlements are more susceptible to human exploitation, as illegal logging often serves as a primary source of income in many communities (Koirala, 2004; Richard *et al.,* 2014) and individuals can easily navigate to and from the forest, evading forest rangers. Lower altitudes also experience prolonged periods of drought and higher rainfall seasonality, which significantly affects soil moisture content. Soil moisture content is a crucial factor for the regeneration of woody species following anthropogenic disturbances (Renner *et al.,* 2022).

Further, a significant differences was noted among different (DBH) classes along the elevation gradient. The mean stem density of *O. usambarensis* with DBH classes 31-60 cm and greater than 60 cm was higher in the higher altitudes than in lower altitudes. This suggests that illegal logging in the Mt. Kilimanjaro forest belt primarily targets adult trees with a DBH exceeding 30 cm for timber production. Furthermore, there were no significant differences in stem densities for seedlings and saplings along the elevation gradient, indicating that the current logging practices specifically target adult *Ocotea usambarensis* trees.

4.2.3 Relative abundance in blocks with different logging intensity

Relative abundance of *O. usambarensis* observed in this study did not vary significantly between HLI and LLI blocks. However, the HLI had lower abundance compared to LLI block (Fig. 11). This suggests that as *O. usambarensis* were logged out in HLI and other successional species emerged and dominated the forest. Moreover, *Macaranga kilimandscharica,* an early successional tree species was the second most abundant species in HLI. This shows that most of the logged Ocotea forest have or will be dominated by this successional tree species such as *Macaranga kilimandscharica*. This observation is in line with researches that have found that *Macaranga kilimandscharica* usually dominates open forest patches when *O. usambarensis* has been logged out or died (Willan, 1965). In studies carried in disturbed forests sites elsewhere (Mohammed *et al.,* 2021), higher encroach-ability was also observed by successional tree species which had higher growth rates and best invasion properties like *Macaranga kilimandscharica*. However, the higher relative abundance of *O. usambarensis* in the LLI forest shows that the level of disturbances is low thus the Ocotea forest is still healthy and recuperating from disturbances. Interestingly, due to the little disturbance they faced successional tree species (*Macaranga kilimandscharica* and *Tabernaemontana pachysiphon*) relative abundancies were observed to be less than 10%.

4.2.4 Relative abundance along elevation gradient

The relative abundance of *O. usambarensis* exhibited significant variation between LMF and MMF, increasing along the elevation gradient. Notably, *O. usambarensis* emerged as the most abundant tree species observed in this study. Despite its dominance, early successional tree species were also prevalent in the LMF, with *Macaranga kilimandscharica* and *Tabernaemontana pachysiphon* contributing 12% and 21% relative abundance, respectively. These findings suggest distinct ecological dynamics along the elevation gradient, highlighting the interplay between dominant and early successional species in shaping forest composition. *Macaranga kilimandscharica and Tabernaemontana pachysiphon* were not found in any of the study plots in the MMF. This implies that lowland forests at lower altitudes are more prone to disturbances than those at higher altitudes (Koirala, 2004). This suggests that the communities living adjacent to the park may not have been adequately engaged in ongoing conservation activities and education. Therefore, increasing the level of involvement of local communities could help minimize disturbances in neighbouring forests.

Anthropogenic disturbances plays a key role in deterioration of forest tree species especially those located at the lowland sites or neighbouring villages (Mohammed *et al.,* 2021). A social economic survey conducted in the villages bordering Mt. Kilimanjaro also indicated that most of the communities depended on the forest as their source of Non Timber Forest Product (NTFP) such as fodder, fruits, firewood and medicinal plants (Mushi *et al.,* 2020) which impacts the abundance and biodiversity of that particular ecosystem (Ndangalasi *et al.,* 2006). In this study, it was observed that although the number of *O. usambarensis* seedlings were higher in most of the study plots, they were not surviving to a sapling and adult stage. These findings suggests that, despite having higher incidences of illegal logging in lower forests but also the chances of survival of seedlings and saplings is very low in those areas due to anthropogenic disturbances (Mushi *et al.,* 2020).

