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NATIVE TREE SPECIES DIVERSITY, STRUCTURE AND REGENERATION OF MASHOZA REMNANT NATURAL FOREST IN EASTERN RWANDA

A thesis submitted in partial fulfillment of the requirements for the degree of Master in Biodiversity Conservation and Natural Resources Management

By

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DECLARATION

I, **MANAYABAGABO Floribert** , declare that this master's dissertation "**Native Tree Species Diversity, Distribution, And Regeneration in Mashoza Remnant Natural Forest in Eastern Rwanda**"is the result of my own work in partial fulfilment of the requirements for the award of a master's degree in Biodiversity Conservation and Natural Resource Management at the University of Rwanda, College of Science and Technology and has not been submitted for any other degree at the University of Rwanda or any other institution. All sources that I have used or quoted have been indicated and acknowledged in the references.

Signed by:

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APPROVAL

I certify that this research project entitled "**Native Tree Species Diversity, Distribution, And Regeneration in Mashoza Remnant Natural Forest in Eastern Rwanda "** was done under my supervision and has been submitted for examination with my approval.

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Nyarugenge on....../.... /…….

DEDICATION

My family

My parents,

My brothers

My sisters

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LIST OF ACRONYMS AND ABBREVIATIONS

CBD: Convention on Biological Diversity

CBNRM: Community Based Natural Resource Management

CST: College of Science and Technology

DBH: Diameter at Breast Height

DV: Dependent variable

IV: Independent variable

EAC: East African Community

FAO: Food and Agriculture Organization

GPS: Global Position System

H: Height

IUCN: International Union for Conservation of Nature

MEA: Millennium Ecosystem Assessment

MoE: Ministry of Environment

NAFA: National Forestry Authority

REMA: Rwanda Environment Management Authority

RFA: Rwanda Forestry Authority

UA: University of Arizona

UN: United Nations

UNEP: UN Environment Programme

USAID: United States Agency for International Development

ABSTRACT

A remnant forest is a fragmented area of a formerly extensive forest that has survived through significant disturbances, often characterized by the presence of remnant trees. Mashoza remnant forest preserves a variety of biological diversity. However, human pressure has caused reduction of its biodiversity. By assessing the tree species diversity, composition and regeneration of native trees in Mashoza remnant natural forest in the eastern Rwanda to fill the gaps on data on the remnant forest and therefore generate a baseline data to researchers, policymakers. Sampling plots of 20 by 20 meters were used for the tree species inventory. Plots were situated within the forest precisely from 50 meters far the edge to avoid edge effect. The sampling plots were located on hills and in valleys in southern, central, and northern parts of the forest. On each hill, three sites were chosen on foot, in the center, and on the top of the hill and in valley. In each plot, species diversity and abundance of adult trees, saplings, and seedlings were recorded. Every tree species in each plot was identified and registered. The height and DBH of all trees inside the plots were measured for all trees with a DBH of at least 5 cm, using a Suunto Clinometer PM-5/360PC and a diameter tape. Samplings and seedlings were counted and recorded in each sample plot and R (vegan package) studio has been used for data analysis. In total, 27 tree species were identified in the Mashoza remnant natural forest and no statistical difference was observed in terms of tree species diversity in sites located on hill foot, middle, and top of the hills neither in valleys. Higher values of the Evenness index in the foot (0.42) than in the middle (0.40) and the top (0.28) indicate a higher degree of evenness and diversity of species in the central regions of the hill. There is less diversity in the top and foot compared to the middle part of the hills in the forest. With over 24 adult trees, 88 saplings, and 44seedlings, the Mashoza remnant natural forest demonstrates a promising low capacity for recovery and self-sustainability. The seedlings are less than samplings indicating a problem of survival of seedlings in the forest. As the study was conducted in the dry season, it is recommended that further studies be conducted in rain season to understand the reason behind the less numerous seedlings in the forest. In addition, the Mashoza remnant forest should be protected because of its biodiversity and particularly its tree species diversity, which can serve as a gene pool for important native tree species.

Keywords: Mashoza remnant Natural Forest, Tree species richness, Trees species diversity, Natural regeneration, Diameter at Breast Height (DBH).

CHAPTER 1: INTRODUCTION

1.1. Background of the study

The world has a total forest area of 4.06 billion hectares (ha), which is 31 percent of the total land area. Ninety-three percent (3.75 billion ha) of the forest area worldwide is composed of naturally regenerating forests and 7 percent (290 million ha) is planted. However, the area of naturally regenerating forests has decreased since 1990 (at a declining rate of loss), but the area of planted forests has increased by 123 million ha. The area of forest in protected areas globally has increased by 191 million ha since 1990, but the rate of annual increase slowed in 2010–2020 (FAO, 2020) . More than one-third of the forest area is primary forest, and nearly half is relatively intact. While many forests have more biodiversity than other ecosystems, the FAO asserted that forest ecosystems constitute an essential part of the world's biodiversity in its report on the state of the world’s forest (FAO, 2020).Forests provide habitats for most of the terrestrial biodiversity (MEA, 2005). The way the forest is conserved and managed is highly impacting biodiversity conservation. They provide shelters for most of the fauna, such as 80 per cent of amphibian species, 75 per cent of bird species, and 68 per cent of mammals (Jean-Christophe Vié, 2009). In addition, 60 per cent of vascular plants found in tropical forests and mangroves help trap sediments that might negatively affect more marine species and serve as nurseries for several species of fish and shellfish (FAO, 2020) .

Africa hosts diverse forests from mangroves to Afromontane, dry, and tropical rainforests. All those African forests represent 17 per cent of the world’s forests (FAO, 2021). According to FAO, many people depend directly on that forest while 60 per cent of Africans depend either indirectly or directly on their goods and services (FAO, 2021). Despite the role of forests to Africans, the natural forests are being cut at an alarming rate. FAO claim the loss of more than 10 per cent of the continent’s forest cover registered between 1980 and 1995. This results in poor forest management policies, natural disasters, and forest fires. Furthermore, the high dependence on wood for domestic energy needs is a handicap for forest conservation (UN, 2008).

Forests of Rwanda occupy now about 724,695 hectares of the total country land (30.4%) of which 130,850 hectares (18.1%) are natural mountain rainforests (MoE, 2019).

The remnant terrestrial ecosystems are considered as natural habitats with rich biodiversity (flora and fauna) and their extinction would result in loss of threatened species or species in extinction and the associated effects would be an imbalance of ecological functions (Bizuru Elias, et al., 2011). Mashoza remnant forest is under protected reserved forest under the ministerial decree 06/2015 (DFMP, 2016).

