NATURAL REGENERATION OF MIOMBO TREES AFTER SHIFTING CULTIVATION: A CASE STUDY OF CHIBOMBO AND RUFUNSA DISTRICTS, ZAMBIA

BY

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A dissertation submitted to the University of Zambia in partial fulfilment of the requirements for the degree of Master of Science in Tropical Ecology and Biodiversity

The University of Zambia

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DECLARATION

I, Chanda Ngoma, do hereby declare that this piece of work entitled: 'Natural Regeneration of Miombo trees after shifting cultivation: a case study of Chibombo and Rufunsa districts Zambia' is solely my own, and that all the works of other persons have been duly acknowledged. This work has hitherto never been previously presented at the University of Zambia and indeed at any other establishment for similar purposes. Therefore, I affirm that it's unique, unrivalled and authentic in its own right.

Candidate's Name: Chanda Ngoma. Signature:……………….. Date: ……………

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CERTIFICATE OF APPROVAL

This dissertation by Chanda Ngoma is approved as fulfilling part of the requirements for the award of the Degree of Master of Science in Tropical Ecology and Biodiversity of the University of Zambia.

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ABSTRACT

The objective of the study was to assess the regeneration of Miombo woodlands after shifting cultivation in Chibombo and Rufunsa districts in comparison to undisturbed woodland. The study analysed different descriptors that characterize the woodland including: species composition, diversity, richness, stem density and mode of regeneration. To achieve these objectives, three sites were selected. In each site, 40 circular plots of radius 10 meters were sampled. All trees within the plot were identified and counted. Trees that were ≥0.6cm in height were measured for height and diameter. The main stems were counted and the mode of regeneration for each shoot was recorded. The GENSTAT and Python were used to analyse the data. The Shannon Diversity Index was used to assess species diversity. The Non-Metric Multidimensional scaling (NMDS) results show that there is some separation between the sites, particularly between Chibombo and the other two sites, suggesting that Chibombo might have a distinct species composition compared to Mfunganisha and Nyampande. However, the Analysis of Similarlity (ANOSIM) like analysis suggests that the observed differences in species composition are not statistically significant (p-value is 0.10). Analysis of species diversity revealed that Chibombo had the highest species diversity with H'=2.83 and D=0.11. The undisturbed woodland recorded H'=2.68 and D=0.13 while Rufunsa had the lowest diversity with H'=2.60 and D=0.12. However, the undisturbed woodland had the highest species richness (60); Rufunsa recorded 43 while Chibombo had the least with 40. Generally, the species diversity was quite high in all three sites, an indication of good recovery in terms of species. Determination of stem density revealed that Rufunsa had the highest number of stems per hactor (10417), higher than the undisturbed woodland which recorded 9063 stems ha^{-1} while Chibombo recorded the lowest number of stems of 3165 stems ha^{-1}. An analysis of mode of regeneration showed that root sucker is the most dominant mode of regeneration, followed by stump and seed regeneration in both sites. This can be attributed to the type of shifting cultivation and the farming equipment which favours root sucker. No mature trees were recorded in both sites accounting for the low number of seed regeneration. The study revealed a potential for Miombo woodland to recover provided the fallow period is followed and the regenerating Miombo trees are not exploited for other use such as poles and fibre before maturity. Further, there is need to educate farmers on the importance of coppice with standards. While this study has provided insights into species diversity and stem density, further research should investigate additional indicators of recovery, such as soil health, carbon sequestration, and the presence of keystone species.

DEDICATION

To my love Zipporah, and our children Nikonda and Loruhamah, this is for you!

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA:	Analysis of Variance
AER:	Agro Ecological Regions
CIFOR:	Centre for International Forestry Research
CO_2:	Caborn dioxide
DF:	Degrees of freedom
D:	Diameter
E:	Evenness
GHG:	Green House Gas
H’:	Shannon-Weaver index
H:	Height
ICZ:	Inter tropical Convergence Zone
ILUA:	Integrated Land Use Assessment
JAICAF:	Japan Association for International Collaboration of Agriculture and Forest
MS:	Mean Square
REDD:	Reducing Emissions from Deforestation and Degradation
SADCC:	Southern African Development Coordination conference
SS:	Sum of Squares
cm:	Centimeter
m:	Meter
FAO:	Food Agricultural Organisation
GRZ:	Government of the Republic of Zambia
NMDS:	Non-Metric Multidimension Scaling
ANOSIM:	Analysis of Similarity

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CHAPTER 1: INTRODUCTION

1.0 Overview

This chapter provides the background and context for the study, outlining the problem statement, significance of the research, objectives, and hypothesis. It sets the stage by discussing the broader ecological and socio-economic issues related to Miombo woodlands and the impact of shifting cultivation in Zambia.

1.1 Background

Miombo is a term used to describe woodlands of central, southern, and eastern Africa dominated by the genera Brachystegia, Julbernardia, and Isoberlinia(Dewees *et al.*, 2011). It is a Swahili/Bantu word for a large tree of the Brachystegia, common in African woodland. The woodland is linked to the Zambezi River and its tributaries, namely Kafue, Luangwa, and Shire (WWF, 2012). The Miombo ecoregion constitutes the largest savannah in the world. It covers approximately 2.4 to 2.7 million km^2 and stretches from the northernmost tip of South Africa to Tanzania and Mozambique in the east to Angola in the west (Njoghomi *et al*., 2020a). It comprises dry and moist woodlands that support living African mammals, including the less-known species of plants, birds, reptiles, fish, and insects. It is estimated to have about 8500 plant species. Among its main characteristics is the presence of large expanses of rolling savannah woodland (Timberlake and Chidumayo, 2004).

Although forests provide a wide range of values, various forms of land use, such as agricultural expansion, grazing, and infrastructural development, continue to pile immense pressure on the forests (ILUA II, 2016). Among these land uses, agriculture is among the largest land users, with its impact on forests, grasslands, and biodiversity (World Bank Group, 2021). Forest resources in Zambia and other African countries are further threatened by natural and anthropogenic disturbances (Gonçalves *et al.*, 2017). Charcoal production, firewood collection, seasonal forest fires are among the major drivers of forest degradation of Miombo woodlands (Dewees *et al.*, 2011). An estimated 1.4 million ha of woodland is cleared every year. This loss of woodlands often leads to a loss of carbon stocks, biodiversity, and plant nutrients. This further can affect hydrology, mainly due to alterations in interception, infiltration, evapotranspiration, and groundwater recharge(Swali, 2022).

Shifting cultivation has been a major livelihood for the people of Southern Africa, including Zambia. The intensification and expansion of this agricultural practice are considered the primary cause of Miombo deforestation(Grogan *et al.*, 2013). In many rural areas, it is the main source of subsistence for people(Gonçalves *et al.*, 2017). A study in Tanzania reported that more than 68% of the sampled population practices shifting cultivation (Luoga *et al.*, 2000).

Shifting cultivation can be defined as the clearing of natural vegetation mainly by slashing and burning for farming purposes. After cropping for a few years, farmers move to other areas (Wallenfang *et al.*, 2015). The sustainability of this form of agriculture largely depends on the balance between the number of cultivators (population) and the available suitable woodland. Overpopulation may result in a reduced fallow period necessary for natural regeneration (Chidumayo, 1987). Shifting cultivators have generally intensified their agricultural land use and activities, sometimes extending into protected areas. Concern has therefore been raised with regards to the sustainability of shifting cultivation, leading to research, development efforts, and alternative land uses (Thrupp *et al.*, 1997). According to Chidumayo (1987), shifting cultivation is only sustainable when the population density is less than four people per km^2. This allows a fallow period of more than 20 years for woodland fertility to be restored(Luoga *et al.*, 2000).

Regeneration of Miombo after shifting cultivation is an integral component of sustainable management. It is a survival strategy of trees after a disturbance (Matowo *et al.*, 2019). Knowledge of regeneration is significant in understanding structural and composition changes, essential for ecological resilience and stability (Njoghomi *et al.*, 2020). The standard shifting cultivation practice utilises the branches of the trees instead of cutting down the entire tree (Oyama, 1996). When the optimal number of years in each cycle is followed to allow maximum regeneration, the practice can be sustainable (Thrupp *et al.*, 1997).

As the population grows, the demand for additional agricultural land rises, resulting in increased deforestation of Miombo trees and shorter fallow periods. Consequently, this may lead to a decline in an ecosystem's species diversity.

Kamangadazi (2009) noted that “loss of biodiversity and extinction of most woodland resources are imminent if the current exploitation of Miombo continues unchecked.”

We need to know the biological diversity of these regenerating tree communities using diversity assessment indices. As Miombo trees regenerate, what is the species composition and diversity? How does the stem density of the disturbed woodland compare to undisturbed woodland? As Miombo trees regenerate, which is the most common and promising disturbance-dependent regeneration mode? The study attempted to answer these questions regarding regeneration after shifting cultivation.

1.2 The Statement of the Problem

Deforestation caused by agricultural expansion, particularly shifting cultivation, is a major environmental concern contributing to climate change and biodiversity loss. In Zambia, rapid population growth has escalated the demand for agricultural land, resulting in significant deforestation and degradation of Miombo forests (Dewees *et al.*, 2011). Agriculture is responsible for more than 90% of deforestation in Zambia, with shifting cultivation accounting for 50% of that total (Kapekele, 2022). Although slash-and-burn agriculture temporarily enhances soil fertility, it ultimately results in abandoned fields and significant tree loss, jeopardizing the long-term sustainability of ecosystems. Despite prior studies on Miombo regeneration in other countries, there has been little concentrated research in Zambia, notably on the major regeneration strategies and stem density in areas affected by shifting farming. This study seeks to fill this gap by examining woody species composition, variety, and stem density in the Chibombo and Rufunsa regions. Understanding these aspects is critical for devising ways to reduce the subtle but considerable consequences of human activity on Miombo woods while assuring their long-term recovery and sustainability.

1.3 Significance of the Study.

The continuing rise of the rural population and the reduction in fallow cycles has made shifting cultivation increasingly unsustainable, resulting in significant biomass loss and forest degradation. As a result, there is an urgent need for sustainable land management approaches. Despite the importance of Miombo forests, little is known about their regeneration processes, which are critical for forest health and resilience(Piiroinen *et al.*, 2008). The study addressed this gap by examining species composition, stem density, and regeneration mechanisms in Miombo woods altered by shifting cultivation. The findings give useful information for conservation initiatives to lower carbon loss, forest degradation, and biodiversity loss. Furthermore, this knowledge is necessary for planning and decision-making at national and district levels, especially in agriculture.

1.4 Objectives

1.4.1 Main objective

The main objective of this study was to analyse species composition, species diversity, stem density and regeneration type after shifting cultivation.

1.4.2 Specific objectives

The following specific objectives guided the study:

1. To analyse the species composition and species diversity of regenerating Miombo woodlands after shifting cultivation compared to undisturbed Miombo woodland
2. To determine the stem density of regenerating Miombo trees after shifting cultivation compared to undisturbed Miombo woodland.
3. To assess the most dominant regeneration type through quantification of data after shifting cultivation.

1.5 Research Questions

The following were the research questions of this study:

1. What is the woody species composition and species diversity in Miombo woodlands after shifting cultivation compared to undisturbed woodland?
2. Is the stem density of regenerating Miombo trees after shifting cultivation different from that of undisturbed woodland?
3. What is the most dominant regeneration type after shifting cultivation?

1.6 Research Hypothesis

1. There are no differences in species composition and species diversity of Miombo woodlands after shifting cultivation compared to undisturbed Miombo woodland.

   Reasoning:

   > Miombo forests may have a robust species composition, returning to pristine conditions following shifting agriculture cessation. Furthermore,

the robust seed bank and soil conditions may facilitate the recovery of a species composition similar to that found in undisturbed areas.

2. There are no differences in stem densities of Miombo woodlands after shifting cultivation compared to undisturbed Miombo woodland.

   Reasoning:

   The density of regenerated stems may approach equilibrium quickly due to certain species' uniform growth patterns, particularly those that dominate early successional stages. Furthermore, after shifting cultivation, certain species may have a compensatory increase in growth rate, resulting in stem density similar to that of undisturbed forests.

3. There are no differences in the most dominant regeneration type after shifting cultivation between Chibombo and Mfunganisha.

   Reasoning:

   If both sites have a similar species pool, particularly those that regenerate through similar modes like coppicing or seeding, the dominant regeneration mode may not differ. Human activities like shifting cultivation can homogenize regeneration processes in both areas if applied similarly, resulting in no significant differences in the dominant mode of regeneration.

CHAPTER 2: LITERATURE REVIEW

2.0 Overview

The literature review covers existing research on Miombo woodlands, focusing on species diversity, species composition, regeneration processes, stem density, and the effects of anthropogenic activities like shifting cultivation.

2.1 Miombo Woodlands

The genera that dominate Miombo woodlands are but not limited to *Brachystegia, Julbernardia* and *Isoberlinia* (Dewees et al., 2011). The major species of miombo woodland are *Brachystegia spiciformis* Benth, *Brachystegia floribunda* Benth, *Julbernadia paniculata* Benth and *Isoberlina angolensis* (Benth.) Hoyle and Brenan with *Pterocarpus angolensis* DC, *Burkea africana* Hook, *Albizia antunensiana* Harms and *Parinari curatellifolia* Planch.ex Benth being canopy associates. *Anisophyllea boehmii* Engl, *Syzygium guineense* (Wild.) DC and *Uapaca* spp as common understory species (Syampungani, 2008). It is one of the most extensive biomes covering southern Tanzania, much of Southern Congo, Malawi, Angola, Zambia and Zimbabwe. Much of it is found on elevated inland plateaus of southern central Africa (Thomas and Packham, 2007). It constitutes the largest savannah in the world. Which is estimated to be 2.4 to 2.7 million km across seven African countries (Njoghomi et al., 2020).

The Southern African Development Coordination Conference (SADCC) gathered data that was used in the classification of forests. The data was based on a fuel study done from 1978 to 1984. This data was then used to estimate total biomass, leading to the division of Zambia into nine biomass classes. The results indicate that wet Miombo, dry Miombo and seasonal Miombo cover a combined area of 402743 km^2 representing 39.5% of the total area. The growing stock of miombo woodland was estimated at 2107.4 million tonnes representing 71.3% of the total growing stock (Chidumayo, 2016). Chidumayo (1987) divided miombos into subtypes based on a combination of variables and rainfall. These classes were: northern wetter miombo, north-western wetter miombo, central drier miombo and western drier miombo (Chidumayo, 2016). A more recent estimate carried out in Zambia indicates that miombo woodland is by far the most dominant woodland covering about 68% of total forest cover. Zambia’s miombo has the highest diversity of tree species in all countries where it is found (World Bank Group, 2019).