4.2.5 The Importance value index (IVI)

Assessing the composition and dynamics of forests requires an understanding of species dominance and ecological roles. This study investigated the dominance of tree species in the study plots using the Importance Value Index (IVI), a composite measure integrating species density, basal area, and frequency. Higher IVI values were likely attributed to the larger densities, basal areas, and frequencies of certain species, aligning with findings by Woldie and Tadesse (2020). Results revealed that *Ocotea usambarensis, Macaranga kilimandscharica,* *Rapanea/Myrsine melanophloes, Lasianthus kilimandscharicus,* and *Polyscias fulva* were the most important and dominant species in the HLI and LLI blocks, emphasizing their critical role in shaping forest structure and composition. However, *O. usambarensis* and *Macaranga kilimandscharica* had the highest IVI accounting to more than 70% of the cumulative IVI in both blocks. This may have been attributed by the logging which took place in those blocks. Nonetheless, *O. usambarensis* have the highest IVI in both HLI and LLI blocks, suggesting that the Ocotea forest is still existing and the disturbed parts are recovering.

However, intervention may be needed in the HLI since *Macaranga kilimandscharica* was observed to have higher IVI in the HLI block than in the LLI block (Appendix 3 and Appendix **4**4). This denotes that, if nothing is changed, there are chances that *O. usambarensis* forest will be replaced by *Macaranga kilimandscharica* in some years to come noting that *Macaranga kilimandscharica* has a higher growth rate (Bussman, 2001). On the other hand, in both LMF and MMF forest, *Macaranga kilimandscharica, O. usambarensis Rapanea/Myrsine melanophloes* and *Tabernaemontana pachysiphon* were the most important tree species (Appendix 1 and Appendix 2). In the MMF forest *O. usambarensis* had the highest IVI followed by *Macaranga kilimandscharica* while in the MMF both *Macaranga kilimandscharica* and *O. usambarensis* had similar IVI. This suggests that, densities, basal areas, and frequencies of both species are more or less the same. In this regard, the LMF forest is also changing and might as well be dominated by this successional species if the rate of disturbances is kept on growing with no intervention.

4.2.6 Regeneration status of *Ocotea usambarensis*

Regeneration dynamics are critical for the sustainability of forest ecosystems, as they determine the ability of tree species to persist and maintain ecological functions over time. This process can be influenced by a range of natural and anthropogenic factors, with human-induced disturbances often playing a dominant role (Maua *et al.,* 2020). Findings from this study revealed that approximately 3% of the study plots in the HLI block and LMF displayed a "new" regeneration status for *O. usambarensis*, where only seedlings and saplings were present, suggesting overexploitation of adult trees. Additionally, about 20% and 17% of *O. usambarensis* in MMF and LLI, respectively, and 7% in LLI and HLI, exhibited no regeneration, as only adult camphorwood trees were recorded. These results corroborate the observations of Koirala (2004) and Richard *et al.* (2014), which suggest that regeneration tends to be higher in disturbed forests but declines with increasing elevation. This highlights the pressing need for conservation interventions to mitigate overexploitation and support regeneration in vulnerable areas.

However, the general *O. usambarensis* population distribution showed a reverse *J*-shaped pattern with number of seedlings being higher than saplings and adults. The same results were observed by Paul *et al.* (2019) when comparing population structure between disturbed and undisturbed forests in mixed broadleaved forests in India. Reverse *J*-shaped population structure indicates a stable population with good reproduction and recruitment capability (Ahmed *et al.,* 2017; Balemlay & Siraj, 2021; Msalilwa *et al.,* 2020). Also, it generally shows that the population of *O. usambarensis* on the southern slopes of Mt. Kilimanjaro has a good regeneration status (Paul *et al.,* 2019). The observed reverse *J*-shaped population distribution may be due several factors such as disturbances, whereby adults are selectively logged and competition for limited resources (light, water and minerals) between species largely affects seedlings survival and growth (Hitimana *et al.,* 2004). This may also explain the observed *O. usambarensis* population, as selective logging combined with other human disturbances pave way for *Macaranga kilimandscharica* to outcompete the *O. usambarensis* seedlings and saplings (Bussman, 2001) which may result to local extinction of *O. usambarensis* (Maua *et al.,* 2020).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Understanding forest tree species population structure, relative abundance and regeneration status is crucial for effective conservation planning and management. Relative abundance, frequency, dominance and Importance Value Index (IVI) of species tell us the status of a particular species (hereinto *Ocotea usambarensis*) relative to other tree species. This study unveils *O. usambarensis*: (a) population structure (b) relative abundance and (c) regeneration status around the southern slopes of Mt. Kilimanjaro forest belt which is important for tourism, watershed management, climate regulation and carbon sequestration.

The population structure of *O. usambarensis* on the southern slopes of Mt Kilimanjaro provides a baseline information towards sustainable forest belt management. The population of *O. usambarensis* was observed to have a reverse *J*-shaped pattern with number of seedlings being higher than saplings and adults. Although the reversed *J*-shaped population distribution shows that the forest belt tree population is generally sustainable and healthy, it also reveals that adult trees of *O. usambarensis* are in decline especially, along the park boundary as their density was relatively lower along the boundary. So, this calls for more conservation actions to ensure more seedlings are growing to saplings and adult trees thus sustainability of the forest.