Species diversity refers to the variety and abundance of different species within a specific area, it includes the number of different species present (species richness), how evenly individuals are distributed among these species (species evenness), and the types of species and their relative abundances (species composition) (Biodiversity: an introduction, Measuring Biological Diversity., (Gaston, & Spicer, Magurran, 2004). However, this is affected by a variety of different processes, only some of which operate across spatial scales. At a global scale, change in species diversity is only affected by two processes, extinction and speciation, and the net balance between these two processes determines whether diversity is increasing or decreasing on Earth while at regional scales, diversity is also increased by speciation and decreased by extinction (Sax, D. F; Gaines, S. D., 2003) The decreases in diversity include those caused by regional extinction events that extirpate species from the region in question but not necessarily from all other areas at local scales, diversity is affected by the same processes that operate at larger scales, except that the process of speciation is rarely important. However, biological and physical interactions become extremely important in determining diversity at local scales. This is because interactions between species and between species and their physical environment will significantly affect the total number of species within a local area (Sax, D. F; Gaines, S. D., 2003)

In this regard, we take into consideration the contribution of tree species diversity analysis to the conservation of nature, by assessing the variety of species, their distribution, and their roles within the ecosystem. This will be achieved by tree species assessment to identify of species composition and structure of the Mashoza remnant natural forest, one on the list of the remnant natural forests in Rwanda. The knowledge of tree species composition and richness is a key aspect during the development of the management plan and the biological conservation process of the forest ecosystem. Mashoza natural forest was selected for the study because remnant natural forests have been left out.

The ecological classification of tropical trees proposed by (Swaine, M. D., & Whitmore, T. C., 1988) which is the most widely used in the tropics, is based upon the concept of regeneration niche (Grubb, 1977) . (Swaine, M. D., & Whitmore, T. C., 1988) have established that tropical forest trees can only be grouped in two ecological categories: pioneers and climax (no pioneers) species and they believe that pioneers can only germinate and establish in clearings, whereas climax species generally germinate and establish in shaded sites or under the forest canopy. However, (Bullock., 2000) have claimed that this classification does not correspond to the high diversity neither to the complex of competition stages of substitution and stabilization found in tropical forests. They also remark that pioneers and climax are the opposite extremes in a wide succession gradient, which represents all the possible responses to environmental perturbations. Therefore, the forest succession continuum cannot possibly rely on just two succession or establishment groups.

Eastern African forests are rich in biodiversity and even unique. Regional forest cover is being significantly impacted by deforestation and forest degradation. Between 1990 and 2015, Uganda's forest cover decreased by over half, from 24% to 12.4% of the country's total land area. Tanzania has some of the highest rates of deforestation in the world; if current trends continue, all of Tanzania's forests will disappear within 50 to 80 years. Deforestation and degradation in the region are caused both directly and indirectly by the expansion of agriculture for commercial and subsistence farming, unsustainable timber harvesting, the manufacture of firewood, charcoal, and poles, the development of infrastructure, and wildfires. (Esther Mwangi et al, 2018).

In Rwanda, the analysis done on forests distributions indicates that 40 percent of country forests are found in Eastern province almost 274,630 hectares. And then 85,688 hectares of forests are found in Northern Province (REMA, 2021). Despite its small size of 26,338 square kilometers, an array of species from the Albertine Rift in the West to the savannah lake and swamp systems of the Akagera region in the East. The natural forests of Rwanda are considered a habitat of various species and play a big role in biodiversity conservation. They are considered as an essential provider of ecosystem services including food, improvement of water and air quality, medicine, wood, climate control and diseases, nutrients cycling, cultural and relax around the area. Also, Rwanda has several natural galleries forests located in different districts countrywide, these forests are used for providing tree to other sites and as well goods and services, among them we have one situated in Ngoma District, Eastern Province. This study focuses on the natural remnant forest named as Mashoza or Rugomero or Rujambarara or Parike is natural forest situated in Ngoma district, Rurenge sector.

1.2. Problem statement

Mashoza forest is natural forest located in Eastern Province, Ngoma District, Rurenge Sector. It counts about 17.78 hectares and is edged by Mwambu wetland for rice plantation in its south while agricultural practices of Maize crops are being practiced in the East, West and north (REMA, 2015) . The forest is composed by different native tree species including *Albizia adianthifolia* (Umusebeya), *Acacia sieberiana var. vermoesenii* (Umunyinya), *Combretum molle* (Umurama), *Clausena anisate* (Umuno), *Allophylus chaunostachys* (Umunywamazi), *Securinega virosa* (Umubwirwa*)*, etc. Given the importance of the Mashoza natural forest to conserve biological diversity, it is facing by serious problems such as illegal activities such tree cutting by local people for firewood and construction, harvesting of traditional medicines that lead to the trees debarking and even uprooting them, scraping the culmiferous layer by surrounding people to fertilize their agricultural land, clearing the forest land for agriculture activities, no distinct limit of the forest, unclear evenness and richness of the native tree species within the forest. The observation demonstrates how different tree species are throughout the forest state that a variety of interrelated factors, including competition, geographic location, historical and evolutionary history, and environmental conditions, may have contributed to this variation (Criddle et al., 2003).

Even if there is still some biodiversity present in Mashoza remnant natural forest, human pressures have caused the area to reduce from 36.25 ha in 1985 to 17.78 ha (REMA, 2015). This reduction may be linked to a loss of biodiversity in terms of species variety, abundance, and distribution. According to (Bernard, et al., 2017) current information on the composition, abundance, and diversity of the forest's flora is necessary for improved forest management. They emphasized that there is a lack of information in many tropical regions, particularly about the smaller and frequently fragmented forests (Bernard, et al., 2017) . To determine the species composition, richness, and evenness of trees in the Mashoza natural forest ecosystem, comprehensive research is thus required. This is why it is seen to be crucial to advance our understanding of the state of biodiversity, beginning with an investigation of the diversity of tree species. Tree species are the foundation of the forest ecosystem; therefore, we begin by analyzing them.Studies were done on the woody species richness of a remnant gallery forest in eastern Rwanda by (Nduwamungu j & Habyarimana., 2011) the Rwanda's tropical forests and biodiversity analysis by the (USAID, 2019) .In addition, (Mugunga C et al., 2022) carried out a study on the diversity of tree species in a naturally regenerated secondary forest in the Ruhande Arboretum in Rwanda. These studies demonstrate how Rwanda's diverse forest ecosystems support a wide variety of tree species, but many of these studies just looked at species identification; they neglected to look at diversity indices. Moreover, although the Mashoza natural forest, spanning 17.78 hectares, is a significant biodiversity hotspot and one of the remaining natural forests, there is lack of data on its diversity and regeneration. This work contributed to the understanding of its diversity, distribution and tree species natural regeneration.