Many households benefit directly from woody forest products by harvesting them and selling them to generate income as well as non-timber forest products that are either sold or consumed. This therefore highlights the importance of Miombo woodlands not only in income generation for individuals and a nation, but also in food security of individuals, households and the nation. Another significant contribution to the livelihood of mankind is through medicinal plants and products. In certain cases, it contributes up to 80% of rural health (Matowo *etal.*, 2019). This therefore underscores the value of Miombo in the lives of people in urban and rural populations. It is therefore safe to conclude that to a significant degree, the livelihoods of people depend on the stable population of these woodlands that regularly recruits over time.

Forests play an important role in mitigating climate change, they act as natural filters for CO_2 absorption in the atmosphere (Ali *et al*., 2014). As part of the global solution, countries must develop national frameworks and devise strategies aimed at mitigating forest-based emissions of GHG gases such as CO. REDD activities must be encouraged and supported, and there is a need to boost forest resilience and resistance (WWF, 2000). Given this, the regeneration of miombo is an important process in combating not only climate change but also mitigating forest and land degradation.

2.2 Land use and anthropogenic activities- a threat to Miombo

It is believed that areas of Miombo that are degraded are more extensive than can be estimated. Anthropogenic activities are believed to play a significant role in the ecological impacts in Miombo woodlands (Chidumayo, 1987a). Charcoal production, firewood collection, seasonal forest fires, and shifting cultivation are among the major drivers of forest degradation of Miombo woodlands (Dewees *et al.*, 2011). The major problem is the unsustainable utilisation of these resources which is so worrying because this often leads to land degradation and habitat loss for forest taxa (Gonçalves *et al.*, 2017).

The largest sources of greenhouse gas (GHG) emissions linked to agriculture are land conversions e.g. clearing forests for cropland (World Bank Group, 2021). The land cover changes assessment carried out between 2000-2014 revealed significant changes. It shows a decrease in total forest cover and an increase in cropland (ILUA II, 2016). The assessment further revealed that agricultural expansion is the major driver of deforestation in Zambia, accounting for 68.78% of forest cover loss (ILUA II, 2016).

2.3 Farming systems in Zambia

Farmers are categorised into three; small scale, medium scale and large scale. Agricultural production is mainly driven by smallholder farmers who cultivate less than five hectares and rely on family labour (Phiri, 2017). The main crop that dominates production is maize which is grown by 80% percent of smallholder farmers (CSO, 2015). The farming system employed in different parts of the country depends largely on the physical environment, soil types and rainfall patterns. Based on these factors, the following are the cultivation systems practised in Zambia as described by Saasa (2003):

1. The shifting axe and hoe system. This system includes shifting cultivation (clear-cutting and Chitemene system). It has been the most widely practised agricultural system; it involves 40%of the country and 20% of the rural population.

2. Fishing and semi-permanent hoe system. Covers 7% of the rural population and practised mostly along main rivers and swamps, and is common in the Agro-eco region III.

3. Semi-permanent hoe system is mostly practised in AER I. Due to harsh climatic conditions associated with this region, crop production is limited

4. Semi-permanent hall and ox ploughs. Common in AER II. Livestock plays an important role in this system and it is practised by 25 % of the population.

5. Semi-commercial ox and tractor plough system. Mostly practised in AER II and consists mainly of emergent farmers. Cultivated land is mainly above 5 hectares, cash crops such as maize and groundnuts are dominant.

6. Commercial system. Highly specialised and mechanized systems with big variations. Appears both in AER II and III but mainly in Region II.

2.4 Shifting Cultivation and Miombo

Shifting cultivation encompasses several diverse activities and therefore quite difficult to define. Generally speaking, it refers to any temporal and partially cyclical agricultural system that involves clearing natural vegetation followed by phases of cultivation and fallow periods. The features, stages and lengths of cycles have evolved significantly, for example, the cycles have reduced to as low as 5 years from as high as 30 years. This greatly affects soil fertility restoration (Thrupp *et al.*, 1997). This form of agriculture follows a cycle that includes various land use activities. However, specific stages as well as features of each cycle vary and sometimes can be difficult to distinguish. In Miombo and mopane woodlands for example, shifting cultivation has six stages namely: selecting the site and clearing it, burning, planting crops, weeding, harvesting and finally succession(Thrupp *et al.*, 1997).

In Zambia, it is a traditional agricultural practice in which branches are cut and burnt in order to increase soil fertility. After this, a farmer is able to grow an average of three successive crops after which yields begin to dwindle significantly indicating that a farmer needs to open new fields. Studies have shown that this system can be sustained so long population does not exceed seven people per kilometre (Siame, 2006).

The standard shifting cultivation practice in Zambia that only utilizes the branches of the tree as opposed to cutting down the entire tree (Oyama, 1996), and one that follows the number of years in each cycle to allow maximum regeneration is not entirely bad altogether (Thrupp *et al.*, 1997). Stromgaard (1988) recommended that instead of clear felling, clowns of larger trees are lopped. The advantage that this has is that the regrowth of the trees is significantly reduced, and thus the trees reach reproductive age faster.

However, due to the demand for more land resulting from population growth, farmers no longer wait for the recommended twenty-five years fallow period but rather only ten years (Siame, 2006). Chidumayo (1987a) acknowledges that overpopulation undermines the stability of shifting cultivation. The study reviewed that for the system to survive; the fallow period had to be reduced from the recommended twenty-five years to twelve years. Another study carried out in Mozambique acknowledged that while in many areas of miombo woodland, the traditional agriculture of the swidden type can support 2-4 persons per square kilometre; this density has been exceeded greatly. This has resulted in the fallow period being shortened greatly to the extent that regeneration is not possible (GoM, 2011). Therefore, shifting cultivation is considered to be among the major contributors to stand degradation. Agricultural expansion and intensification are considered to be the primary causes of miombo deterioration(Grogan *et al.*, 2013). More than 90% of deforestation in Zambia is due to clearing land for agriculture. Shifting cultivation contributes to half the loss of this woodland. As of 2006, an estimated biomass loss of 35% (43000km) was recorded in the past 40 years (Kapekele, 2006). This indicates that this form of agriculture is unsustainable, especially with the continued growth of the population. A study carried out in Tanzania reviewed that the effect of anthropogenic activities is discernible and stresses the need for proper management especially for species with economic importance (Mwakalukwa *et al.*, 2014)

2.4.1 Natural Regeneration after Shifting Cultivation

Regeneration can be defined as the renewal of the forest through the recruitment of young plants (Mwansa, 2018). A disturbance on Miombo such as shifting cultivation is followed by a succession process for re-establishment. Regeneration is, therefore, a survival strategy of Miombo after shifting cultivation (Matowo *et al.*, 2019), and a key process in the existence of species in a community of varied environmental conditions (Arya *et al.*, 2017) .

The replacement of old disturbed Miombo trees by new individuals of the next generation through stump shoots, root suckers or seedlings can be described as regeneration. Early succession species such as Uapaca spp start, then late succession shade tolerant Miombo trees regenerate from coppices sprouts and seedlings (Biofund, 2011). A study carried out in Tanzania in the Kiturago forest showed that forests can recover after abuse (Njoghomi *et al.*, 2020a). A study carried out in Brazil indicated that forests can recover through natural regeneration from sprouts and seedlings. It further predicted that even after 90 years of shifting cultivation, the forest had the potential for forest regeneration and was able to recover values similar to primary forest (Viera, 1996). The recovery of Miombo species after shifting cultivation is influenced by forest type, fire, differences in anthropogenic pressure and rainfall regimes in different areas (Montfort *et al.*, 2021).

2.4.2 Importance of Natural Regeneration

According to Mwansa (2018), natural regeneration is superior to artificial regeneration as seeds that are locally dispersed adapt well to harsh environmental conditions. The author adds that the processes are reliable in restoring large areas following a disturbance and that it’s a valuable means of bringing about forest types that prove efficient in providing very important forest products and values. In addition, natural regeneration is very fast in forest recovery and is said to promote species richness (Mwansa, 2018).

2.4.3 Sexual Regeneration

Sexual regeneration refers to recruitment of trees through seedling that establish themselves through geminating seeds (Chidumayo and Gumbo, 2010). It is considered the primary forest recovery mechanism (Mwansa, 2018). The success of seedling establishment is generally very low. The mortality of seedlings is initially very high during the establishment phase. Seedling survival depends on the pattern of rainfall after the seeds have germinated. Because most of the seeds germinate on the soil surface, the radicle must penetrate the soil soon after germination before the soil begins to dry. Many seedlings fail at this stage if the soil is compacted or capped (Frost, 1996). The majority of the seeds experience shoot dieback caused by water stress and or fire during the dry season (Frost, 1996).

2.4.4 Asexual Regeneration

Asexual regeneration, also known as vegetative regeneration results from the coppicing of existing trees that were cut or damaged leading to the recruitment of sprouts (Mwansa, 2018). Secondary trunks can also be induced by changes in growing conditions such as severe injury caused by herbivory, fire, floods or drought(Chidumayo and Gumbo, 2010). The sprouts can be classified into trunk sprouts and root sprouts (root suckers) (Mwansa, 2018). Trunk regeneration happens when either adventitious roots develop inside a disintegrating old stem, giving rise to a new succession trunk or the entire trunk of an old tree dies and decomposes, but small active remains give rise to new shoots (Thomas and Packham, 2007).

Miombo can regenerate sexually through seedling and vegetative reproduction, the latter is highly recommended because it offers maximum regeneration with a rapid growth rate which enables fast recovery after the disturbance (Matowo *et al.*, 2019). A study carried out in the northern part of Zambia reviewed that for Miombo to regenerate to the proto-climax stage, fallow periods should be about 30 years in tree-cutting areas and more than 50 years in garden areas. It further suggested that if fallow periods are reduced, then woodland biomass is likely to reduce (Oyama, 1996).

2.5 Species Composition and Diversity

Species diversity refers to the taxonomic variety of living organism (Kempton *et al.*, 2002). It consists of three components: species richness, taxonomic diversity and species evenness. Species richness is the number of species in the community or region while evenness quantifies how equal the abundances of species are. Species richness and tree diversity are fundamental to total forest biodiversity as they provide resources and habitat for other species. Regeneration of Miombo is therefore a key process in the existence of species in a community of varied environmental conditions (Arya *et al.*, 2017). Species composition refers to the contribution of each plant species to the vegetation or the total number of different living organisms within a given biome. The dominance of Brachystegia, Julbenadia and Isoberlinia distinguishes Miombo as floristically distinct African woodland (kamangadazi, 2009). Assessment of forest community composition and structure helps in understanding the status of tree population, regeneration and diversity for conservation purposes (Arya *et al.*, 2017).

Several studies report clear trends in other biomes that show the impact of climate change on species composition in many ecosystems (Kamangadazi, 2009). A study was carried out in Zambia on charcoal and agricultural fallows to assess species diversity and composition. The results show that Miombo systems recover fast in terms of species diversity and species composition takes longer to recuperate.

2.6 Stem Density

Stem density refers to the total count of all stems (usually per hectare). This can refer to the total number of (N_{tot}) or the number of main stems (N_{main}) (Njoghomi *et al.*, 2020b). Stem density is an important indicator of forest recovery after a disturbance.

A study carried out in Tanzania (Kitulangalo forest reserve) aimed at evaluating silvicultural treatments on regeneration dynamics of Miombo woodlands did quantify the dynamics of the number of regeneration stems across different treatments and the resulting changes. The study was carried out over a 9-year observation period. The empirical results indicated a significant drop in the total number of stems and a significant increase in the number of main stems (Njoghomi *et al.*, 2020b).

Chidumayo (2002) carried out research to determine whether the rate of Miombo recovery after clearing and regrowth structure was determined by land tenure and use.

The results indicate that the highest stem density was on customary land in comparison to forest reserves (Chidumayo, 2002).

CHAPTER3: MATERIALS AND METHODS

3.0 Overview

This chapter details the study area, study site, sampling design data collection, and data analysis techniques used in the study. It explains the rationale for choosing specific sites and methods, ensuring that the reader understands how the data was collected and analyzed.

3.1 Study Area Description

Zambia is located in central southern Africa at 8o-18oS and 22o-34oE of the equator (Mcsweeney *et al.*, 1960). It covers a total surface area of approximately 75.3 million hectares (ILUA II, 2016).