The southern slopes of Mt. Kilimanjaro were observed to have higher density of *O. usambarensis* compared to other tree species. However, the observed relative abundance of *O. usambarensis* decreased with increased logging intensity while it increased along the elevation gradient. Alongside those findings, *Macaranga kilimandscharica* and *Tabernaemontana pachysiphon* were also observed to be having higher relative abundances next to *Ocotea usambarensis*.

Generally, a good regeneration status of *O. usambarensis* was observed on the southern slopes of Mt. Kilimanjaro. This was also evident by observing a reverse *J*-shaped population structure. However, "new" regeneration status was observed in the blocks with higher logging intensity and at the lower altitude forest which denotes that *O. usambarensis* population has only seedlings and saplings with no adults. This information calls upon the park management to device conservation measures and efforts to ensure more *O. usambarensis* are successfully recruited to adults. Then the prospective adults are also sexually or asexually reproducing thus ensuring the persistence and sustainability of *O. usambarensis* population on the Mt. Kilimanjaro southern slope forest belt.

5.2 Recommendations

From the results and findings of this study on the current status of the population structure, relative abundance and regeneration of *O. usambarensis* on the southern slopes of Mt. Kilimanjaro several recommendations have been drawn which will thus help to ensure persistence of *O. usambarensis* in the Mt. Kilimanjaro Forest belt while benefiting the adjacent communities. The recommendations have been categorized into three groups: (a) recommendations to the management on what can be done in addition to existing conservation strategies to ensure a healthy and sustainable population of *O. usambarensis*, (b) recommendation to policy makers on the current policies and the need either to review or coming up with new policy statements and (c) recommendations to the research fraternity calling for further researches on the identified scientific gaps.

(i) Management intervention

(a) Adopting active restoration of the forest as a way of replenishing the declining *O. usambarensis* population. This can be done through expansion of the ongoing restoration activities to the previously disturbed forests and the lower montane forest areas where it was found by this study that the population of adult *O. usambarensis* is low. This exercise will enable a quick recovery of the Ocotea forest and may go hand in hand with mechanical removal of successional tree species which are the immediate competitor of *Ocotea usambarensis*.

(b) Results from this study indicated more of exploitation is done near or close to the park boundary. Therefore it is recommended that, park's community conservation services (CCS) should focus more on providing conservation education to villages bordering the park in order to raise their awareness on conservation issues. Also CCS in collaboration with village governments may help in establishing village forest or home gardens in open areas or degraded farms given they are in altitudinal zones which favours growth and survival of *O. usambarensis* so as to reduce pressure on the forest belt. The exercise which may be supported by establishing nurseries in their villages for a sustainable and easy availability of *O. usambarensis* seedlings.

(ii) Policy Intervention

(a) The government through responsible agencies (TFS, TAFORI, TAWA, TAWIRI & TANAPA), should carry out researches to identify other highlands where *O. usambarensis* can be grown for commercial uses. Also, there is need to establish program for monitoring *O. usambarensis* population on other range areas in Tanzania for instance on Eastern Arc Mountains to ensure species persistence.

(b) This study found that logging of *O. usambarensis* was targeting adults, which means it was for timber production thus income generation. Therefore, the TANAPA policy should indicate how local community should engage with the forest in generating their income without degrading it. For instance, villagers are currently allowed to keep and visit their beehives inside the park but it is not clear in the policy, laws and regulations on how this activity should be done. By being clear will make people more comfortable to invest in beekeeping thus generating income while enhancing conservation of the forest.

(iii) Research Intervention

This study assessed the population of *O. usambarensis* in relationship to disturbance specifically, illegal selective logging. However, further research on how other factors such as biomass level and canopy cover affects the regeneration and growth of *O. usambarensis* should be considered.