Existing studies have primarily focused on broader ecological assessments and conservation strategies, often overlooking detailed analyses of specific native tree species (Smith, J., & Doe, A. , 2020). The limited data available on species composition and spatial distribution hinders the development of targeted conservation and management plans. Additionally, the regeneration dynamics of these species remain poorly understood, with insufficient information on seedling survival rates, growth patterns, and factors influencing successful regeneration (Jones et al., , 2019). Furthermore, there is a need to investigate tree regeneration in Mashoza remnant natural forest.

1.3. Research objectives

1.3.1. General objective

The general objective of this research is to assess the species diversity, composition and regeneration of native trees in Mashoza remnant natural forest in the eastern Rwanda to fill the gaps on data on the remnant forest and therefore generate a baseline data to researchers, policymakers.

1.3.2. Specific Objectives

The specific objectives of the research are:

1. To analyze tree species diversity of the Mashoza remnant natural forest
2. To evaluate the structure of the Mashoza remnant natural forest
3. To analyze tree regeneration of the Mashoza remnant natural forest

1.4. Research questions

1. How diverse are tree species in the Mashoza remnant natural forest?
2. How tall and large are trees in the Mashoza remnant natural forest?
3. How do tree species regenerate in the Mashoza remnant natural forest?

1.5. Research hypotheses

1. The Mashoza remnant natural forest has a high level of tree species diversity.
2. Trees in the Mashoza remnant natural forest exhibit significant variation in height and diameter.
3. The status of tree regeneration in the Mashoza remnant natural forest has regeneration both seedlings and saplings.

1.6. Significance of the study

The results on the diversity of tree species in Mashoza natural forest will serve the Rwanda Forestry Authority (RFA) and Rwanda Environment Management (REMA) in their advocacy to protect and rehabilitate tree species. The study will help the RFA to domesticate and disseminate the indigenous tree species across the country. The community will benefit from this research as it will enhance its knowledge on the remnant forest and improve its interaction with the forest ecosystem.

CHAPTER 2: LITERATURE REVIEW

2.1. Forest and biodiversity

Forests are "ecosystems dominated by trees" (NAFA., 2022). A tree is defined as a woody perennial plant having a single main stem or several stems in the case of coppice (FAO., 2020) or as a perennial plant that has a trunk and an upper portion composed of branches and leaves, and that, when fully grown, stands at least six meters tall (Paterson, 2004). Globally, forests cover nearly one third of the land area and they contain over 80% of terrestrial biodiversity. Both the extent and quality of forest habitat continue to decrease and the associated loss of biodiversity jeopardizes forest ecosystem functioning and the ability of forests to provide ecosystem services. As population pressures rise, it's crucial to maintain and restore forest ecosystems (Aerts, R. and Honnay, O. , 2011) . The resilience of a forest ecosystem to changing environmental conditions is determined by its biological and ecological resources, in particular (i) the diversity of species, including micro-organisms, (ii) the genetic variability within species (i.e., the diversity of genetic traits within populations of species), and (iii) the regional pool of species and ecosystems. Resilience is also influenced by the size of forest ecosystems (generally, the larger and less fragmented, the better), and by the condition and character of the surrounding landscape.

Primary forests are generally more resilient (and stable, resistant, and adaptive) than modified natural forests or plantations. Therefore, policies and measures that promote their protection yield both biodiversity conservation and climate change mitigation benefits, in addition to a full array of ecosystem services. Nevertheless, it must be recognized that certain degraded forests, especially those with invasive alien species, may be stable and resilient, and these forests can become serious management challenges if attempts are made to re-establish the natural ecosystem to recover original goods and services. Some forest ecosystems with naturally low species diversity nevertheless have a high degree of resilience, such as boreal pine forests. These forests, however, are highly adapted to severe disturbances, and their dominant tree species have a broad genetic variability that allows tolerance to a wide range of environmental conditions.

Rwanda's biodiversity resources are a valuable natural endowment that offers a wide range of benefits and opportunities for local and national economic development, improved livelihoods and provision of environmental goods and services such as biodiversity and watershed protection. The challenge is to sustainably manage its biodiversity for present and future generations, by better balancing human needs with those of the environment. Meeting this challenge will require fundamentally new strategies and approaches for valuing and managing biodiversity goods and services (Kenny., 2015).

The Rwandan biodiversity policy provided resource managers with objective perspectives of the relationships between humans, and ecosystems and their interactions on which decisions on conservation and sustaining of environmental goods and services shall be based (Billy., 2004). It has been observed that human activity has been changing the natural ecosystems through agricultural and industrial development, and human settlement, over-exploitation of certain species and the introduction of invasive species. This has resulted in habitat loss and degradation, and the pollution or toxification of the soil, water and atmosphere. In addition, some species have been lost and ecological processes impaired. This policy provides the framework for effective strategies for action to save biodiversity and promote sustainable use (Hekkens, 2011) .

In addition, while protected areas will continue to serve as core and center pieces of the conservation efforts, they will be complemented by other categories of conservation areas and conservation-based production systems. This policy provides for comprehensive conservation planning through the formulation of a National Conservation Plan. The current network of National Parks covers just over 8 percent of the national territory, while Vision 2020 calls for its expansion to over 10 percent. This policy provides for the expansion of the protected area network through the establishment and gazetting of new national parks and other categories of protected areas (Salesa, 2014). It is recorded that 634,000 hectares of natural forest were decreased to 221,200 hectares for a period of 40 years. It means that 65% of area of the natural forest were disappeared from the year 1960 to 2000 (Bikorimana, D., et al. : , 2023). Currently, the forests of Rwanda occupy 30.4 per cent of the total country land area either 387,425 hectares (53.5 per cent) are occupied by forests plantations, 130,850 hectares (18.1 per cent) are occupied by natural mountain rainforests, 161,843 hectares (22.3 per cent) covered by wooded savannah, 43,963 hectares (6.1 per cent) are shrubs and only 613 hectares (0.1 per cent) are for Bamboo stands (REMA, 2021)

There has long been global concern about the long-term capacity of forests to maintain their biodiversity and associated rates of supply of goods and services (including carbon storage, food, clean water, and recreation). This concern has been amplified following observed impacts occurring to global forests as a result of climate change (e.g., (Phillips, O. L., et al., 2009).