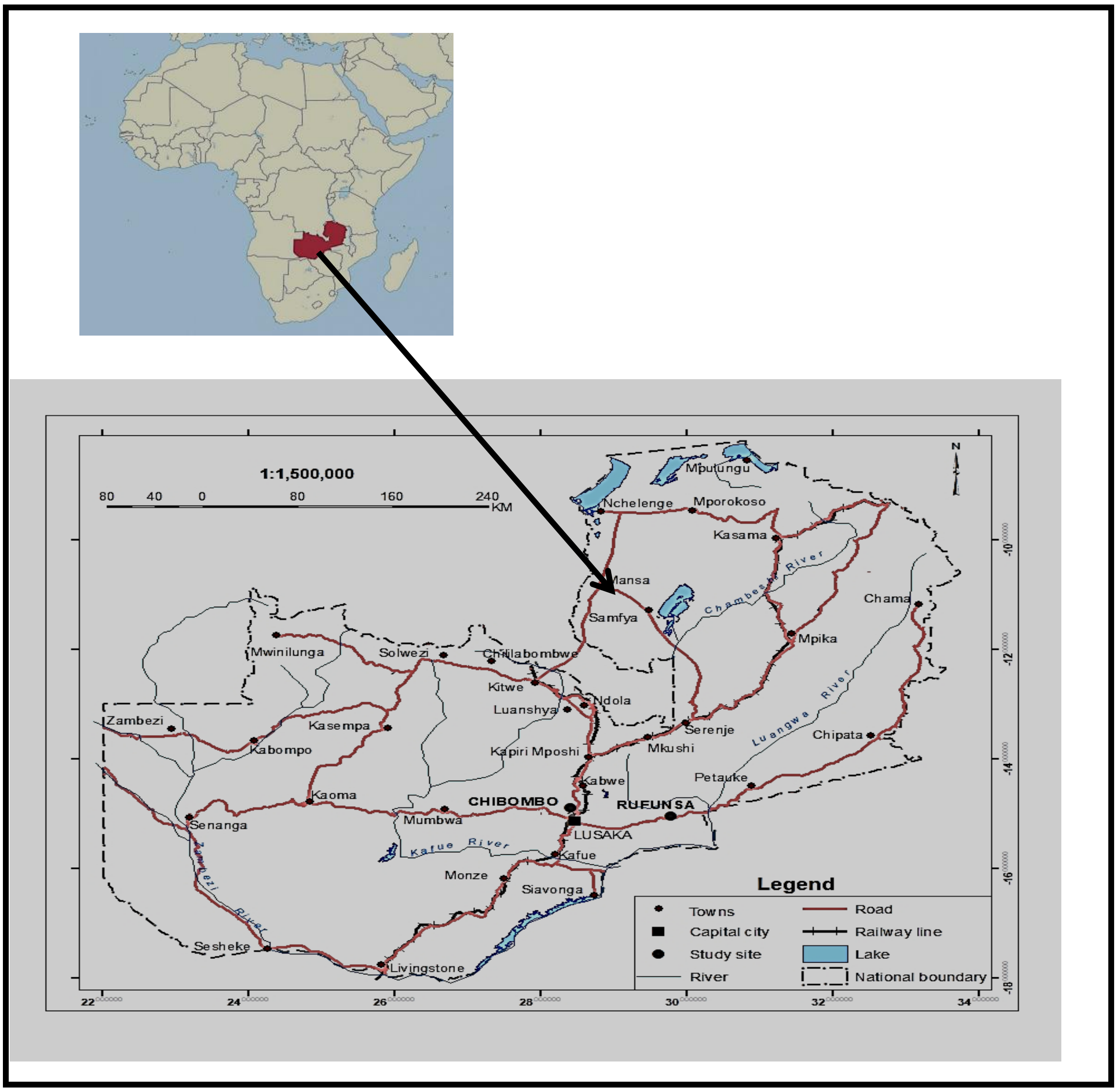

Figure 3.1 Showing map of Zambia (Ngoma, 2023).

3.1.1 Zambia's Climate

The climate is generally categorised as subtropical, mostly humid subtropical or tropical wet/dry all year (Bailey *et al.*, 2021). The subtropical climate is characterized by three distinct seasons: a hot and dry season (mid-August to mid-November), a wet rainy season (mid-November to mid-April) and a cool dry season (mid-May to mid-August) (World bank Group, 2021). The average annual precipitation ranges from 700-1500 mm (World Bank Group, 2021). Rainfall is strongly influenced by the movement of intertropical convergence zone (ITCZ) as well as the El Niño-Southern Oscillations. The average annual temperature is 22.12oC (World Bank Group, 2021).

3.1.2 Agro Climatic Zones

Zambia is divided into three agro-climatic zones. In the south AER I is the driest zone receiving less than 800 mm of annual precipitation. In the central and east AER II receives between 800 mm and 1000 mm annual precipitation. Finally in the north and west AER III is the largest land area and the wettest region with annual precipitation of 1000-1500 mm (Mcsweeney *et al.,* 1960). The map below shows the agro-eco regions of Zambia.

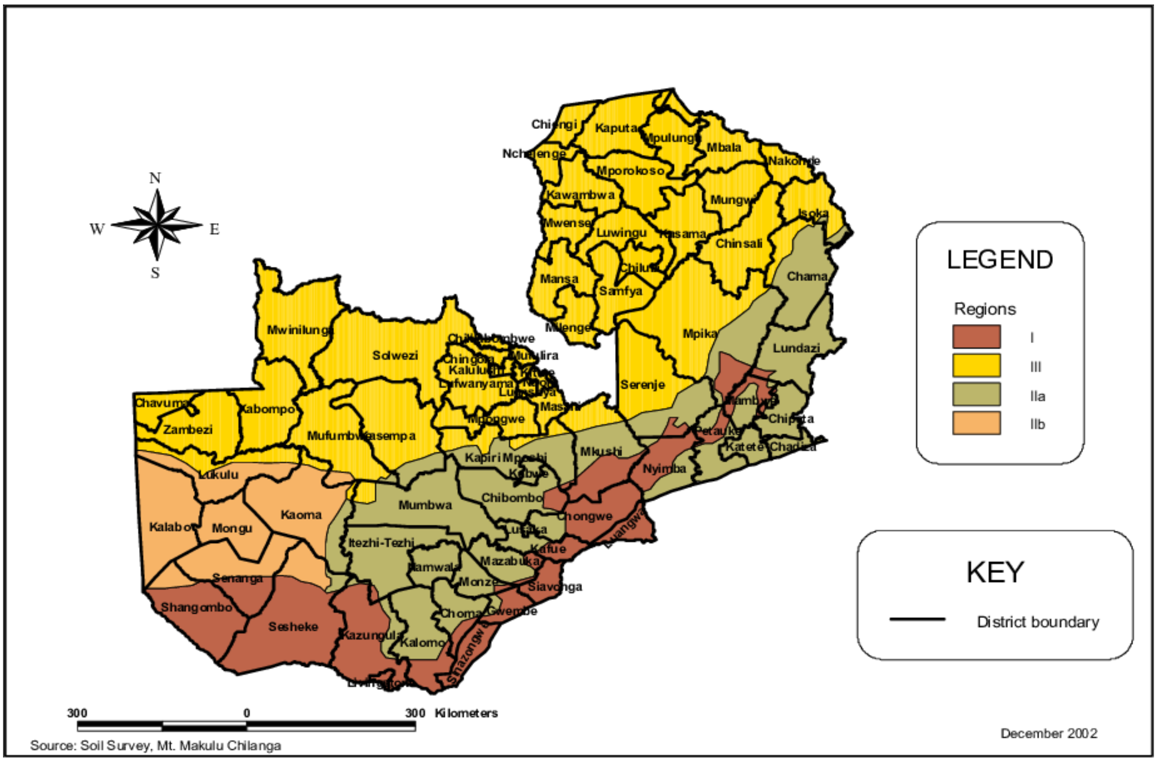

Figure 3.2: Map of Zambia showing Agro eco regions (source: Mount Makulu)

3.1.3 Soil types by Agro Ecological Regions

The Agroecological regions are divided into three regions (I to III) based on annual precipitation, and region II is subdivided into IIa and IIb based on differences in soil characteristics (JAICAF, 2008). In Region I, the soils are slightly weathered and moderately to non-reached. Rainfall has less influence on soil formation in this Agroecological region; however, Kalahari sands, unconsolidated sandstones or limestone formed are strongly leached resulting in acidic soils. This region is dominated by Phaeozems, Nitisols and Cambisols (JAICAF, 2008). Region II soils show moderate weathering and leaching. Limestone, Dolomites and mudstone often develop into Lixisols and Luvisols. These soils are of medium mineral content, infertile and highly leached (JAICAF, 2008). Region IIa is covered by fertile soils such as Luvisols, Acrisols and Vertisols while region IIb is covered by Arenosols and Gleysols (JAICAF, 2008). The soil pH ranges from 3.5 to 4.5 (ILUA II, 2016). Region III is covered by soils that are highly weathered and strongly leached with a pH ranging from 4 to 5.5. It's covered by well-drained, deep red Ferrasols and Acrisols (ILUA II, 2016).

3.1.4 Rufunsa District, Lusaka Province

Rufunsa district is situated in Lusaka province of Zambia, at coordinates 15o 04’52.42’’S, 29o 08’.84’’E (table 3). The boundary for Rufunsa was again recently extended to cover more land that was previously part of Chongwe. Nangwenya Bridge, Chitemalesa and Chinyunyu are now part of Rufunsa. It is also home to the Rufunsa Game Management area. The original occupants of Rufunsa are the Soli people (Milupi *et al.*, 2020). The district is characterized by three main vegetation types: dry Miombo woodland, Mopane woodland, and Munga woodlands. Agriculture and charcoal production are the primary economic activities, both of which have led to alterations in the vegetation. Over the years this has caused an alteration to the vegetation type, due to the continuous cutting down of trees. This is exacerbated by the higher demand for these products due to the proximity to Lusaka (Milupi *et al.*, 2020).

Rufunsa was selected for this study because it provides a representative example of how human activities, particularly shifting cultivation, impact woodland ecosystems. The district's diverse vegetation types and ongoing land-use changes make it an ideal location to study the effects of these activities on species composition and woodland recovery.

3.1.5 Chibombo District, Central Province.

Kabwe and covers a total area of 13423 km2 (5183 sq mi). Its geographical coordinates: are 14o39'.5408''S, 28o5'19.8888'E. It is a plateau at an average of between 900 m and 1200m above sea level. Chibombo experiences precipitation between 800 mm and 1000 mm, with a mean annual temperature of 18 to 24oC (GRZ, 2002). The main tree species that dominate the Chibombo district are Accacia, Brachystegia, Julbenadia and Isoberlinia. All these species are important for fuel wood and timber production (Phiri, 2017). The district is dominated by tree species such as Acacia, Brachystegia, Julbernardia, and Isoberlinia, which are crucial for fuelwood and timber production. Chibombo is predominantly rural, with agriculture being the main activity, supported by various forms of farming, including smallholder, emergent, and commercial farming.

The analytical report on the Central Province of 2010 shows that the population stood at 309,519 which translates into a population density of 22.6 persons per Km2 (CSO, 2014). This population density exceeds the recommended density of 4 persons per km2 required for shifting cultivation to be sustainable.

Chibombo was chosen due to its ecological and socio-economic characteristics, which differ from Rufunsa. The district's higher population density, intense agricultural activity, and reliance on specific tree species for fuel and timber provide a contrasting environment to Rufunsa, allowing for a comparative analysis of how different levels of human pressure and land use affect Miombo woodlands.

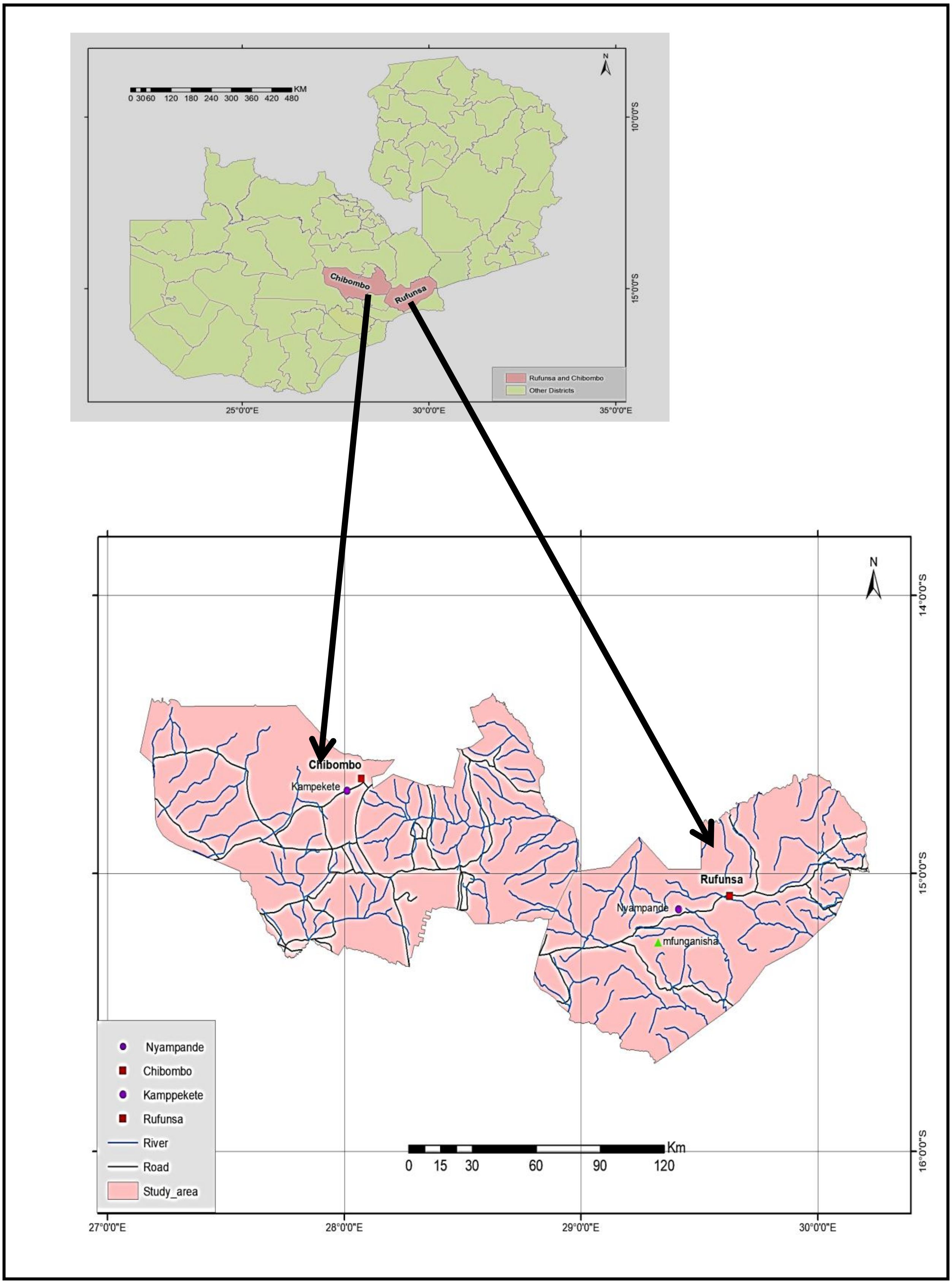

Figure 3.3: Showing study area map for Chibombo and Rufunsa districts (Ngoma, 2023)

3.2 Site Selection

The site selection was done with the help of the village headman and the community members, aiming to identify sites of former slash-and-burn agriculture. Three sites were identified, one in Chibombo district and two sites in Rufunsa district. Two of these sites were former shifting cultivation sites (one in Chibombo and the other in Rufunsa), and the third site was an undisturbed woodland (in Rufunsa) that served as a control. The number of years after abandonment was 0-5 years in the disturbed woodland (Chibombo and Mfunganisha), while the fallow period in both sites ranged from 3-6 years. The exact period of exposure to shifting cultivation could not be established. However, based on current owners of the fields, in Mfunganisha, exposure was 17 years, while in Chibombo it was 23 years. Nyampande served as a control for both Chibombo and Mfunganisha, given that they are all tropical dry forests. Chibombo does not have undisturbed woodland. The difference in agroecological region between Chibombo and Rufunsa was accounted for in the discussion.