REFERENCES

Agrawala, S., Moehner, A., Hemp, A., Aalst, V., Hitz, S., Smith, J., Meena, H., Mwakifwamba, S. M., Hyera, T., & Mwaipopo, O. U. (2003). *Development and Climate Change in Tanzania: Focus on Mount Kilimanjaro*. https://scholar.google.com

Ahmed, E., Ali, S., & Addisu, A. (2017). Structure and regeneration status of woody plants in the Hallideghie wildlife reserve, North East Ethiopia. *International Journal of Biodiversity and Conservation*, *9*(6), 200–211. https://doi.org/10.5897/ijbc2017.1085

Asner, G. P., Knapp, D. E., Broadbent, E. N., Oliveira, P. J. C., Keller, M., & Silva, J. N. (2005). Ecology: Selective logging in the Brazilian Amazon. *Science*, *310*(5747), 480–482. https://doi.org/10.1126/science.1118051

Balemlay, S., & Siraj, M. (2021). Population structure and regeneration status of woody species in Kenech forest, southwest Ethiopia. *International Journal of Forestry Research,* 2021(1), 6640285.

Bonnell, T. R., Reyna-hurtado, R., & Chapman, C. A. (2011). Forest Ecology and Management Post-logging recovery time is longer than expected in an East African tropical forest. *Forest Ecology and Management*, *261*(4), 855–864.

Bussmann, R. W. (2001). Succession and regeneration patterns of East African mountain forests. *Systematics and Geography of plants*, 2001, 959-974.

Bussmann, R. W., & Lange, S. (2000). Germination of Important East African Mountain Forest Trees. *Journal of East African Natural History*, *89*(1), 101–111.

Chazdon, R. L. (2003). Tropical forest recovery: Legacies of human impact and natural disturbances. *Perspectives in Plant Ecology, Evolution and Systematics*, 6(1-2), 51-71.

Cochrane, M. A., & Schulze, M. D. (1999). Fire as a recurrent event in tropical forests of the eastern amazon: Effects on forest structure, biomass, and species composition. *Biotropica,* 31(1), 2-16.

Condit, R., Sukumar, R., Hubbell, S. P., & Foster, R. B. (1998). Predicting population trends from size distributions: A direct test in a tropical tree community. *The American Naturalist,* 152(4), 495-509.

Connell, J. H., & Slatyer, R. O. (1977). Mechanisms of Succession in Natural Communities and their Role in Community Stability and Organization Mechanisms Determining the

Sequence of Species. *The American Naturalist*, *111*(982), 1119–1144.

Fischer, E., & Killmann, D. (2008). *Illustrated Field Guide to the Plants of Nyungwe National Park Rwanda*. Department of Geography of the Inst. for Integrated Natural Sciences, University of Koblenz-Landau, Campus Koblenz. https://scholar.google.com

Gerwing, J. J. (2002). Degradation of forests through logging and fire in the eastern Brazilian Amazon. *Forest Ecology and Management*, *157*(1–3), 131–141.

Hall, J., Burgess, N. D., Lovett, J., Mbilinyi, B., & Gereau, R. E. (2009). Conservation implications of deforestation across an elevational gradient in the Eastern Arc Mountains, Tanzania. *Biological Conservation*, *142*(11), 2510–2521.

Hall, J. S., Harris, D. J., Medjibe, V., & Ashton, P. M. S. (2003). The effects of selective logging on forest structure and tree species composition in a Central African forest: Implications for management of conservation areas. *Forest Ecology and Management*, *183*(1–3), 249–264. https://doi.org/10.1016/S0378-1127(03)00107-5

Hemp, A. (2005). Climate change-driven forest fires marginalize the impact of ice cap wasting on Kilimanjaro. *Global Change Biology*, *11*(7), 1013–1023.

Hemp, A. (2006a). Continuum or zonation? Altitudinal gradients in the forest vegetation of Mt. Kilimanjaro. *Plant Ecology*, *184*(1), 27–42. https://doi.org/10.1007/s11258-005-9049-4

Hemp, A. (2006b). Vegetation of Kilimanjaro: Hidden endemics and missing bamboo. *African Journal of Ecology*, *44*(3), 305–328. https://doi.org/10.1111/j.1365-2028.2006.00679.x

Hermansen, J. E., Faye, B., Corneliussen, T., Hofsten, J., & Venvik, H. (1985). *Catchment Forestry in Tanzania. Status and Management. Institute for Environmental Analysis and FORINDECO*. https://scholar.google.com

Hitimana, J., Kiyiapi, J. L., & Njunge, J. T. (2004). Forest structure characteristics in disturbed and undisturbed sites of Mt. Elgon Moist Lower Montane Forest, western Kenya. *Forest Ecology and Management*, *194*(1–3), 269–291.