Maintaining and restoring biodiversity in forests promotes their resilience to human-induced pressures and is therefore an essential ‘insurance policy’ and safeguard against expected climate change impacts. Biodiversity should be considered at all scales (stand, landscape, ecosystem, bioregional) and in terms of all elements (genes, species, communities). Increasing the biodiversity in planted and semi-natural forests will have a positive effect on their resilience capacity and often on their productivity including carbon storage (Lamb, D., et al. , 2018)

2.2. Forest multilayered canopy

One of the most important signs of a natural forest is its multilayered canopy. This is caused by the varying traits of several tree species found in the natural forest environment and its succession group, namely the late succession trees known as climax trees and the early succession "pioneer species." Species that spontaneously grow on formerly barren or disturbed land usually led to ecological succession, according to (Ashton et al. , 2012). Pioneer species are often plants that have adapted to live in open, high-light environments, such as having expanded roots and root nodes that contain bacteria that fix nitrogen. This is because uncolonized terrain may have thin, nutrient-poor soils. Alternatively, trees that develop in mature (climax) forests with shade are known as Climax Tree Species. These species can endure shadows in their saplings (forru, 2008)Trees in forest can be native or non-native. The native tree is the living, growing, and reproducing tree that is naturally produced in the particular region (Wolde-Rufael, 2010) *or* one that has not been introduced by man and occurs naturally (Gitonga, 2005) *or* indigenous and original to a particular geographical area or indigenous or natural to the site (Medes, 2012). Native trees are perfect for providing food and shelter for our wildlife (Gitonga, 2005).

"Biodiversity" is defined by CBD as "the diversity of life represented at the ecological, species, and genetic levels." The Earth is a special location where humans can live because of the diversity of living forms and how they interact with one another and the environment (McNeely et al. , 2022). The world wildlife claimed that a wide range of species, including fungus, animals, plants, and even bacteria, comprise our natural habitat. Additionally, biodiversity maintains all of the natural resources necessary for human survival, such as food, clean water, medical care, and a place to live ((UNEP, 2020)

The reduction of biodiversity in Rwanda can be attributed to both natural processes and anthropogenic activity. Recent research indicates that risks to biodiversity include deforestation and poaching that result in resource abuse, habitat loss due to agricultural encroachment, and rising socioeconomic activities including mining and urbanization (UNEP, 2022)

2.3. Forest fragmentation

A major problem influencing ecosystem health and world biodiversity is forest fragmentation. It happens when big, continuous forest areas split up into smaller, more isolated patches as a result of agricultural growth, urbanization, and deforestation. Due to the increased risk of extinction for species that depend on vast, continuous ecosystems; this process has major ecological ramifications, including a notable loss of biodiversity. Edge effects where environmental conditions at the margins differ significantly from the interior are common in fragmented forests and have the potential to change species composition and habitat quality (Fahrig, 2003). In addition, species mobility can be impeded by habitat isolation brought about by fragmentation, which can lower genetic diversity and increase extinction risk (Laurance, W. F., et al., 2014)

Beyond the effects on a single species, forest fragmentation affects entire ecosystems by interfering with biological processes like seed distribution and nutrient cycling. Degradation of ecosystem services and disturbed ecological balance are examples of long-term effects that can be difficult to reverse (Haddad, N. M., et al., 2015).The major impacts of humans on forest ecosystems include loss of forest area, habitat fragmentation, soil degradation, depletion of biomass and associated carbon stocks, transformation of stand age and species composition, species loss, species introductions, and the ensuing cascading effects, such as increasing risk of fire . (Uhl, C., & Kauffman, J. , 1999)

The term natural remnant natural area, also known as remnant habitat, is an ecological community containing native flora and fauna that has not been significantly disturbed by destructive activities such as agriculture, logging, pollution, development, fire suppression, or non-native species invasion (Zahara, 2017). In order to preserve ecological integrity and promote biodiversity, effective forest conservation initiatives must address fragmentation by safeguarding large, contiguous areas and establishing links between fragmented patches (Gardner, T. A., et al. , 2009)

2.4. Tree regeneration

Tree regeneration is the process that allows a forest to sustain itself through the growth and survival of seedlings and saplings that replace large forest trees as they die. In another word, Natural regeneration is how trees have reproduced, unassisted by people, throughout their millions of years of evolution. Tree regeneration is a fundamental indicator of restoration success. The tree regeneration is the rebirth or re-production of the tree for making them into the existence again. The process of natural regeneration involves the renewal of forests by means of self-sown seeds, root suckers, or coppicing. Tree regeneration is a key process in forest dynamics, particularly in the context of forest resilience and climate change. The recovery of tree richness and density in pastures released from grazing varies depending on the presence of and distance to forest remnants in the landscape, as well as the life history and dispersal mode of the colonizing plants (Derroire, 2023).

Forest ecosystem resilience and sustainability depend on the efficient regeneration of tree species. Numerous ecological factors, including as soil quality, availability of light, and competition from other vegetation, affect regeneration processes. According to studies, in order to guarantee that a variety of tree species can, successful regeneration frequently entails a combination of natural and aided approaches. For instance, a study shows that species-specific regeneration strategies can improve forest recovery and biodiversity. These strategies include protecting young saplings from browsing and encouraging seedling establishment through selective thinning

CHAPTER 3: MATERIALS AND METHODS

This chapter covers the methods and materials used to collect and analyze the information for responding the research question of trees species diversity analysis in Mashoza natural forest. It outlines the research design, study area, sample procedures, data source, and instruments to be used for data collection and analysis.

3.1. Description of the study area

Mashoza is located on 2°06'37.2"S 30°30'39.5"E, also known as Rujambara or Rugomero or Parike is a natural gallery forest. The state-owned forest is located in Rurenge Sector and Rujambara Cell along Mwambu marshland, Rusasa and Mwambu streams, approximately 750m downriver and west of Abudada Dam and 6.2km southwest of Kigarama town. It is a relatively small forest of about 17.78 hectares, situated on a hillside of Mashyoza. In the south, Mashoza is bordered by Mwambu wetland, site of extensive rice plantations. According to ministerial decree (06 / 2015) there is only one protected forest in Ngoma District. Forest Law nº47bis/2013 of 28/06/2013 states in Article 2 that ‘a protected forest is a forest in which it is forbidden to carry out any activities other than those provided for by this law.