3.3 Sampling Design

The sampling of trees was done in abandoned shifting cultivation fields for sites one and two, while site three was undisturbed woodland. From each site, 40 smaller circular plots of radius 10m were sampled. Along each transect line, the circular plots were systematically established with 10 meters between the plots. The transect lines were taken 20 m apart. More than one transect line was established in all three sites. The number of plots along the transect line differed depending on the field length being worked on in the disturbed woodland; however, five transect lines with ten plots along each line were taken in the undisturbed woodland (Mugunga *et al.*, 2022).

3.4 Data Collection

All trees in a plot were identified to species level and counted (Mugunga *et al.*, 2022). To assist with tree identification, a checklist of the vernacular names of the woody plants of Zambia prepared by the Ministry of Lands and Natural Resources (forest research bulletin No. 3) was used in conjunction with the book 'Know Your Trees.' In addition, an ecologist from the forest department (herbarium in Ndola) was engaged to assist with tree identification. In cases where the tree could not be identified using the botanical name, the local name was recorded. This data was used to determine tree species composition and species diversity.

All trees that were greater than (≥0) 6 cm in height were measured for height (H) and diameter (D) (Mugunga *et al.*, 2022). In cases of clustered shoots of the same species, only the tallest was measured for height and diameter, and the rest were just counted (Njoghomi *et al.*, 2020b). A tape measure and height meter were used to measure height while a calliper was used to measure diameter (appendix A and C). However, it was not possible to collect the height and diameter data for the undisturbed woodland as the instruments fell short due to the height of the trees, which ranged between 10-15m, whereas the instrument could only go as high as 9m. The height and diameter data were used to assess correlation.

All main stems were counted (Njoghomi *et al.*, 2020b). This data was used to determine stem density. For purposes of determining the most dominant regeneration mode, physical inspection was carried out, which involved digging in certain cases.

3.5 Data Analysis

The statistical package that was used to analyse data is GENSTAT 2022 and Python 2024. Analysis of variance (ANOVA) was used to test for mean differences. The Shapiro-Wilk test was used to check the data for normalcy and Q-Q plots to visually assess normalcy before doing the analysis. Levene's test was used to check for homogeneity of variance. These tests verified that the ANOVA's assumptions were met, enabling the legitimate use of this statistical technique. A linear model was tested for ANOVA. Linear regression analysis was used to assess the relationship between variables. The Shannon Diversity Index and Simpson Index of Dominance and Evenness were used to assess species diversity according to Mugunga et al. (2022) and Kamangazi (2019). The formulas that were used are:

$H' = -\sum_{i=1}^{s} Pi In(Pi)$……………………………………………………………a

H_{max}=In(S)……………………………………………………………………...b

E=H/H_{max}…………………………………………………………………………c

Where:

H'= Shannon-Weaver index, H_{max}= Maximum diversity, E= Evenness, *Pi*=proportion of each specie in the sample, *InPi*= natural logarithm of the proportion of each specie in the sample, In= Natural logarithm and S= species richness.

To assess dominance, Simpsons Index of Dominance (D) was used. The formula is shown below.

$D = \sum_{i=1}^{s} \frac{ni(ni-1)}{N(N-1)}$……………………………………………………………………..e

Where:

D= Simpson's index

n= the total number of trees of a particular specie

N= total number of trees of all species.

Non-Metric Multidimensional scaling (NMDS) was used to visualize the differences in species composition between the three sites. Analysis of similarity (ANOSIM) was used to evaluate whether there is a significant difference in species composition between the three sites (in this case, the Bray-Curtis dissimilarity of species composition). Pearson's correlation coefficient was used to measure the association between two variables.

CHAPTER 4: RESULTS

4.0 Overview

The results chapter presents the findings of the study, including data on species composition, stem density, and regeneration modes in the Miombo woodlands of Chibombo and Rufunsa districts. The chapter includes tables, figures, and statistical analyses to support the findings.

4.1 Species Composition

The most common woody tree species encountered in each site varied as well as well as the number of individual trees within species. The highest number of individuals was found in the two smallest height classes (0.1-1.1 m) and size classes (0.1-2.2 cm) while the least was recorded in the largest classes, a consistent pattern observed in all sites.

Results of species composition in Mfunganisha in Rufunsa are presented in figure 4.1. A total 6867 shoots were recorded in Mfunganisha. The most common species encountered were: *Piliostigma thonningii* Schumach (27%), *Brachestygia spiciformis* Benth (13%), *Bauhinia petersiana* Bolle (11%) *and Ambligonocarpus andongensis* (Welw. ex Oliv.) Exell & Torre (9%). The least common species encountered in Mfunganisha were *Diplorhynchus condylocarpon* (Mull.Arg.) Pichon and *Pseudolachnostylis maprouneifolia* Pax making up only 1% of the total species encountered.

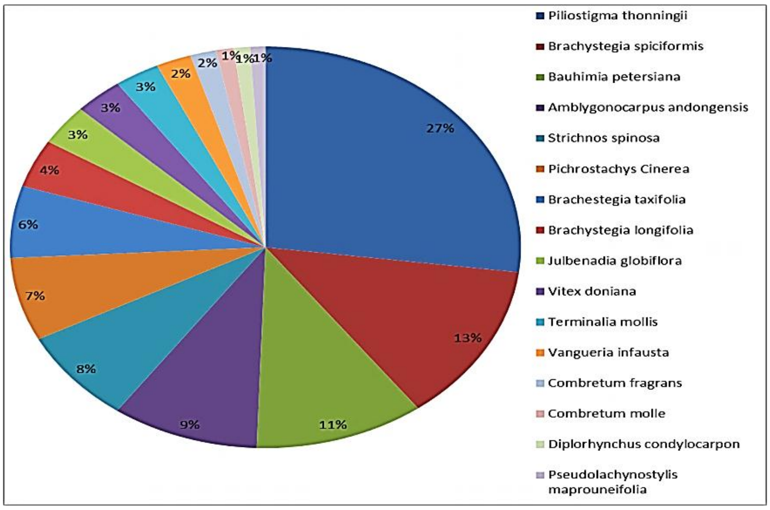

Figure 4.3: The most common woody plant species by percentage in Mfunganisha for all plots. n=40, Age=0-5 years.

Results of species composition for Chibombo are presented in figure 4.2. The total number of shoots recorded in this site was 1877. The results indicate this site to be dominated by the species *Parinari curatellifolia* Planch.ex Benth (30%), *Julbenadia paniculata* Benth (21%) and *Brachystegia taxifolia* Harms (7%). The least encountered species in this site were *Schrichnos spinosa* Larm and *Syzygium guineense* (Wild) DC at 2% each. The species richness recorded in this site was 41.

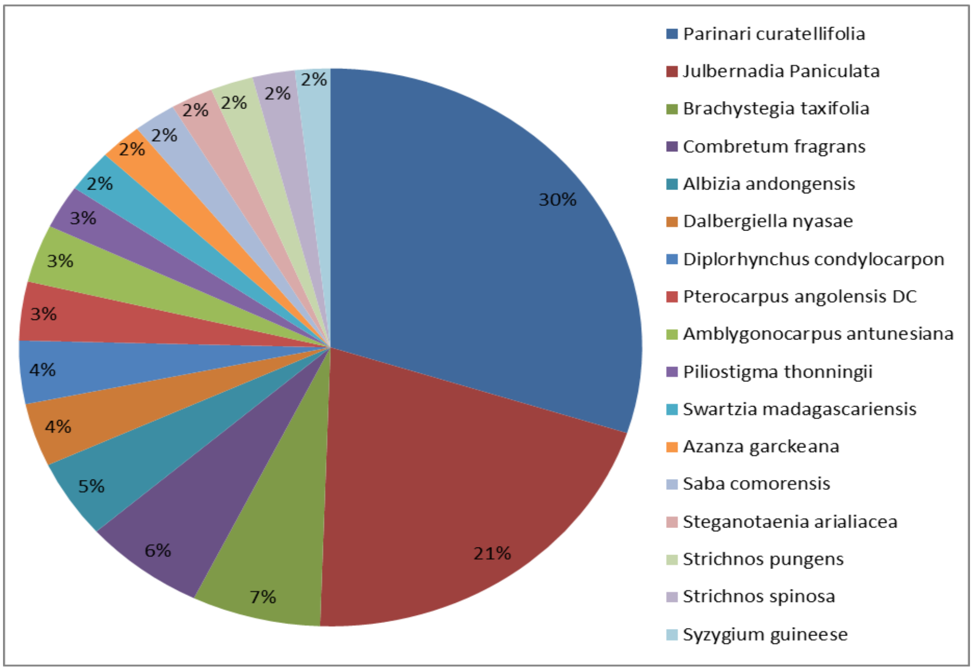

Figure 4.4: The most common woody plant species by percentage encountered in Chibombo for all plots. n=40, age= 0-5years. (Source: this report).

Results of woody species composition for Nyampande in Rufunsa are presented in figure 4.3. A total of 7907 trees were recorded in this site. The results indicate this site three to be dominated by *Julbenadia globiflora* Benth (27%), *Bachystegia utilis* Hutch and Berth (24%), *Uapaca kirkiana* Muel.Arg (7%). Among the least common species in this site were *Brachestygia longifolia* and *Brachestygia bohemii.* This is undisturbed woodland which has never been cultivated before or undergone major disturbance. The species richness for this site was 60.

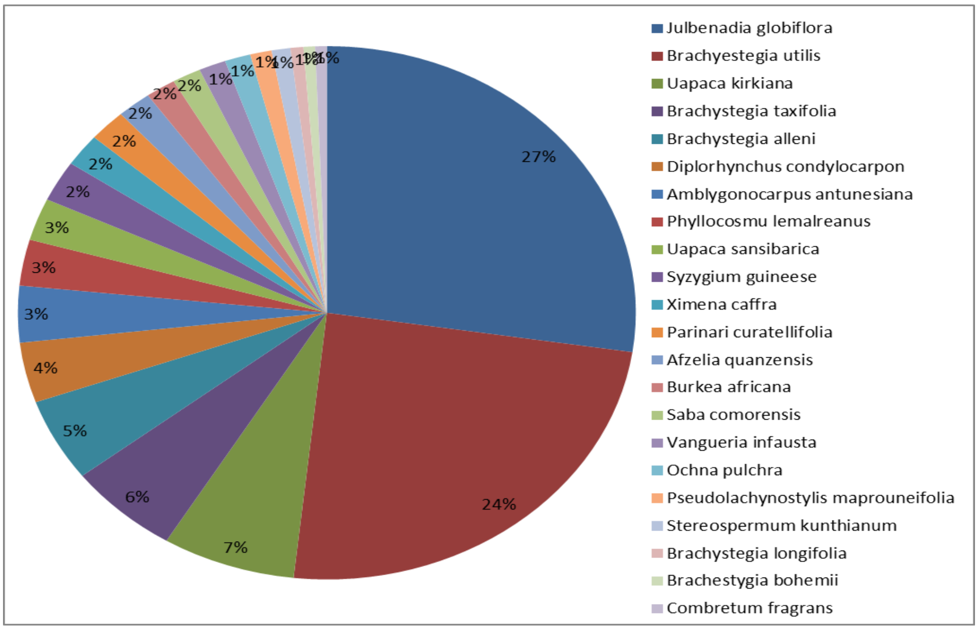

Figure 4.5: The most common woody species encountered by percentage in Nyampande of Rufunsa District for all plots, n=40, Age 0-5 years. (Source: this report).

Figure 4.4 shows the results of the NMDS plot, which visualises the differences in species composition across the three sites. The results of the NMDS plot show some visual separation between the three sites (Mfunganisha, Chibombo, and Nyampande), implying that Chibombo may have a distinct species composition than Mfunganisha and Nyampande. The ANOSIM test, which quantifies variations in species composition, produced a p-value of 0.10 and an F-test statistic of 2.31.

A p-value of 0.10 implies that the observed variations in species composition are not statistically significant at the widely accepted 0.05 level. This means that while the results point to probable changes in species composition, particularly for Chibombo, these differences cannot be confirmed using with statistical confidence under this criterion.

Thus, we conclude that the communities are not statistically different, yet the pattern seen in the NMDS plot implies that Chibombo may have ecological characteristics worth investigating further.

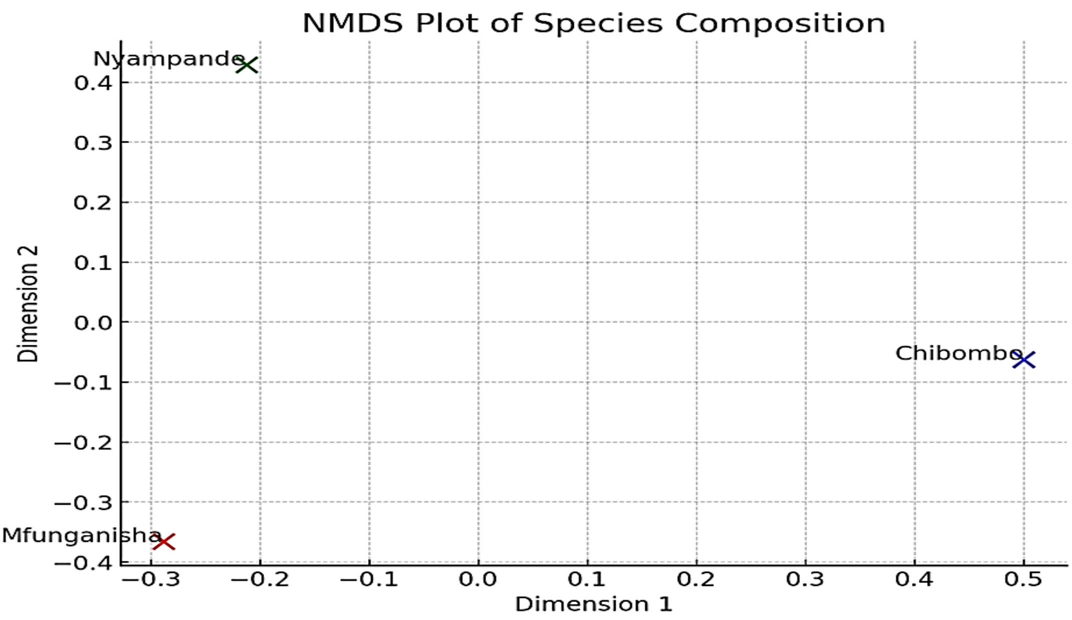

Figure 4.4 NMDS plot visualization of the differences in species composition between Mfunganisha, Chibombo, and Nyampande. P-value: 0.10 and F-test 2.31. The calculated stress value is 0.00045. (Source: This Report).