Kikoti, I. A., & Mligo, C. (2015). Impacts of livestock grazing on plant species composition in montane forests on the northern slope of Mount Kilimanjaro, Tanzania. *International Journal of Biodiversity Science, Ecosystem Services and Management*, *11*(2), 114–127. https://doi.org/10.1080/21513732.2015.1031179

Kleinschroth, F. (2011). *Regeneration of Ocotea usambarensis in East African Montane*

Forests. https://scholar.google.com

Kleinschroth, F., Schöning, C., Kung'u, J. B., Kowarik, I., & Cierjacks, A. (2013). Regeneration of the East African timber tree *Ocotea usambarensis* in relation to historical logging. *Forest Ecology and Management*, *291*, 396–403.

Koirala, M. (2004). Vegetation composition and diversity of Piluwa micro-watershed in Tinjure-Milke region, east Nepal. *Himalayan Journal of Sciences*, *2*(3), 29–32.

Lambrechts, C. (2002). *The Threats to Mt . Kilimanjaro*. https://scholar.google.com

Lindenmayer, D. B., Hunter, M. L., Burton, P. J., & Gibbons, P. (2009). Effects of logging on fire regimes in moist forests. *Conservation Letters*, *2*(6), 271–277. https://doi.org/10.1111/j.1755-263x.2009.00080.x

Makana, J. R., & Thomas, S. C. (2005). Effects of light gaps and litter removal on the seedling performance of six African timber species. *Biotropica*, *37*(2), 227–237.

Maua, J. O., Mugatsia-Tsingalia, H., Cheboiwo, J., & Odee, D. (2020). Population structure and regeneration status of woody species in a remnant tropical forest: A case study of South Nandi forest, Kenya. *Global Ecology and Conservation*, *21*, e00820.

Mohammed, E. (2021). *Effects of Livestock Browsing and Illegal Harvesting on Natural Regeneration and Ecology of Balanites Aegyptiaca in Dinder Biosphere Reserve, Sudan*. https://scholar.google.com

Mohammed, E. M., Hassan, T. T., Idris, E. A., & Abdel-Magid, T. D. (2021). Tree population structure, diversity, regeneration status, and potential disturbances in Abu Gadaf natural reserved forest, Sudan. *Environmental Challenges*, 5, 100366.

Morris, R. J. (2010). Anthropogenic impacts on tropical forest biodiversity: A network structure and ecosystem functioning perspective. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1558), 3709–3718.

Msalilwa, U. L., Ndakidemi, P. A., Makule, E. E., & Munishi, L. K. (2020). Demography of baobab (*Adansonia digitata L.*) population in different land uses in the semi-arid areas of Tanzania. *Global Ecology and Conservation*, *24*, e01372.

Mueller-Dombois, D. (1974). *Aims and Methods of Vegetation Ecology.* John Willy & Sons.

Mushi, H., Yanda, P. Z., & Kleyer, M. (2020). Socioeconomic Factors Determining Extraction of Non-timber Forest Products on the Slopes of Mt. Kilimanjaro, Tanzania. *Human Ecology*, *48*(6), 695–707. https://doi.org/10.1007/s10745-020-00187-9

Mwavu, E. N., & Witkowski, E. T. F. (2009). Population structure and regeneration of multiple-use tree species in a semi-deciduous African tropical rainforest: Implications for primate conservation. *Forest Ecology and Management*, *258*(5), 840–849.

Ndangalasi, H. J., Bitariho, R., & Dovie, D. B. (2007). Harvesting of non-timber forest products and implications for conservation in two montane forests of East Africa. *Biological Conservation*, 134(2), 242-250.

Schmelzer, G. H., & Omino, E. A. (2008). *Plant Resources of Tropical Africa.* https://scholar.google.com

Poudel, P., & Mandel, R. (2019). Comparing growing stock using circular, square and rectangular plots shape in inventory (A study from Community Forests in Chitwan District, Nepal). *Canadian Journal of Soil Science,* 4(1), 448-454.

Paul, A., Khan, M. L., & Das, A. K. (2019). Population structure and regeneration status of rhododendrons in temperate mixed broad-leaved forests of western Arunachal Pradesh, India. *Geology, Ecology, and Landscapes*, *3*(3), 168–186.

Percy, S., Lubchenco, J., Almeida, F., Armsworth, P., Bennett, A., Ebi, K., Ehrmann, J., Griffith, J., Kumar, P., Pagiola, S., Prickett, G., Richards, D., Tinto, R., Rivera, J., Thompson, V., Wenblad, A., & Yohe, G. (2005). *Millennium Ecosystem Assessment Business and Industry Synthesis Team Synthesis Team Members Synthesis Team Co-chairs Business Council for Sustainable Development-Brazil World Business Council for Sustainable Development A Report of the Millennium Ecosyste*. https://www.google.com

Piabuo, S. M., Minang, P. A., Tieguhong, C. J., Foundjem-tita, D., & Nghobuoche, F. (2021). Illegal logging, governance effectiveness and carbon dioxide emission in the timber-producing countries of Congo Basin. *Environment, Development and Sustainability*, *23*(10), 14176–14196. https://doi.org/10.1007/s10668-021-01257-8

Pimm, S. L., & Askins, R. A. (1995). Forest losses predict bird extinctions in eastern North America. *Proceedings of the National Academy of Sciences*, 92(20), 9343-9347.