Mashoza is highly degraded due to anthropogenic activities. The surrounding wetland exploited for rice cultivation progressively encroaches on the forest, and in other sides, there are no limits between the fields of various crops and the forest. Additionally, tree cutting for firewood and building materials is like a custom to local population. This degradation has led to many clearings, and as consequence, invasive plant species are widely spread in this ecosystem and have replaced original native species. Mashoza Natural Forest change over time since 1984 to 2015 are 36.25ha and 17.78ha respectively. This results to 51.0% of loss. Mashoza remnant forest is under protected reserved forest under the ministerial degree 06/2015 (DFMP technical report 13, 2016).

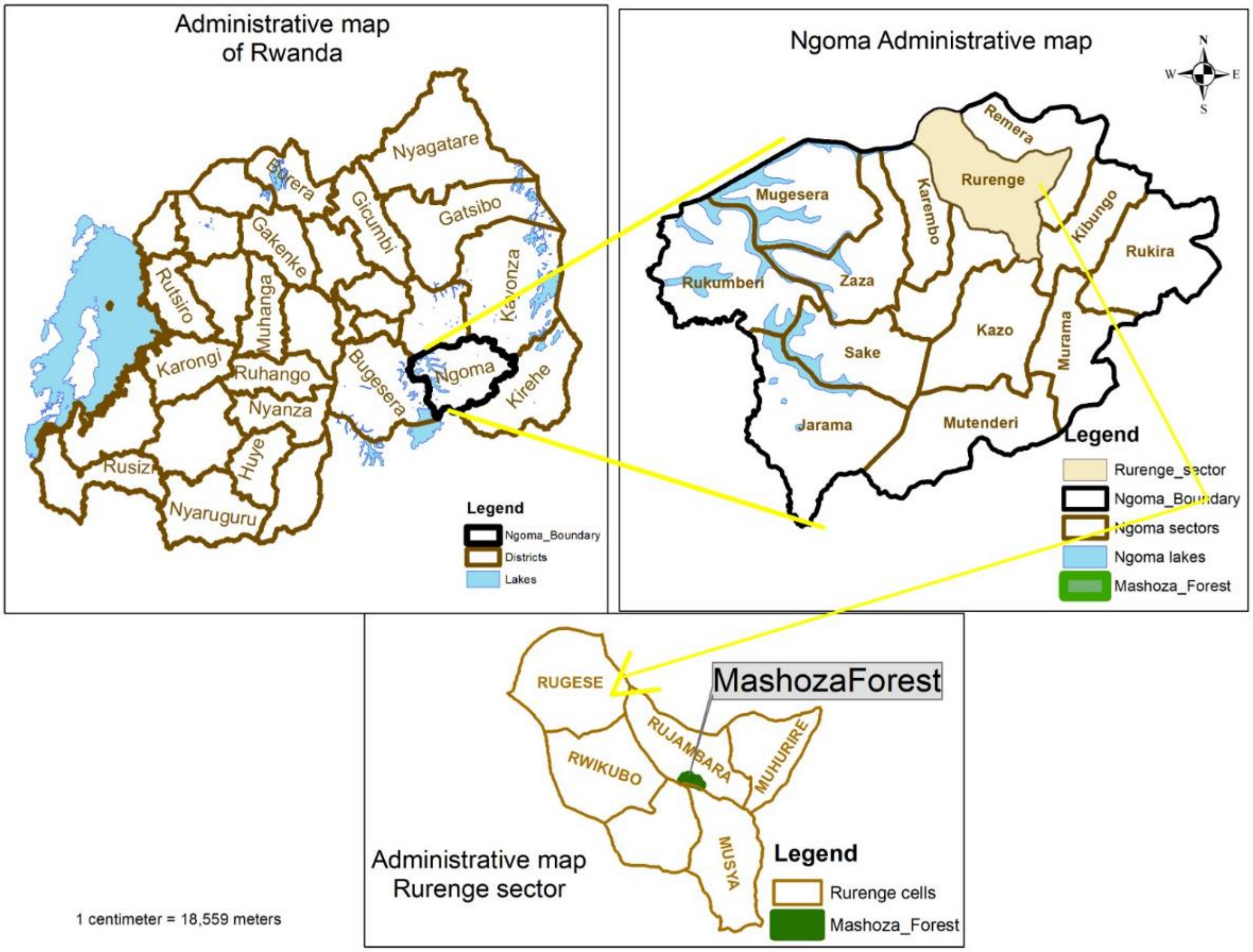

Figure 1:Localization of Mashoza Natural Forest in Rurenge Sector, Ngoma District

3.2. Sampling design and data collection

Systematic sampling was carried out for the inventory of the tree species diversity, composition, structure, and regeneration. The inventory of tree species was conducted in plots of 20m x 20m plots. Sampling plots were located inside the forest at exactly 50 m from forest edge. In each plot, adult trees, tree saplings and seedlings were identified and their abundance recorded. The sampling plots were designed in valleys, at the foot of hills, in their middle parts, and on their tops at both east and west orientation of the hills. Nine hills were sampled in total: three hills in the south, other three hills in the center and other three hills in the north part of the forest. In each plot, all tree species in the plots, both adults, saplings and seedlings, were identified in the field or at National Herbarium of Rwanda Using handbooks conserved specimen. Additionally, diameter at breast height (DBH) and total height data of all trees having DBH ≥ 5 cm were recorded. Height and

DBH data of all trees inside the demarcated plots were collected using Suunto Clinometer PM-5/360PC and diameter tape respectively.

The quantity of tree species provides information on species richness, evenness, and composition, and the tree DBH and height data are helpful for the analysis of the forest structure. The species richness is the number of distinct species found in a given area whereas the evenness determines how evenly or equally individuals are distributed among species (Lára, 2023) . To perform the data collection exercises, a series of equipment were used: the DBH was assessed using a Caliper 0.02 mm, and the height of the trees using a Suunto clinometer PM-5/360PC.