4.2 Species Diversity

The results of species diversity indices for all three sites are presented in Table 4.1. Chibombo recorded the highest H' value of 2.83, followed by Nyampande with 2.68, while Mfunganisha recorded the lowest H' value of 2.60, which indicated less diversity. Simpson's index of diversity shows that Chibombo recorded the highest value, and then Mfunganisha and Nyampande recorded the lowest. However, site 3 had the highest species richness (60) of all three sites, with site 2 having the lowest value of 41 units.

Table 4.1: Species diversity for Mfunganisha, Chibombo and Nyampande. n=40, Age= 0-5 years. * H'= Shannon weaver index, H_{max} = Maximium diversity, E=Evennes, D= Simpsons index of Diversity. (Source: This Report).

Site	district	H'	E	D	Richness
Mfunganisha	Rufunsa	2.60	0.69	0.12	43
Chibombo	Chibombo	2.83	0.77	0.11	41
Nyampande (control)	Rufunsa	2.68	0.66	0.13	60

4.3 Stem Density

The results of stem density are given in table 4.2 and figure 4.4. Mfunganisha redorded 10417 stem ha^{-1}, the highest of all three sites. Site 2 rcorded stem density of 3165 stems ha^{-1} while site 3 recorded stem density of 9063 stems ha^{-1}.

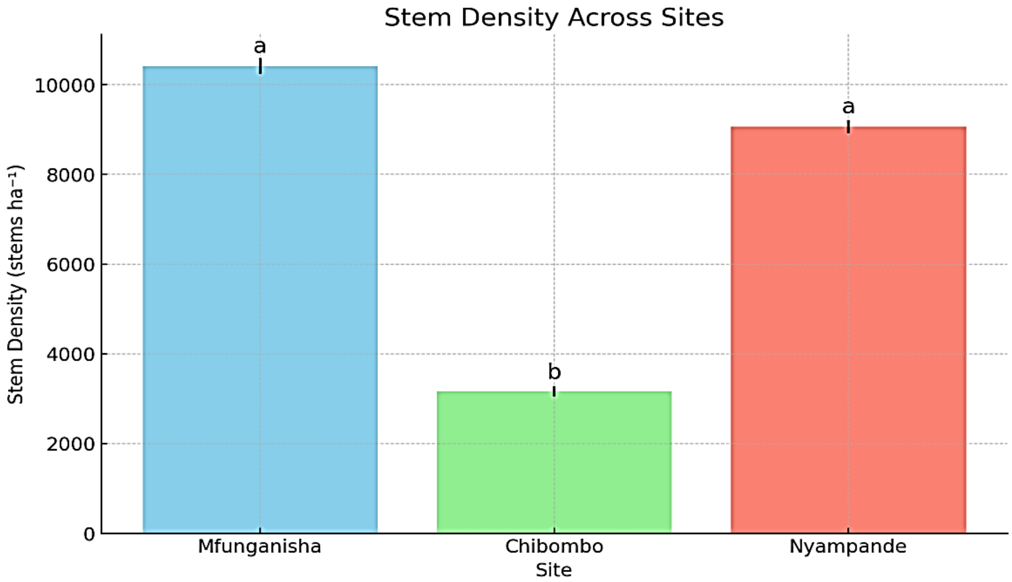

Figure 4.5: bar graph of stem density per hector for all three sites. Age 0-5, N=40. (Source: This Report).

The bar graph below shows the average number of stems by location with standard error and significance letters based on Tukey's HSD Test. The means of the number of stems across these locations is not equal, indicating that the stem density varies significantly depending on the location.

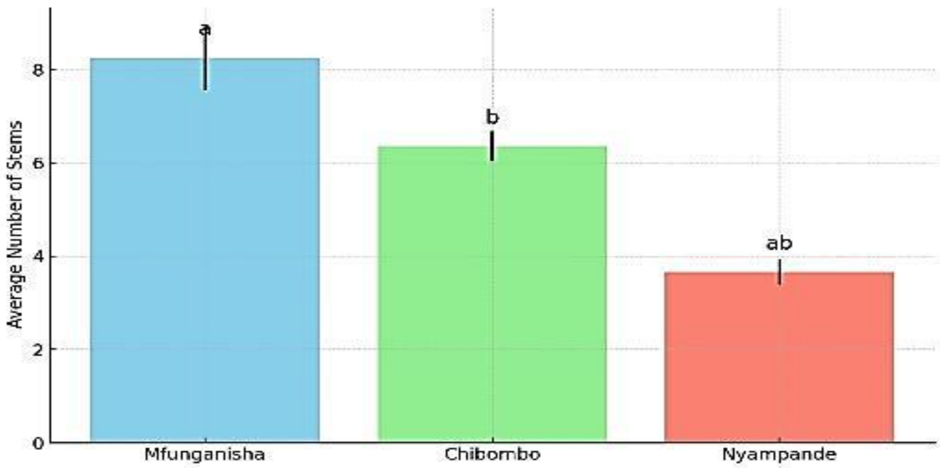

Figure 4.5: Average number of stems by location. F test-24.75 and P-value 1.09E-09 (Source: This Report).

4.4 Height and Diameter Data Analysis

4.4.1 Height Class Percentage Distribution

The height of trees in Mfunganisha ranged from 0.1 to 3.7 m, while in Chibombo it ranged from 0.1 to 3.6 m. The distribution of height classes for regenerating trees in Mfunganisha and Chibombo are presented in Figures 4.5 and 4.6.

The results for Mfunganisha reveal a consistent reverse J-shaped distribution with decreasing density as the height increases. The largest proportion, 58.33%, was of the lowest height class of 0.07 to 0.57 m. The second smallest height class of 0.57 to 1.07 m was 28.22%, and the least highest height class of 4.07 to 4.57 m was 14% in proportion. However, in Chibombo, the second height class of 0.6 to 1.1 m was 36.36% in proportion. The lowest height class of 0.1 to 0.6 m was 35.27 in proportion.

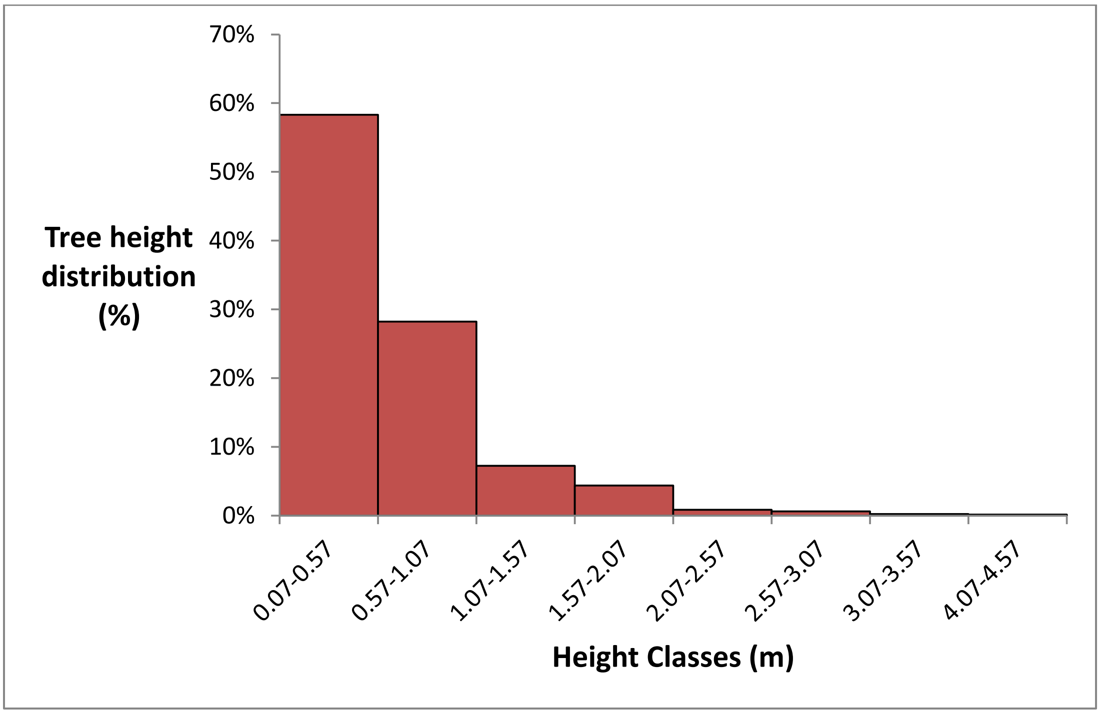

Figure 4.6: Height class percentage distribution in Mfunganisha for age 0-5years woody species. Bin= 0.5. n=40 (Source: This Report).

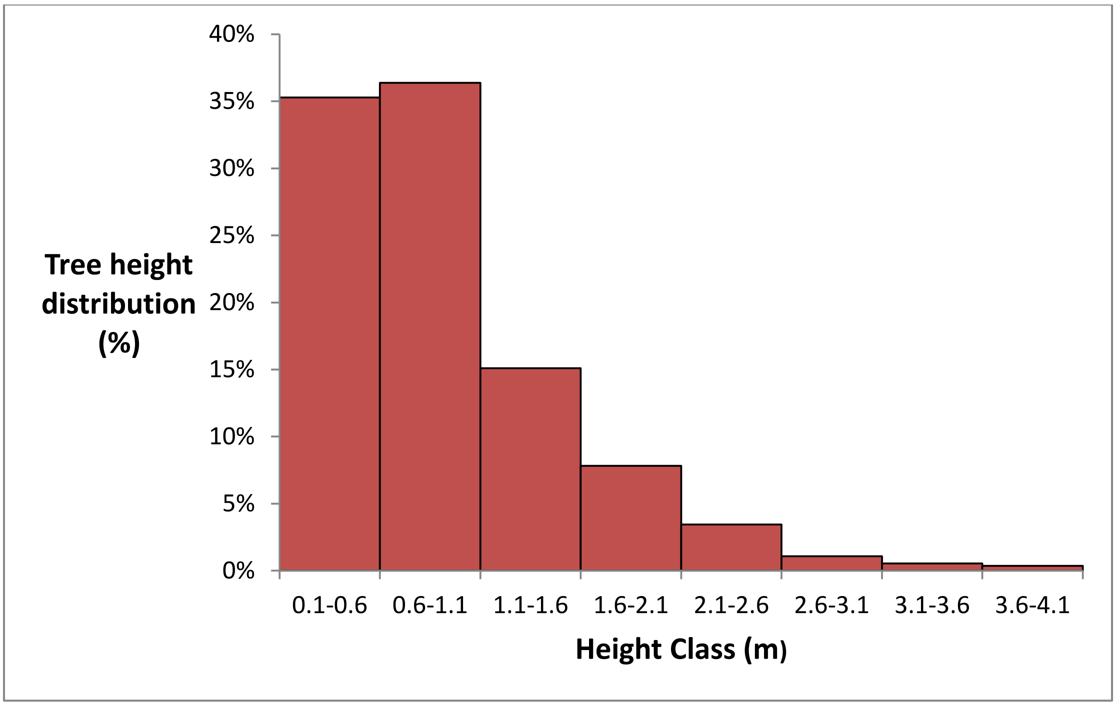

Figure 4.7: Height class percentage distribution in Chibombo for age 0-10years woody species. Bin= 0.5. n=40 (Source: This Report).

4.4.2 Analysis Size Class Percentage Distribution

The tree diameters recorded in Mfunganisha ranged from 0.1 to 6.3 cm, while in Chibombo, they ranged from 0.2 to 8.6 cm. The size classes of the different tree species found in Mfunganisha and Chibombo are illustrated in Figures 4.7 and 4.8, respectively. All trees with a height greater than 0.6 m were grouped into size classes. In Mfunganisha, the smallest size class of 0.1 to 1.1 cm had the highest proportion at 54.61%. This was followed by the second smallest size class of 1.1 to 2.1 cm, which recorded 35.80%, while the largest size class of 6.1 to 7.1 cm recorded the lowest percentage at 0.18% (figure 4.7). In Chibombo (figure 4.8), the highest percentage of 49.86% was recorded in the smallest size class of 0.2 to 1.2 cm, and the second highest percentage of 24.23% was recorded in the second smallest size class of 1.2 to 2.2 cm. However, unlike in Mfunganisha, the lowest percentage was recorded in the third largest size class of 6.2 to 7.2 cm, with just 0.28%. In both sites, the size class distribution reveals a consistent inverted J-shaped pattern.

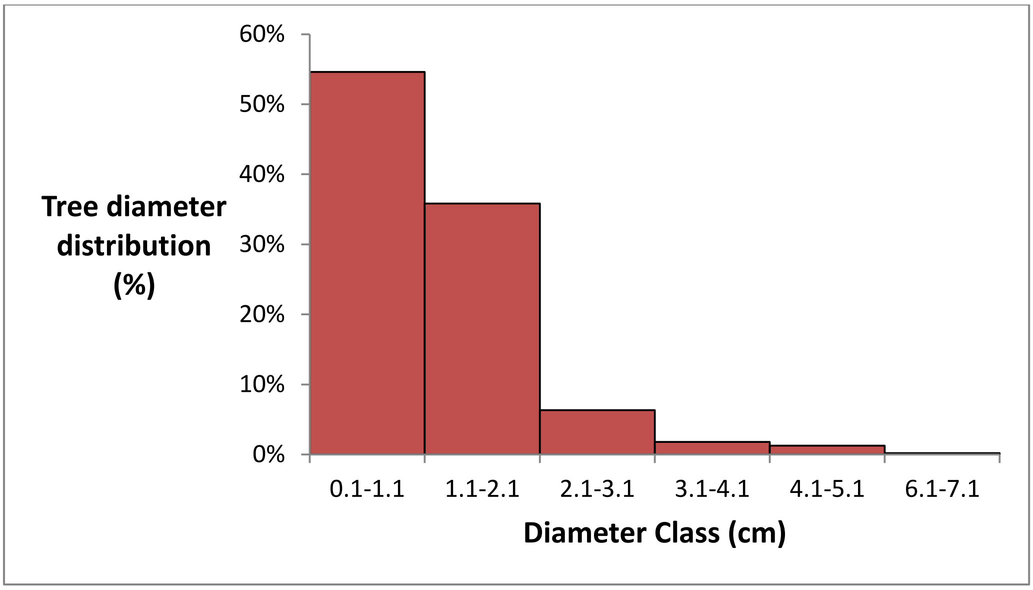

Figure 4.8: Size class frequency distribution in Mfunganisha for age 0-5 years. Bin=1. n=40. (Source: This Report).