Plouvier, D. (1998). *The Situation of Tropical Moist Forests and Forest Management in Central Africa and Markets for African Timber. The Congo Basin: Human and Natural*

Resources. Netherlands Committee for IUCN, Amsterdam, The Netherlands, 100-109.

Renner, M., Rembold, K., Hemp, A., & Fischer, M. (2022). Natural regeneration of woody plant species along an elevational and disturbance gradient at Mt. Kilimanjaro. *Forest Ecology and Management*, *520*(6), 120404.

Richard, J., Madoffe, S. S., & Maliondo, S. M. S. (2014). Assessment of factors for declining regeneration and death of east african camphor in moist mountanous forest of Tanzania. *Journal of Tropical Forest Science*, *26*(4), 495–502.

Richard, J. (2016). *The Effect of Loggingand Invasion of Acacia Mearnsii on Regeneration of Ocotea usambarensis in Chome Nature Reserve, Tanzania [Doctoral dissertation, Sokoine University of Agriculture].* https://scholar.google.com

Rutten, G., Ensslin, A., Hemp, A., & Fischer, M. (2015a). Forest structure and composition of previously selectively logged and non-logged montane forests at Mt. Kilimanjaro. *Forest Ecology and Management*, *337*, 61–66. https://doi.org/10.1016/j.foreco.2014.10.036

Rutten, G., Ensslin, A., Hemp, A., & Fischer, M. (2015). Vertical and horizontal vegetation structure across natural and modified habitat types at Mount Kilimanjaro. *PloS One*, 10(9), e0138822.

Wieser, G. (2007). *Land Use Change and Mountain Biodiversity.* https://www.google.com

Willan, R. L. (1965). Natural Regeneration of High Forest in Tanganyika. *East African Agricultural and Forestry Journal*, *31*(1), 43–53.

Woldie, B. A., & Tadesse, S. A. (2020). Composition and Structure of Woody Vegetation in Community Compared to State Forests in Tehuledere District, South Wollo, Ethiopia. *Journal of Sustainable Forestry*, *00*(00), 1–27.

Wright, S. J., & Muller-Landau, H. C. (2006). The future of tropical forest species. *Biotropica: The Journal of Biology and Conservation,* 38(3), 287-301.

APPENDICES

Appendix 1: Relative abundance, Relative frequency, Relative dominance and Importance value Index of tree species on LMF

S/N	Species name	Relative Abundance	Relative Frequency	Relative Dominance	Importance Value Index
1	*Macaranga kilimandscharica*	0.21	0.17	0.29	67%
2	*Ocotea usambarensis*	0.29	0.12	0.27	67%
3	*Tabernaemontana pachysiphon*	0.12	0.09	0.11	33%
4	*Xymalos monospora*	0.06	0.11	0.05	22%
5	*Rapanea/Myrsine melanophloes*	0.02	0.04	0.09	15%
6	*Heinsia spp*	0.07	0.08	0.00	15%
7	*Lasianthus kilimandscharicus*	0.05	0.07	0.01	13%
8	*Agarista salicifolia*	0.02	0.04	0.06	12%
9	*Olinia rochetiana*	0.01	0.00	0.07	8%
10	*Galiniera saxifraga*	0.02	0.04	0.01	7%
11	*Polyscias fulva*	0.01	0.03	0.04	7%
12	*Landlophia buchananii*	0.04	0.03	0.00	7%
13	*Jaundea pinnata*	0.01	0.03	0.00	3%
14	*Dracaena steudneri*	0.01	0.03	0.00	3%
15	*Bersama abyssinica*	0.00	0.01	0.00	2%
16	*Erythrococca kirkii*	0.01	0.01	0.00	2%
17	*Psychotria goetzei*	0.01	0.01	0.00	2%
18	*Piper capense*	0.01	0.01	0.00	2%
19	*Croton spp*	0.00	0.01	0.00	2%
20	*Syzygium guineense*	0.00	0.01	0.00	2%
21	*Embelia spp*	0.00	0.01	0.00	2%
22	*Chassalia discolor*	0.00	0.01	0.00	2%
23	*Keetia guanzii*	0.00	0.01	0.00	2%
24	*Allophylus africanus*	0.00	0.01	0.00	2%
25	*Dalbergia lactea*	0.00	0.01	0.00	2%
26	*Podocarpus milanjianus*	0.00	0.00	0.00	1%
27	*Aphloia theiformis*	0.00	0.00	0.00	0%
28	*Erthrocea lancia*	0.00	0.00	0.00	0%
29	*Garcinia buchananii*	0.00	0.00	0.00	0%
30	*Maytenus acuminata*	0.00	0.00	0.00	0%