3.3. Species richness, diversity and composition analysis

Species richness is the number of different species that are represented in a given community whereas the species diversity is defined as the number of different species present in an ecosystem and relative abundance of each of those species (Dorward, 2009). (Sohier and Charlotte. , 2022) state that the objective of a biodiversity index is to produce a quantitative measure of biological variability in space or time that can be utilized to compare biological entities consisting of different components. The species composition can be expressed either by species groupings or by individual species, depending on the objectives of the inventory or monitoring program (UA, 2022). Two important components to take into account when evaluating the state of biodiversity in a particular environment are species richness and evenness. The number of distinct species found in a given area is referred to as species richness, whereas the relative abundance of the various species in a given area is measured as species evenness. As a result, there will be more species richness in an area with high species diversity. Since the diversity index considers both species richness and evenness, conservationists frequently only use it.

The calculation of different biodiversity indices complied with the different formulas and models developed by several scientists namely: (Sorensen; T. , 1948), (Magurran, 2004), (Shannon - Wiener, 1963), (Pielou.EC., 1966) , etc. The Shannon Index (Shannon-Wiener Diversity Index) and were used for this study to assess the tree species diversity. The Shannon Index assesses tree diversity by taking into account both species richness and species evenness. It is sensitive to both the number of species present and the uniformity of their distribution and higher Shannon index values suggest increased diversity. It is calculated by using the following formula:

$$H' = -\sum_{i=1}^{S} pi ln(pi) \quad \text{Equation 1}$$

where pi is the fraction of individuals belonging to the i-th species, and S is the total number of species.

The Shannon index values rarely go above 4 and range from 1.5 to 3.5 (May, 1975). The more diversified the community, the higher the value (Rita et Al., 2023) recommend calculating the Evenness (E), which give a value ranging from 0 to 1, in order to ease the interpretation of the index result. The "evenness" describes how similar the abundances of various species are throughout the population. A community is considered to be more diversified and even if its value is closer to 1. Additionally, the index that compares the species richness inside a community or between two communities is the similarity index.

There is more concerned with dominance within a group, calculating the probability that two individuals randomly selected from a sample will belong to the same species (dominance). Lower highlight the dominance of one or a few species in a community and its lower values suggest greater diversity. The following equation 2 is used to calculate:

$$D = \sum_{i=1}^{S} pi^2 \quad \text{Equation 2}$$

where pi^2 is the fraction of individuals belonging to the i-th species, and S is the total number of species.

The most commonly used to measure species diversity. Its value ranges from 0 to 1. Complete diversity is represented by values closer to one, whereas less diverse communities are represented by values closer to zero. According to Simpson's diversity index, two randomly chosen individuals will belong to distinct species with a probability equal to the value observed, based on the value of D that was computed. When examining the species diversity of an environment, it's also important to take the species composition into account. Typically, it is stated as a percentage, meaning that 100% represents all species components (Adrienne, 2022) It explains of the role that every kind of plant plays in the vegetation.

3.4. Tree natural regeneration analysis

A comprehensive inventory of the tree species presents in the forest, including both mature trees, saplings and seedlings, have been surveyed, counted and recorded in order to assess the status of tree regeneration in Mashoza remnant natural forests. To ensure representativeness and accuracy, this inventory was done by using plot sampling method. Data on species composition, species richness and distribution of seedlings and saplings provide insights into the regeneration status and potential succession pathways of the forest.

CHAPTER 4: RESULTS PRESENTATION

4.1. Tree species richness and diversity in Mashoza remnant natural forest

In the whole forest 38 plant families have been counted and they are distributed into three different strata which are Foot, Middle, and Top. At the Foot and Top, the family of Rutaceae is more distributed than others with 17.2% and 22.91% respectively while at the Middle, the family of Amaranthaceae is more represented than others with 14.36%. (Figure3).