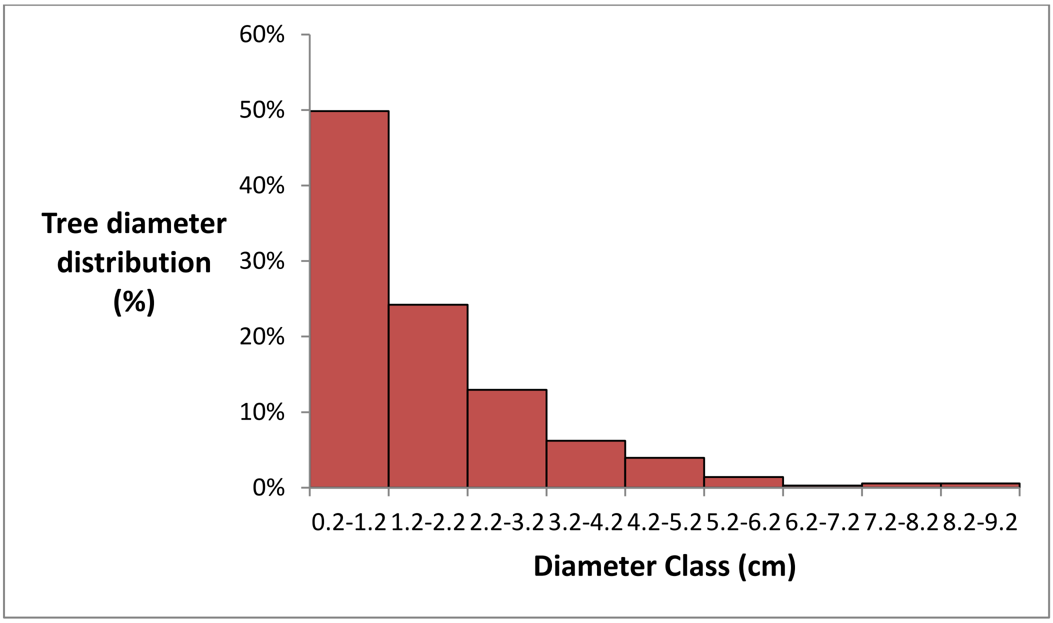

Figure 4.9: Size class frequency distribution in Chibombo for age 0-5 years. Bin=1. N=40. (Source: This Report).

4.4.3 Regression analysis

The results of analysis of variance of mean heights and diameter of trees at 2 years in Mfunganisha and Chibombo sites are given in table 4.3. There was non significant difference in tree height (p=0.77, F stat=0.09) and diameter (p=0.65, F stat=0.23) at the two sites.

Table 4.2: Analysis of variance for Chibombo and Mfunganisha, effects on tree height and diameter (Fstat). (Source: This Report).

Source of variation	Tree height	Tree diameter
Site	0.09 ns	0.2255 ns

Sig: ced ***0.001, **0.01, *0.05, ns: non significant.

The table below shows the results of the analysis of the mean diameter for representative species for Chibombo and Mfunganisha aged 2 years (p-value=0.65). Therefore, there are no significant differences in the mean diameter between Chibombo and Mfunganisha.

The relationship between diameter and height is presented in Figure 4.9. The results show a very weak positive association between Diameter and height (r=0.418). The goodness of fit showed that only 17.5% of the variation in height was explained by diameter (p-value=0.0073).

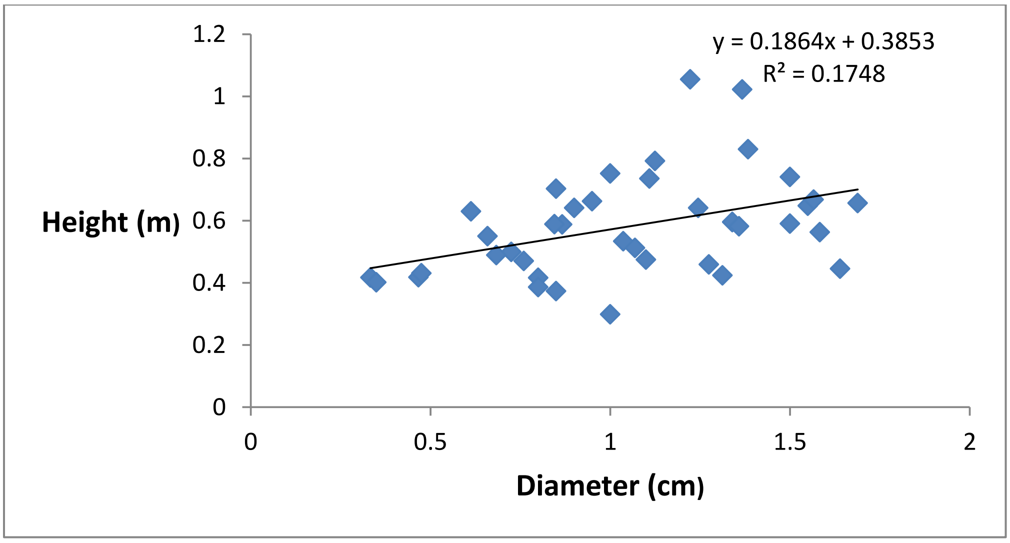

Figure 4.10: Relationship scatter plot of mean heights (m) against mean diameter (cm) of trees aged between 0-5 years, n=40 (Source: This Report).

The relationship between the tree height and diameter for Chibombo is presented in figure 4.01. The results show a strong positive association between height and diameter

(R=0.854). The goodness of fit showed that 72.97% of the variation in height was explained by diameter (p=2.38E-12).

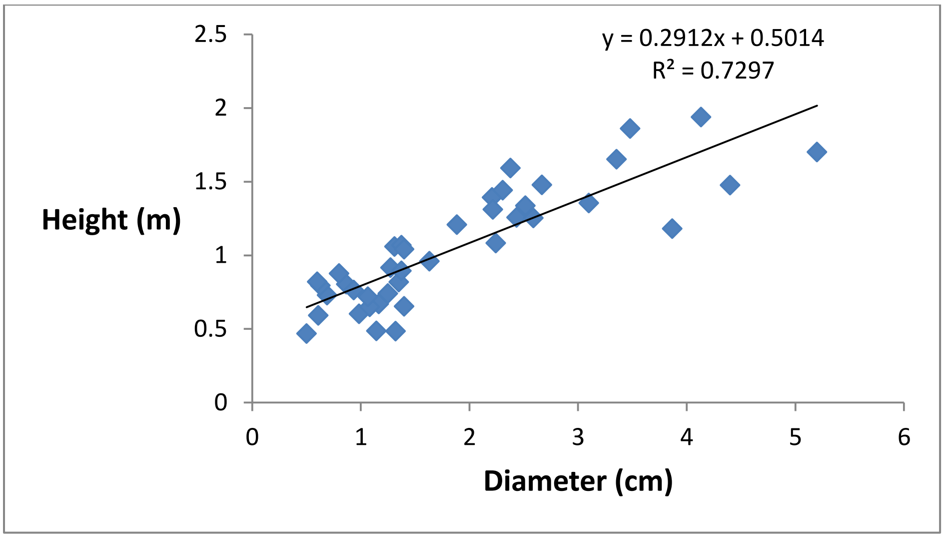

Figure 4.11: Relationship scatter plot of mean height (m) agaist mean diameter (cm) of the trees age 0-5, n=40. (Source: This Report).

Results for the average height and diameter for each year class (age of field after abandonment) are presented in 4.5. These are combined results for both Mfunganisha and Chibombo.

The results do not show a consistent increase in both height and diameter with age. The results show that the average mean height for year one trees is 0.81m while for year two the average mean height reduces to 0.47m. A similar pattern was recorded for diameter. However, after year two a consistent increase in both mean height and mean diameter with height was recorded.

The results presented in Figure 4.11 show the relationship between the duration of field abandonment and tree height. The goodness of fit of 70.3% variation in height could be explained by the duration of abandonment. For every 1 year of field abandonment, the tree increases in height by 6.5 cm (p-value=0.0759).

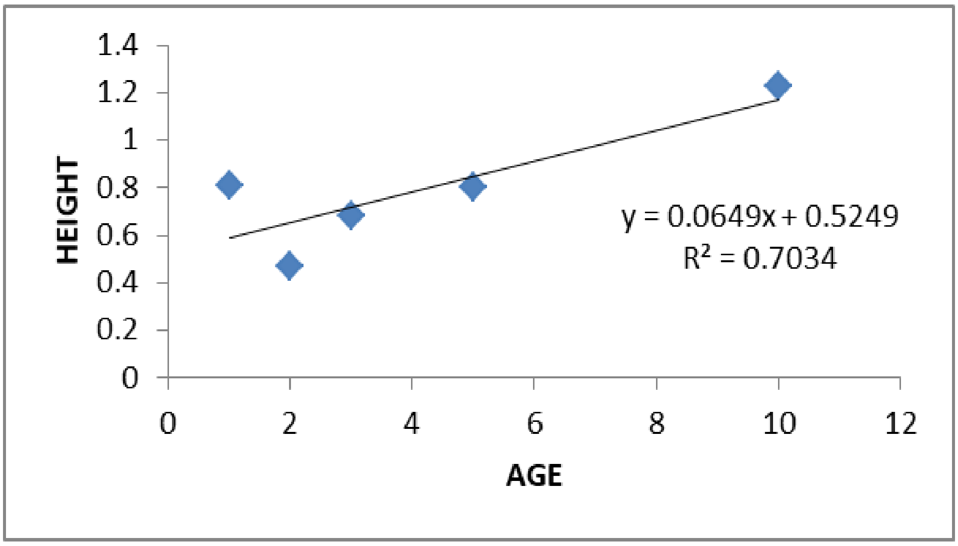

Figure 4.12: Relationship scatter plotof Height (m) against Age (duration of abandonment) of the trees aged between 0-10years. Combined data for Chibombo and Mfunganisha (Source: This Report).

Results for the predicted mean heights with an increase in years for combined data for Chibombo and Rufunsa are presented in Table 4.6. At 20 years the height is expected to be 1.82m, at 50 years height will be 3.77m and after 100 years trees will have attained a height of 7.01m.

Table 4.3: Predicted mean heights (m) after abandonment of regenerating Miombo trees. Combined data for Chibombo and Mfunganisha. Y=0.0649X + 0.5249. Height in Meters (m). Age=year. (Source: This Report)

Age	20	30	40	50	60	70	80	90	100	120	140	160
Height	1.82	2.47	3.12	3.77	4.42	5.07	5.72	6.37	7.01	8.31	9.61	10.91

The results presented in Figure 4.12 show the relationship between the duration of field abandonment and tree diameter. The goodness of fit of 66.72% variation in diameter could be explained by the duration of abandonment. For every 1 year of field abandonment, the tree increases in height by 12.3 cm.

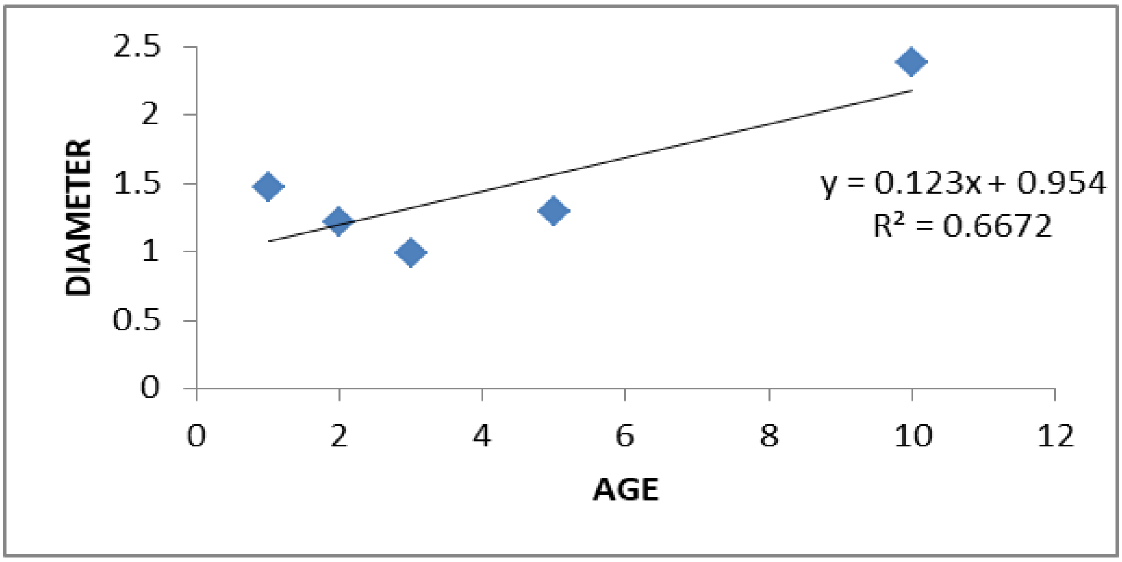

Figure 4.12: Relationship scatter plotof diameter (cm) against Age (duration of abandonment) of the trees aged between 0-10years. Combined data for Chibombo and Mfunganisha. (Souce: This Report).

4.5 Assessment of regeneration type.

The results for the quantification of the most dominant regeneration mode reveal the most dominant regeneration mode is Root sucker, followed by stump and seed in both sites. In Mfunganisha, the top two species that recorded the highest number of cases per each mode of regeneration were: root sucker- Albizia antunesiana and Brachystegia spiciformis, Stump- Piliostigma thonningii and Cassia abbreviata and seed-Bauhinia petersiana and Brachystegia spiciformis. In Chibombo, the following were the top two species in each mode of regeneration: root sucker- Julbenadia paniculata and Parinari curatellifolia, stump- Parinari curatellifolia and Daibe nyase and seed- Julbenadia paniculata and Parinari curatellifolia. Three cases of burning the stump and roots completely to the tree were recorded in Mfunganisha while Chibombo recorded one of stump burning. No mature tree was recorded within the plots in both sites.