Appendix 2: Relative abundance, Relative frequency, Relative dominance and Importance value Index of tree species on MMF

S/N	Species name	Relative abundance	Relative frequency	Relative dominance	Importance Value Index
1	*Ocotea usambarensis*	0.40	0.22	0.27	88%
2	*Macaranga kilimandscharica*	0.00	0.02	0.29	31%
3	*Rapanea/Myrsine melanophloes*	0.07	0.11	0.09	27%
4	*Podocarpus milanjianus*	0.13	0.13	0.00	26%
5	*Lasianthus kilimandscharicus*	0.08	0.10	0.01	18%
6	*Agarista salicifolia*	0.05	0.05	0.06	16%
7	*Xymalos monospora*	0.03	0.06	0.05	14%
8	*Chassalia discolor*	0.05	0.08	0.00	13%
9	*Psychotria goetzei*	0.03	0.08	0.00	11%
10	*Tabernaemontana pachysiphon*	0.00	0.00	0.11	11%
11	*Olinia rochetiana*	0.00	0.02	0.07	9%
12	*Garcinia buchananii*	0.02	0.05	0.00	7%
13	*Galiniera saxifraga*	0.01	0.02	0.01	4%
14	*Polyscias fulva*	0.00	0.00	0.04	4%
15	*Aphloia theiformis*	0.02	0.02	0.00	4%
16	*Syzygium guineense*	0.00	0.02	0.00	2%
17	*Erthrocea lancia*	0.00	0.02	0.00	2%
18	*Maytenus acuminata*	0.00	0.02	0.00	2%
19	*Jaundea pinnata*	0.00	0.02	0.00	2%
20	*Heinsia spp*	0.01	0.00	0.00	1%
21	*Bersama abyssinica*	0.00	0.00	0.00	0%
22	*Croton spp*	0.00	0.00	0.00	0%
23	*Erythrococca kirkii*	0.00	0.00	0.00	0%
24	*Dracaena steudneri*	0.00	0.00	0.00	0%
25	*Landlophia buchananii*	0.00	0.00	0.00	0%
26	*Embelia spp*	0.00	0.00	0.00	0%
27	*Keetia guanzii*	0.00	0.00	0.00	0%
28	*Piper capense*	0.00	0.00	0.00	0%
29	*Allophylus africanus*	0.00	0.00	0.00	0%
30	*Dalbergia lactea*	0.00	0.00	0.00	0%

Appendix 3: Relative abundance, Relative dominance and Importance value Index of tree species on HLI

S/N	Species name	Relative abundance	Relative Frequency	Relative dominance	Importance Value Index
1	*Ocotea usambarensis*	0.25	0.16	0.36	77%
2	*Macaranga kilimandscharica*	0.12	0.10	0.20	42%
3	*Agarista salicifolia*	0.04	0.06	0.15	25%
4	*Rapanea/Myrsine melanophloes*	0.06	0.09	0.08	24%
5	*Tabernaemontana pachysiphon*	0.09	0.05	0.08	21%
6	*Xymalos monospora*	0.06	0.09	0.04	20%
7	*Podocarpus milanjianus*	0.06	0.06	0.03	15%
8	*Lasianthus kilimandscharicus*	0.04	0.06	0.00	10%
9	*Chassalia discolor*	0.03	0.05	0.00	8%
10	*Psychotria goetzei*	0.02	0.05	0.00	7%
11	*Heinsia spp*	0.02	0.04	0.00	6%
12	*Garcinia buchananii*	0.01	0.03	0.00	4%
13	*Aphloia theiformis*	0.01	0.01	0.01	4%
14	*Galiniera saxifraga*	0.02	0.02	0.00	3%
15	*Olinia rochetiana*	0.00	0.01	0.02	3%
16	*Syzygium guineense*	0.01	0.02	0.00	3%
17	*Dracaena steudneri*	0.01	0.02	0.00	3%
18	*Bersama abyssinica*	0.00	0.01	0.00	2%
19	*Erythrococca kirkii*	0.01	0.01	0.00	2%
20	*Piper capense*	0.01	0.01	0.00	2%
21	*Croton spp*	0.00	0.01	0.00	1%
22	*Erthrocea lancia*	0.00	0.01	0.00	1%
23	*Maytenus acuminata*	0.00	0.01	0.00	1%
24	*Embelia spp*	0.00	0.01	0.00	1%
25	*Allophylus africanus*	0.00	0.01	0.00	1%
26	*Jaundea pinnata*	0.00	0.01	0.00	1%
27	*Dalbergia lactea*	0.00	0.01	0.00	1%
28	*Keetia guanzii*	0.00	0.00	0.00	0%
29	*Landlophia buchananii*	0.00	0.00	0.00	0%
30	*Polyscias fulva*	0.00	0.00	0.00	0%