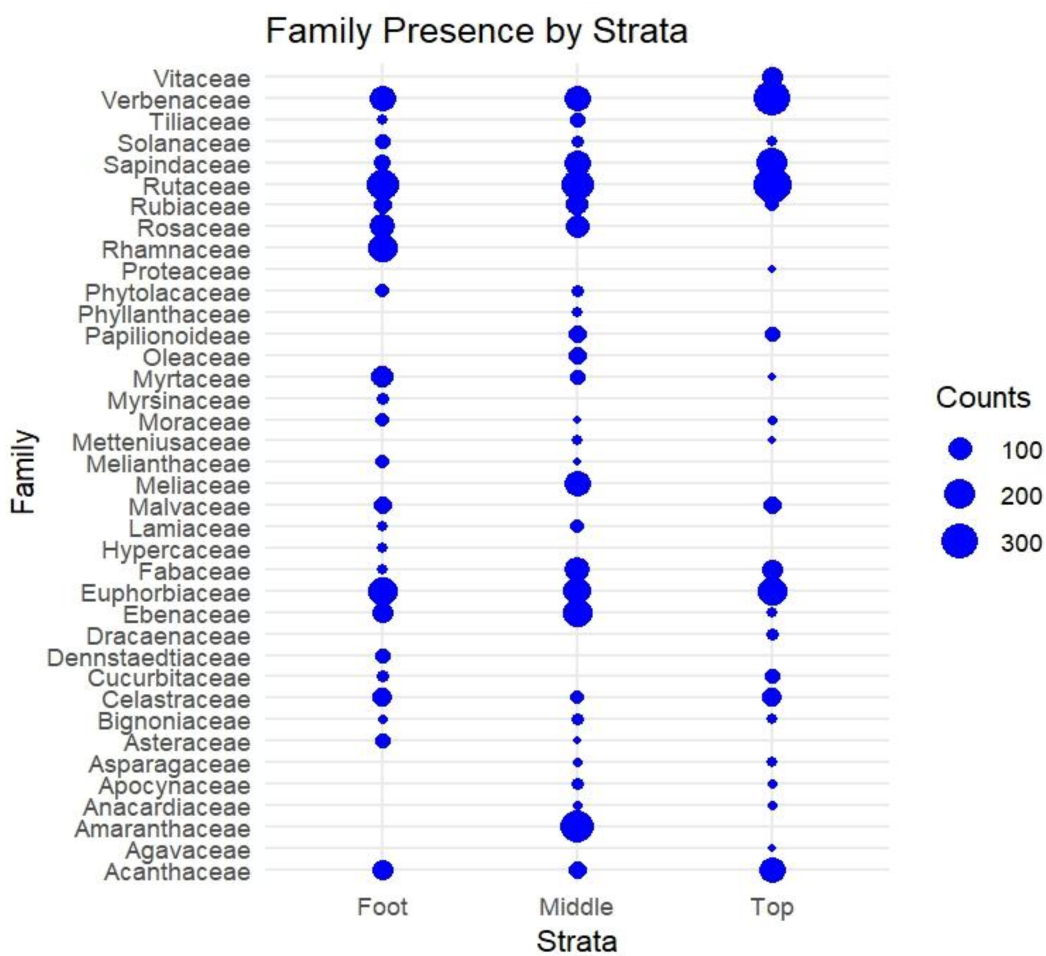

Figure 2 : Family distribution identified in Mashoza remnant natural forest

Table 1: Tree species invented in the Mashoza remnant natural forest

Species Scientific name	Maximum height (m) of mature tree	Species local name	Familly
Acacia sieberiana	25	Umunyinya	Fabaceae
Afrocanthium lactescens	8	Umukondokondo	Rubiaceae
Albizia adianthifolia	15	Umusebeya	Fabaceae
Apodytes dimidiate	20	Umusibya	Metteniusaceae
Bersama abyssinica	10	Umukaka	Melianthaceae
Blighia unijugate	35	Umuturamugina	Sapindacea
Bridelia micrantha	20	Umugimbu	Euphorbiaceae
Clausena anisate	10	Umuno	Rutaceae
Croton macrostachyus	25	Umurangara	Euphorbiaceae
Ekebergia capensis	35	Umufumba	Meliaceae
Entada abyssinica	15	Umusange	Fabaceae
Erythrina abyssinica	15	Umuko	Fabaceae
Euclea divinorum	8	Umudawa(Umushikiri)	Ebenaceae
Ficus asperifolia	30	Umuseno	Moraceae
Kigeria africana	25	Umuvungavungo	Bignoniaceae
Maesa lanceolata	9	Umuhanga	Myrsinaceae
Markhamia lutea	15	Umusave	Bignoniaceae
Maytenus senegalensis	13	Umushubi	Celastraceae
Prunus africana	24	Umwumba	Rosaceae
Pterygota mildbraedii	30	Umuguruka	Malvaceae
Rhus vulgaris	12	Umusagara	Anacardiaceae
Sapium ellipticum	35	Umusasa	Euphrobiaceae
Schrebera alata	15	Umubanga	Oleaceae
Securinega virosa		Umubwirwa	Phyllanthaceae
Teclea nobilis	10	Umuzo	Rutaceae
Toddalia asiatica	10	Umugasa	Rutaceae

The distribution shows that the middle part of the hill has the highest species richness, with 11 species recorded. The hill foot follows with 8 species, while the hill top has the lowest species richness with only 5 species (Table2). The species richness varies with the position on the hills (Table 2). The hill top has the lowest species richness (5 species) and a relatively low Shannon index (1.32). The middle part of the hill has the highest species richness (11 species) and a Shannon index of 1.88. The hill foot, while having slightly lower species richness (8 species) compared to the middle, has the highest Shannon index (1.99). No trees were found in valley sites.

Table 2 Species richness and tree diversity of adult trees in Mashoza remnant forest

Part of Hill	Species Richness	Shannon Index	Evenness Index
Foot	8	1.99	0.70
Middle	11	1.88	0.66
Top	5	1.32	0.47

4.2. Tree population structure

The distribution of tree heights shows a wide range with most trees falling between 15 and 30 m height in the Mashyoza forest. *Prunus Africana* is the highest tree (17.67m) and *Prunus africana* with (17.7m) and *Clausena anisata* the lowest mean height (3.5 m). The highest mean DBH was 41cm for *schrebera alata,* and *vernonia amygdlina* , *ficus asperifolia* have the lowest mean DBH of 7cm.