Analysis of regeneration data shows that 73% of the total cases of regeneration recorded were root suckers while 24% was stump regeneration in Mfunganisha (Figure 4.13). Seed regeneration accounted for 3%. In Chibombo, the regeneration was 5, 23 and &72% by seed, stump and root sucker respectively (Figure 4.14).

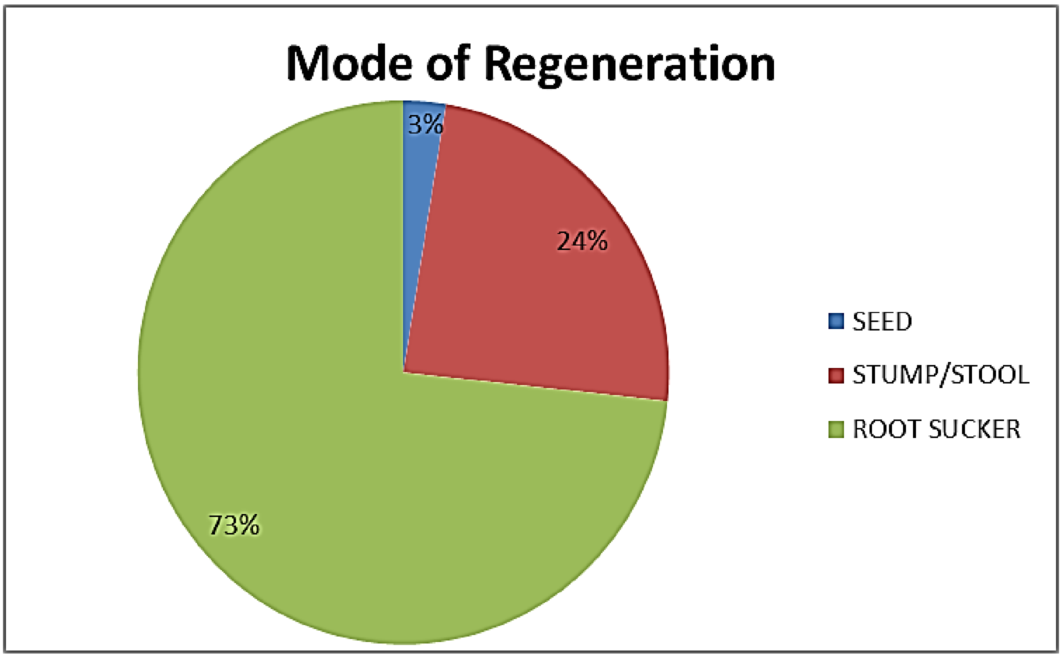

Figure 4.13: Regeneration cases by percentage per mode of regeneration for Mfunganisha. Age 0-5 years, N=40. (Source: This Report).

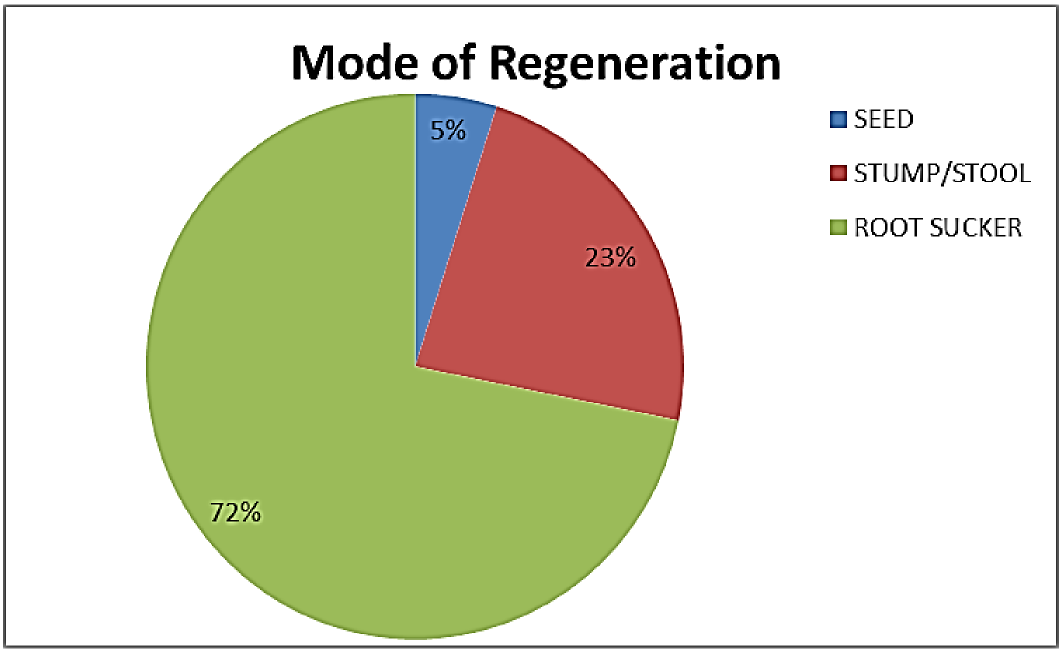

Figure 4.14: Regeneration cases by percentage per mode of regeneration for Chibombo. Age 0-5 years, N=40. (Source: This Report).

CHAPTER 5: DISCUSSION

5.0 Overview

In this chapter, the results are interpreted and discussed in relation to the existing literature. The discussion highlights the implications of the findings for Miombo woodland management, conservation strategies, and the broader context of environmental sustainability in Zambia.

5.1 Species Composition.

The species compositions of the three sites indicated distinct ecological patterns driven by site history, disturbance regimes, and environmental conditions (Figures 4.1, 4.2, 4.3, and 4.4). Mfunganisha was dominated by *Piliostigma thonningii* (Schumach.), a pioneer plant commonly associated with disturbed environments, with major contributions from *Brachystegia spiciformis* Benth (13%), and *Bauhinia petersiana* Bolle (11%). *Pilliostigma thonningii* (Schumach.) Milne-Redh's dominance in Mfunganisha stemmed from its rapid regeneration. It was discovered that *Pillistigma thonningii* (Schumach.) produces more regenerated shoots per stool or root sucker than any other species, accounting for 27% of all individual shots recorded. Based on the distribution and method of regeneration, it appears that *Brachystegia spiciformis* Benth and *Amblygonocarpus andogenisis* (Welw. ex Oliv.) Excell & Torre dominated this site before disturbance; however, a new species profile appears to be taking control. *Diplorhynchus condylocarpon* Pichon and *Pseudolachnostylis maprouneifolia* Pax, which account for only 1% of the species, demonstrate a low representation of late-successional species found in undisturbed woods. The preponderance of pioneer species indicates that this site is in an intermediate successional stage after shifting cultivation, consistent with its history as a disturbed site.

Parinari curatellifolia Plax.ex Benth (30%) and *Julbernardia paniculata* (Benth.) Troupin (21%), which are both typical of Miombo forests but also resistant to some level of disturbance, were the dominant plants in Chibombo. The species richness (41 species) is higher than in Mfunganisha but lower than in Nyampande, possibly as a result of the region's suitable climate (800–1000 mm of annual rainfall) and moderate levels of disturbance. Its Miombo forest identity is seen in the presence of plants like *Brachystegia taxifolia* Harms; however, their composition differs from that of Mfunganisha and Nyampande.

Nyampande was dominated by Julbernardia globiflora (27%) and Brachystegia utilis (24%), hallmark species of mature Miombo woodlands. Species richness (60 species) is the highest among the three sites, reflecting the absence of major disturbances and the site's status as an undisturbed ecosystem. The dominance of climax species such as Uapaca kirkiana and the presence of rare species like Brachystegia longifolia and Brachystegia bohemii further highlight its mature ecological state.

There seems to be a decline in the number of Brachystegia species due to continued exposure to farming and reduced fallow period. In addition, the Brachystegia species seem to be reducing in density in both Mfunganisha and Chibombo where these are major species that are considered very good for charcoal burning with Julbenadia globiflora Benth being the local's favourite for charcoal production.

The presence of fire-tender species such as Brachystegia spiciciformis Benth and Brachystegia longifolia Benth which tend to have higher mortality rates under dry burning (2.5% yr-1) have constantly been exposed to fire. Shifting cultivation abandoned fields tend to have more fuel loads making them vulnerable to fire which affects coppices and other forms of regeneration. This tends to affect the recovery of miombo after a disturbance. Our results are consistent with those of Syampungani et al., (2016) who observed that the presence and development of species like Brachestygia longifolia, Albizia antunesiana, and Brachystegia spiciformis confirm that Miombo grows virtually unchanged following clearing. This is because regeneration mainly consists of root suckers/stump as well as old stunted seedlings.

The NMDS analysis revealed visual separation between species compositions at the three sites (Mfunganisha, Chibombo, and Nyampande), with Chibombo appearing somewhat distinct from the other two sites. This visual trend suggests that ecological factors, such as site history, rainfall patterns, or successional stages, might contribute to compositional differences. However, the statistical results from the ANOSIM test (p-value = 0.10, F = 2.31) indicate that the observed separation is not statistically significant at a 0.05 confidence level. These findings suggest that while there may be ecological trends or factors influencing species composition, the differences are not strong or consistent enough to conclude that the communities are distinct definitively.

This could imply:

- Shared ecological drivers across the sites, such as similar species pools or comparable levels of disturbance and recovery.
- Variability within each site that masks clear distinctions in composition.

The lack of statistical significance might also reflect limitations such as sample size, environmental variability, or the sensitivity of the ANOSIM test to subtle ecological gradients.

5.2 Species Diversity.

Generally, the study revealed a high Shannon Weaver index of diversity (H') values across all three sites ranging from 2.6 to 2.8 (Table 1). An ecosystem with an H' value greater than 2 is considered highly diverse in terms of species (Magurran 1988; Barbour et al., 1999). These values are an indication that the disturbed miombo woodlands are recovering relatively fast in terms of species diversity in comparison to the undisturbed forest, but not so fast in terms of species composition. These high species diversity values could suggest a greater number of successful species, a more stable ecosystem, more ecological niches, and complex food webs. This is important for maintaining ecological diversity and nutrient cycling (Kall, 2006). The high species diversity in all three sites can be attributed to streams that empty rich organic content and mineral resources utilized by species for growth and production. The marginal differences in H values can be attributed to several factors. Chibombo with the highest species diversity belongs to AER IIa which receives a higher precipitation ranging from 800-1000 mm annual rainfall and is characterized by fertile soils such as Luvisols, Acrisols, and Vertisols. These factors, although not investigated could account for the good recovery of Miombos in terms of species diversity (JAICAF, 2008). Mfunganisha recorded the lowest species diversity which could be attributed to animal grazing and trampling of certain species which was observed during data collection. Domestic animals eat some species and trample on them as they feed. In addition, both Mfunganisha and Nyampande belong to AER I which receives less rainfall between 400-800mm annually explaining the stunted growth and yellow leaves observed on some of the species, this could contribute to their lower species diversity in comparison.

Mwakalukwa etal reported H' of 3.44 and 3.6 in Tanzania (Mwakalukwa *etal.*, 2014). In Central Angola, Goncalves *etal*, (2016) reported H' values of 2.9 (mature forest), 2.81, 2.71, and 2.61. All these are high species diversity values that can be attributed to large sample sizes. In Malawi, Kamangadazi (2019) found H' values ranging from 2.4 to 3.3, this was attributed to many tributaries and streams as well as undisturbed woodland's presence in all three sites.

In Zambia, Chidumayo (1987) carried out an assessment of species diversity in Northern, Northwestern, Central, and Eastern provinces and found H' values of 1.98, 2.03, 1.92, and 1.89 respectively. In comparison, our study values were higher than those of Chidumayo (1989). This could be attributed to the fact that Chidumayo's study combined results for shifting cultivation and charcoal burning.

It was expected that in Nyampande, the undisturbed woodland would record higher species diversity values than the disturbed woodlands given that it had not undergone a major disturbance; however, this was not the case as the difference was minimal. Many species seem to have adapted well after the disturbance in Chibombo. Although Chibombo had the highest species diversity, Mfunganisha and Nyampande recorded higher species richness. This can be attributed to drought-resistant trees that were observed and can withstand the little rainfall characteristic of AER I (JAICAF, 2008). Physical examination of the trees in Mfunganisha revealed yellow leaves and stunted growth owing to the little rainfall associated with this area and the erratic rainfall experienced the previous years. An analysis of diversity using the Simpsons index (D) indicates that Chibombo is more diverse than Mfunganisha and Nyampande. This can be accounted for by the fact that Mfunganisha and Nyampande were largely dominated by two species and therefore had low evenness compared to Chibombo which had a high evenness.

5.3 Analysis of Height and Size classes

The high number of individual trees was observed in the smaller height and size classes, and this is expected for recovering forests. These results are in agreement with several other studies (Kamangazi, 2019; Mugunga *et al.*, 2022). This could be an indication of steady forest recovery and development. It shows that there is active regeneration and recruitment in the woodland. The low frequency of larger diameter and height classes can be a result of disturbance from pole cutting and frequent fires

(Kamangazi, 2019). The consistent inverted J-shape of sampling distribution indicates healthy regeneration and is a good indicator of how species composition and diversity may develop in the future.

5.4 Stem Density.

The high number of stems in Mfunganisha in comparison to the undisturbed woodland can be accounted for by the presence of two species with very high coppicing effectiveness and growth. These species are *Pilliostigma thonningii* (Schumach.) Milne-Redh and *Bauhinia petersiana* Bolle. For example, one stump or root sucker of *Pillistigma thinning* Milne-Redh would give rise to about 70 shoots. *Bauhinia petersiana* Bolle seem to do well in high temperatures and drought conditions. The results obtained in this research agree with the results obtained in other studies. A study carried out in Tanzania recorded a decrease in the number of main stems with an increase in years in fenced areas where animal interference was eliminated. This study reported a decrease in stem density from 23350 stems ha-1 to 13905 stems ha-1 (Njoghomi *et al.*, 2020a). Generally the main stems tend to decrease with increase in years.

The low number of trees and stem density in Chibombo could be attributed to seedling shoot die-back caused by overgrazing and uncontrolled fire. Herbivory grazing has a negative effect in that it affects growth in height and stem resulting in the creation of an imbalanced shoot ratio and further severe attacks can kill shoots. It reduces stem density, limits height growth, and reduces foliage density. The presence of herbivores in Miombo forests and the subsequent grazing affects negatively the growth rate of coppices, root sprouts, and seedlings (Matowo *eta l*,. 2019). During the dry season, community members set the bushes on fire to clear the bushes for security reasons and for easy hunting of rodents which is a delicacy and source of proteins for people in this area. Although edaphic factors were not investigated, studies such as those conducted by Chidumayo (1991) cited fire as a major constraint to the sustained growth of seedlings of Miombo trees. Trapnell (1959) adds that seedlings of Miombo canopy species die back because of drought and nutritional stress during the long dry season. Furthermore, it was observed that in Chibombo, the Brachystegia species were exploited for fiber and small poles at an early stage by community members. This exploitation had an impact on the stem density.