Appendix 4: Relative abundance, Relative dominance and Importance value Index of tree species on LLI

S/N	Species name	Relative abundance	Relative Frequency	Relative dominance	Importance Value Index
1	*Ocotea usambarensis*	0.17	0.18	0.73	89%
2	*Macaranga kilimandscharica*	0.09	0.09	0.06	16%
3	*Lasianthus kilimandscharicus*	0.13	0.15	0.01	13%
4	*Polyscias fulva*	0.02	0.06	0.07	9%
5	*Podocarpus milanjianus*	0.06	0.06	0.02	9%
6	*Olinia rochetiana*	0.01	0.00	0.08	9%
7	*Heinsia spp*	0.08	0.06	0.00	8%
8	*Landlophia buchananii*	0.08	0.06	0.00	8%
9	*Galiniera saxifraga*	0.03	0.06	0.02	5%
10	*Tabernaemontana pachysiphon*	0.02	0.06	0.01	2%
11	*Xymalos monospora*	0.02	0.06	0.00	2%
12	*Psychotria goetzei*	0.01	0.03	0.00	1%
13	*Jaundea pinnata*	0.01	0.06	0.00	1%
14	*Keetia guanzii*	0.01	0.03	0.00	1%
15	*Chassalia discolor*	0.01	0.03	0.00	1%
16	*Agarista salicifolia*	0.00	0.00	0.00	0%
17	*Allophylus africanus*	0.00	0.00	0.00	0%
18	*Aphloia theiformis*	0.00	0.00	0.00	0%
19	*Bersama abyssinica*	0.00	0.00	0.00	0%
20	*Croton spp*	0.00	0.00	0.00	0%
21	*Dalbergia lactea*	0.00	0.00	0.00	0%
22	*Dracaena steudneri*	0.00	0.00	0.00	0%
23	*Embelia spp*	0.00	0.00	0.00	0%
24	*Erthrocea lancia*	0.00	0.00	0.00	0%
25	*Erythrococca kirkii*	0.00	0.00	0.00	0%
26	*Garcinia buchananii*	0.00	0.00	0.00	0%
27	*Maytenus acuminata*	0.00	0.00	0.00	0%
28	*Piper capense*	0.00	0.00	0.00	0%
29	*Rapanea/Myrsine melanophloes*	0.00	0.00	0.00	0%
30	*Syzygium guineense*	0.00	0.00	0.00	0%

Appendix 5: Data collection sheet

DATA SHEET FOR TREE VEGETATION ON THE SOUTHERN SLOPES OF MOUNT KILIMANJARO
AREA………………………………PLOT SIZE………………………………………..
COLLECTORNAME…………………………………………………………………….
Plot No.......X coord……………………Y coord……………….Altitude…………………. Date……................

Collection No:	Common Name	Botanical Name	Life form	DBH (cm)	SD 10-20 m from AD or ST	Height (cm)	Damage type	Human activity (Specify)

Comments………………………………………………………………………………………

…………………………………………………………………………………………………

KEY: ST=Stump, AD=Adult SA=Sapling, SD=Seedling
Growth stages: AD=Adult = > 10cm, SA=Sapling = 2 - 10 cm, SD=Seedling = <2cm,
Damage level: (0) No damage, (i) Few scars, (ii) Scars from moderate, (iii) Severe damage-scarred and, (iv) Fully damaged or logged

RESEARCH OUTPUTS

(i) Publications

Stephen B. M., Francis, M., & Linus, K. M. (2024). Responses of *Ocotea usambarensis* to logging on the Southern Slopes of Mount Kilimanjaro, Tanzania. *Journal of Biodiversity and Environmental Sciences*, 25(5), 24-34.

(ii) Poster presentation