All in all, the observed differences among the three sites can be explained by their different histories of land use, vegetation types, and climatic conditions. The regenerating forests at these sites may be at different stages of succession, which could account for the differences in stem density between Mfunganisha and Chibombo. Nyampande served as the control site and is undisturbed woodland. Being undisturbed, it likely has a more stable and mature ecosystem with fewer disturbances that could reduce stem density. Despite belonging to the same eco-region as Mfunganisha, Nyampande's stem density is lower, which might be due to the natural composition of the woodland, which could favor fewer, larger trees rather than much smaller, regenerating stems as seen in the other two sites.

5.5 Mean Height.

The mean stem heights of trees of all species review some differences in comparison to the finding by chidumayo (1993). Below is the comparison of the results obtained in this study (A) and those obtained by chidumayo (1993).

Table 5.4 Mean Stem Heights. (Source: This Report).

Source	Age (years)		
	1	2	3
Current study (m)	0.8	0.5	0.7
Chidumayo (1993) (m)	0.5	0.7	1.1

These differences in height could be attributed to the different conditions that the trees were exposed to such as temperature, availability of nutrients and water.

The high number of stems in Mfunganisha in comparison to the undisturbed woodland can be accounted for by the presence of two species with very high coppicing effectiveness and growth. These species are *Pilliostigma thonningii* (Schumach.) Milne-Redh and *Bauhinia petersiana* Bolle. For example, one stump or root sucker of *Pillistigma thinning* (Schumach.) Milne-Redh would give rise to about 70 shoots. *Bauhinia petersiana* Bolle seem to do well in high temperatures and drought conditions. The results obtained in this research agree with the results obtained in other studies. A study carried out in Tanzania recorded a decrease in the number of main stems with an increase in years in fenced areas where animal interference was eliminated. This study reported a decrease in stem density from 23350 stems ha-1 to 13905 stems ha-1 (Frost, 1996)

5.6 Regression Analysis of Height and Diameter (Analysis of association).

The results obtained in Mfunganisha showed a very weak positive association between diameter and height, r = 0.414 (figure 4.9). The goodness of fit ($R^2 = 0.1748$) indicates that only 17.5% of the variation in height was explained by diameter. There was a significant (p-value = 0.0073) relationship between diameter and height. However, Chibombo showed a much stronger significant (p-value=2.38E-12) relationship between diameter and height (r=0.854, R^2=0.7297). The goodness of fit indicated that 72.97% of the variation in height was explained by diameter (figure 12). This difference can be attributed to site quality; the availability of nutrients and water in site two could be the reason for better growth of the trees. Chibombo is part of AER IIa, which receives a higher annual precipitation (800-1000 mm) in comparison to site two, which receives a lower annual precipitation (400-800 mm) (JAICAF, 2008). Stunted growth of trees was observed in Mfunganisha, with yellow leaves with dark spots. Yellow leaves are an indication of too little water and lack of nutrients in Mfunganisha. The dark spot is a sign of fungal disease in the plants.

5.7 Regression Analysis of Height and Age (Analysis of Association).

The regression analysis of the mean height and age data (age of field after abandonment) for both Mfunganisha and Chibombo (combined data) shows a very strong positive association between height and age (r = 0.8387), i.e., as age increases, so does height. The coefficient of determination was R2 = .7034; therefore, 70.34% of the variation in height is explained by age (figure 14). Regression analysis of diameter and age data (combined data) for Mfunganisha and Chibombo reveals a strong positive correlation (r = 0.8168). R2=0.6672; therefore only 66.72% of the variation in diameter can be explained by height (figure 15). However, there is a probability that the output is by chance (p-value = 0.076).

5.8 Analysis of Variance of Mean Heights and Diameter.

There were no significant differences in mean heights and diameter between Mfunganisha and Chibombo. This can be attributed generally to climate change experienced through erratic rainfall and high temperatures that the entire country has experienced over the last five years.

5.9 Mode of Regeneration.

The results reveal a similar pattern in both sites, Chibombo and Mfunganisha. The most dominant regeneration type or mode in these two former fields of cultivation is root sucker. Stump regeneration ranks second, and seed ranks third. This can be attributed to the form of shifting cultivation practised in both of these sites. It is very different from the one practised in the Northern Province, where only branches are lopped, leaving a stump of considerable height. In Mfunganisha, they use manly tractors for farming, which requires that they remove the stump completely and some roots for smooth passage of the tractor and smooth reaping of the soil. In Chibombo, the farming equipment they use mainly is ploughs and hoes, and in rare cases a tractor. A plough requires the removal of some stumps and surface roots to clear a way for the ow. However, not all stumps were removed, although most of them were cut to the lowest level possible. Coppice production is affected by the height above the ground at which the stem is broken. Most shoots were regenerating from stumps that were cut closer to the ground (<5 cm), leading to less coppice growth than plants that are cut higher up at DBH (Grundy, 1990). Three cases of burning the stump and the roots to completely kill the tree in the field were observed in both sites Mfunganisha and Chibombo.

Very few cases of seed regeneration were recorded in both sites, Chibombo and Mfunganisha. This can be attributed to the lack of coppicing with standard. There was no mature tree recorded in both sites to provide seeds for the next generation, with the exception of a mango tree recorded in Chibombo.

This mango tree was spared because it provides food in the form of fruits to the farmers. The few seed regeneration recorded was mainly by animal dispersal. The mortality of seedlings is initially high during the establishment phase. The major cause of death in both sites appears to be moisture and heat stress. Seed germination and seedling survival are largely dependent on the availability of rainfall, as the radicle must penetrate the soil soon after germination (Frost, 1996). Mfunganisha receives less rainfall compared to Chibombo; however, generally, the country has experienced erratic rainfall over the last few years. Further, the majority of Miombo seedlings experience a lot of shoot dieback due to water stress and fire during the dry season (Frost, 1996). Mfunganisha receives less rainfall compared to Chibombo; however, generally, the country has experienced erratic rainfall over the last few years. Further, the majority of Miombo seedlings experience a lot of shoot dieback due to water stress and fire during the dry season (Frost, 1996). Chidumayo (1992) adds that generally, Miombo seedlings grow slowly even in the absence of shoot dieback.

Although Nyampande was undisturbed woodland, more than 50% of trees recorded in this site were seed germination belonging to different generations. This can be attributed to the many mature trees that provide seeds for the next generation. The few cases of stump and root sucker regeneration were a result of a combination of natural mortality and human exploitation.

A similar finding was reported in Tanzania that Miombo ecosystems regenerate robustly through coppicing and root sprouts (Sangenda and Maleko, 2018). The results obtained in this study are not consistent with results obtained by Syampungani (2008). The study obtained 29%, 62%, and 8%, corresponding to coppices, seed, and root suckers, respectively (Syampungani, 2008). According to these results, the most dominant mode of regeneration is seed. The difference can be attributed to three reasons: Firstly, the results obtained by Syampungani (2008) combined slush and burn with timber harvesting, while this study solely focused on shifting cultivation. Secondly, Syampungani focused on a selected few species, while the results yielded in this study were for all species encountered in this study. Lastly, there were no mature trees encountered in the abandoned fields in this study to provide seeds for regeneration, accounting for the low number of seed regeneration. The cases of seed regeneration were a result of animal dispersal.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.0 Overview

The final chapter summarizes the key findings of the study and provides conclusions based on the results. It also offers practical recommendations for policymakers, conservationists, and local communities, with a focus on promoting sustainable land-use practices and enhancing the regeneration of Miombo woodlands.

6.1 Conclusion

The NMDS results and species composition data collectively suggest ecological distinctions among the three sites, particularly highlighting Chibombo's unique composition and Nyampande's mature woodland characteristics. However, the lack of statistical significance in ANOSIM results calls for cautious interpretation. Further research integrating functional diversity and temporal changes could provide a more comprehensive understanding of these ecosystems.

The study revealed very high species diversity indices indicating a good recovery in terms of species, however, it is very important to assess the recovery in conjunction with other indicators such as stem density and tree density which reveal a slightly different and more realistic picture of recovery. These indicators reveal a good recovery in both tree density and stem density in Mfunganisha while Chibombo does not post a good recovery in comparison. The very low p-value suggests that there are statistically significant differences in the mean number of stems between the three locations. The Null hypothesis is therefore rejected.

Root sucker was found to be the most dominant regeneration mode in the disturbed woodlands mainly due to the agricultural practices in Chibombo and Mfunganisha. Therefore, any conservation management decision and promotion of sustainable agricultural practices must take into account this revelation.

The results of this study generally showed that shifting cultivation causes disturbances that are transient in nature and do not always hinder regeneration. The recovery of Miombo forests may be possible if these fields are kept undisturbed for a long time.

6.2 Recommendation

Following this research, I suggest the following recommendations:

- Reducing the carrying capacity: To promote maximal recovery, restrict herbivorous grazing in the degraded areas.

- Frequent Monitoring: Create long-term monitoring initiatives to evaluate the species variety, composition, stem density, and tree density of both disturbed and undisturbed forests on a frequent basis. This will make it easier to comprehend the process of recovery and spot any unfavourable patterns early on.

- Encourage Alternative Livelihoods: Encourage ecotourism, beekeeping, and the sustainable collection of non-timber forest products as examples of alternative livelihoods. By doing this, the woodlands may be protected from the need for shifting agriculture and the manufacturing of charcoal.
- There is need for more research to determine the site quality and the health of regenerating trees.

- Promote coppicing with standards among farmers to promote seed regeneration.

- Regeneration Modes: The predominant regeneration modes seen in various species should be taken into account in conservation plans. For instance, species like Parinari curatellifolia, which regenerates vigorously through seeds, may benefit from encouraging methods that improve seed regeneration.

- Conserving Important Species: Put conservation measures in place to safeguard important Miombo species, especially those like Brachystegia species, which are in decline as a result of extended exposure to shifting cultivation.

- In order to encourage substantial forest recovery and meaningful height increase, a minimum of 50 years of fallow time must be permitted, according to the anticipated outcomes.

- The NMDS visualisation points to intriguing ecological variations among the locations that demand more research. Use further multivariate approaches, expand the sample size, and take into account additional environmental factors.

- Coppicing with Standards: Encourage farmers to adopt sustainable agricultural practices such as coppicing with standards, where some trees are left standing during harvesting. This practice can promote seed regeneration and maintain a diverse species composition in disturbed woodlands.

- Agroforestry: Introduce agroforestry systems that integrate trees with crops. This can reduce the pressure on woodlands and promote the regeneration of native Miombo species by providing alternative sources of fuelwood and timber.

- Community Involvement: Include nearby communities in monitoring and restoration initiatives and educate them about the value of Miombo woodlands to involve them in conservation efforts. Their sense of accountability and ownership for managing forests sustainably may grow as a result.

- Examine Other Recovery Indicators: Although species diversity and stem density have been clarified by this study, more research should look into other recovery indicators such soil quality, carbon sequestration, and the existence of keystone species.

- Examine the Effects of Climate Change: Research how the Miombo forests are being affected by climate change, with an emphasis on how species composition and regeneration are impacted by shifting weather patterns. This will aid in the creation of plans to lessen the impact that climate change is having on these ecosystems.

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APPENDICES

Appendix A: Field inventory tools

FIELD TREE INVENTORY DATA	* FIELD WITH RED INK ARE MANDATORY

DATE:	TIME:	SITE:	CHIEF:	AGE:	SuB-PLOT:

ID	BOTANNICAL NAME	LOCAL NAME	HEIGHT	DIAMETER	STEMS	NO TREES	REGENERATION
1							
2							
3							
4							
5							
6							
7							

Recording standard form.

Basic field inventory equipment

ITEM	PRIMARY USE	QUANTITY
9M Height Meter	Measuring height	1
5M Tape	Measuring height	1
10M string	circular plot	1
Pencil	Data recording	5
Pens	Data recording	5
Calipers	Measuring diameter	1
Stickers	Labels	10 packs
Know your trees book	tree identification	1
Exercise books	Data recording	2
Chalk	marking tree	1 pack
Hoe	regeneration type determination	2
100M string	transect	2
Plant checklist	tree identification	1

Appendix B: Statistical Tables

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.010096191	1	0.0100962	0.091826	0.76705748	4.747225
Within Groups	1.319389868	12	0.1099492			
Total	1.329486059	13				

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.10243483	1	0.10244	0.2255	0.645111	4.9646027
Within Groups	4.543377531	10	0.454338			
Total	4.645812356	11				

Appendix C: Field Images

Measuring diameter in the field. (Source: This Report)

Determing the mode of regeneration in Mfunganisha (Rufunsa). (Source: This Report)

Tagging of *Brachystegia bohemi* after taking measurements in Mfunganisha (Source: This Report)

Appendix D: Ethical Approval

THE UNIVERSITY OF ZAMBIA

DIRECTORATE OF RESEARCH AND GRADUATE STUDIES

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APPROVAL OF STUDY

IORG No. 0005376
NASRECREC IRB No. 00006465

22nd December, 2023

REF NO. NASREC-2023- NOV – 005

Mr. Chanda Ngoma
The University of Zambia,
P.O. Box 32379,
LUSAKA.

Dear, Mr Chanda

RE: "NATURAL REGENERATION OF MIOMBO TREES AFTER SHIFTING CULTIVATION: ACASE STUDY OF CHIBOMBO AND RUFUNSA DISTRICTS."

Reference is made to your protocol dated as captioned above. NASREC resolved to approve this study and your participation as Principal Investigator for a period of one year.

REVIEW TYPE	ORDINARY REVIEW	APPROVAL NO. NASREC-2023 - NOV - 005
Approval and Expiry Date	Approval Date: 22nd December, 2024	Expiry Date: 21st December, 2024
Protocol Version and Date	Version - Nil.	21st December, 2024
Information Sheet, Consent Forms and Dates	• English.	To be provided
Consent form ID and Date	Version - Nil	To be provided
Recruitment Materials	Nil	Nil
Other Study Documents	Questionnaire.	