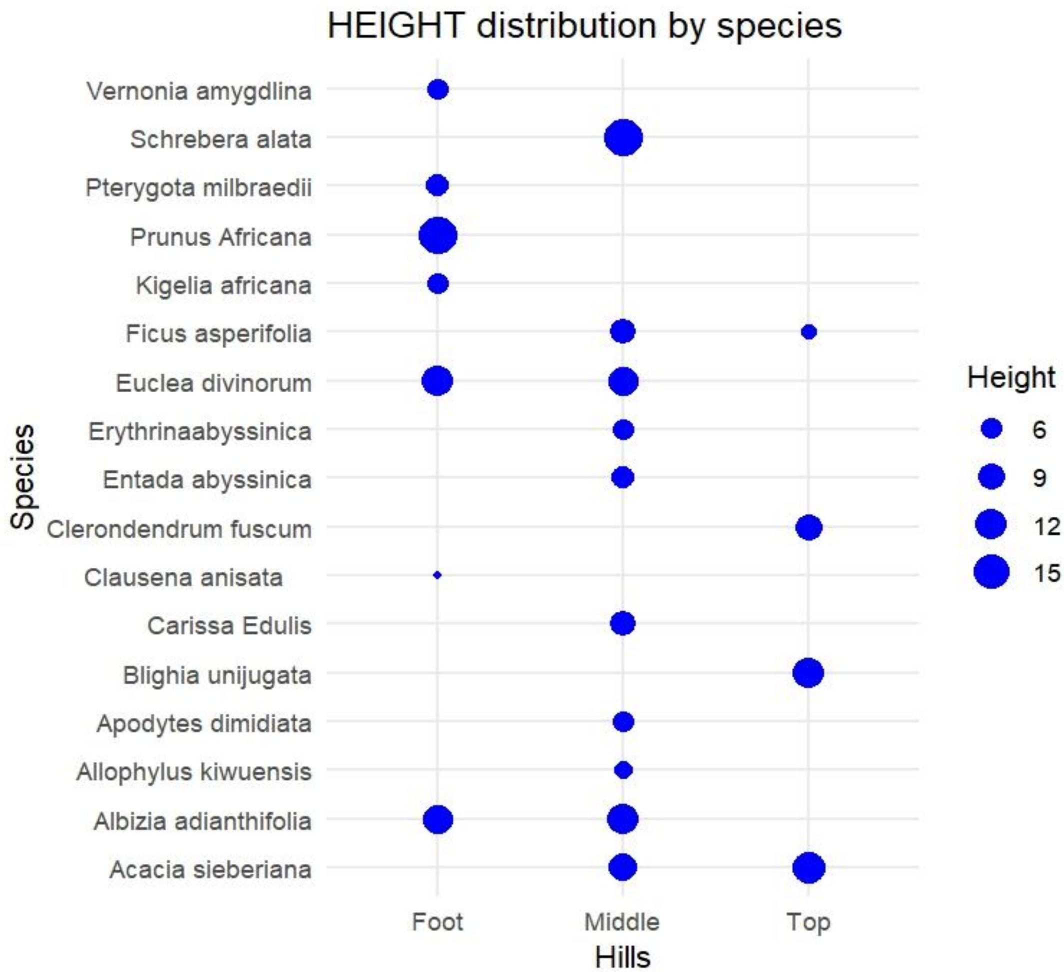

Figure 3: Height distribution by species in the whole forest

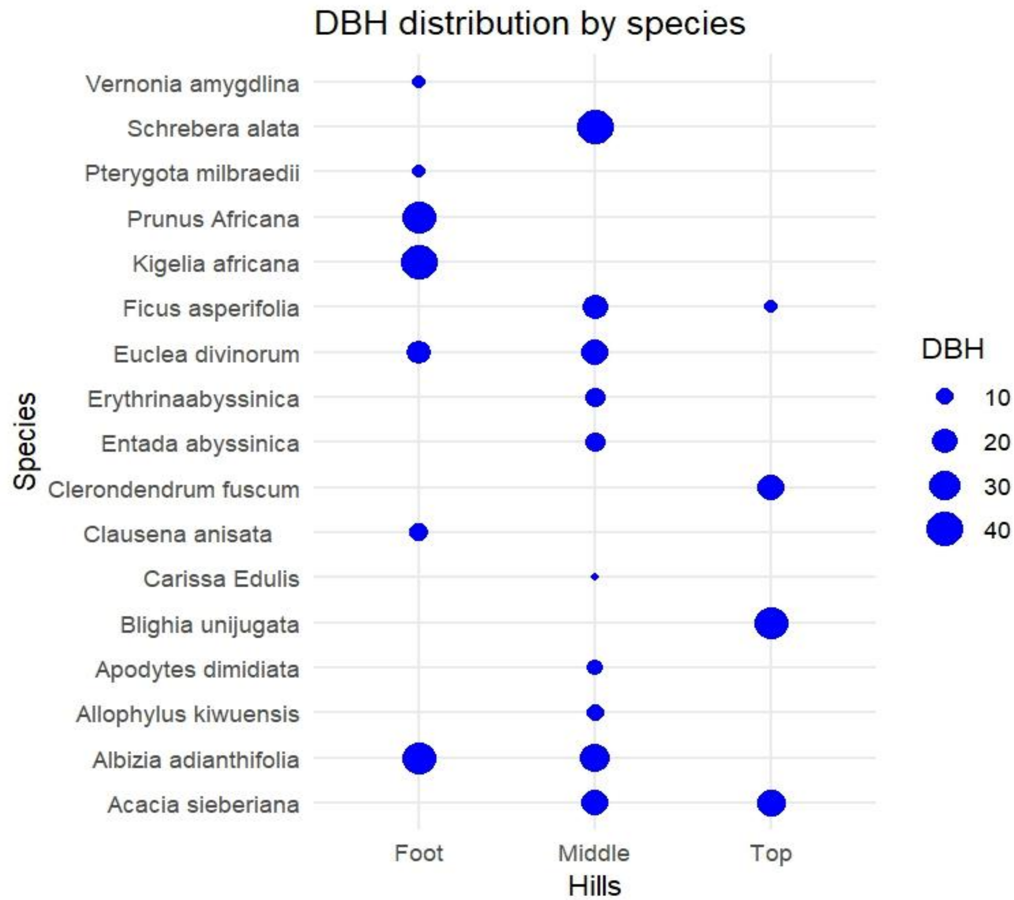

Figure 4: DBH distribution by species in the whole forest

4.3. Tree regeneration in the Mashoza remnant natural forest

The forest not exhibits a dynamic and healthy regeneration process, as evidenced by the population distribution across different growth stages. In total, there are 2,745 saplings, 1,636 seedlings, and 54 adult trees. This distribution pattern aligns with no expectations for a well-regenerating forest, where the number of saplings surpasses that of seedlings, which in turn outnumbers the adults. Such a pattern indicates that new plants are not successfully replacing older ones. The distribution shows that the foot part of the hill has the highest seedling species richness with 17 species recorded. The hill top follows with 14 species, while the hill middle has the lowest species richness with only 13 species. The Shannon index was 2.07 in the hill middle, 1.78: in the top part of the hill, and 1.82 in the hill foot (Table 3).

Table 3: Species richness, diversity of seedlings in Mashoza remnant natural forest

Part of Hill	Species Richness	Shannon Index	Evenness Index
Top	14	1.78	0.51
Middle	13	2.07	0.54
Foot	17	1.82	0.38

Regarding the tree saplings in the Mashoza forest, the analysis shows that the middle part of the hill has the highest sapling species richness with 31 species recorded. The hill foot follows with 29 species, while the hill top has the lowest species richness with only 28 species. The hill top has a relatively low Shannon index (2.20). The middle part of the hill has a Shannon index of 2.90. The hill foot, has the highest Shannon index (2.90) (Table 4).

Concerning the sapling evenness, the data reveals that the distribution of saplings across different species is relatively balanced at both the foot and middle of the hill, with an evenness value of 0.71. This indicates that saplings are fairly evenly spread among the various species in these areas. In contrast, the evenness value at the top of the hill is lower at 0.54, suggesting a less balanced distribution, where certain species may dominate while others are less represented. This pattern highlights the importance of monitoring and managing species composition to ensure balanced regeneration and biodiversity throughout the forest.

Table 4: Species richness and diversity of tree saplings in the remnant forest

Part of Hill	Species Richness	Shannon Index	Evenness Index
Foot	29	2.90	0.71
Middle	31	2.90	0.71
Top	28	2.20	0.54

CHAPTER 5: DISCUSSION OF RESULTS

5.1. Tree species richness differs on different hill parts in Mashoza remnant natural forest

The tree species richness data across different forest zones was shown in table 2, it is evident that the middle of the forest hosts a higher diversity of species compared to the top. This can be attributed to the more stable microclimatic conditions in the middle, which provide a conducive environment for both shade-tolerant and moisture-dependent species (Jones, A. et al. , 2015). (Whittaker, R.H. , 1967) explained that the highest species richness can be attributed to several ecological and environmental factors such as this area benefiting from moderate temperatures, balanced sunlight exposure, and sufficient moisture levels, making it an optimal habitat for many tree species. Additionally, the accumulation of organic matter in this zone likely enhances nutrient availability, supporting a richer variety of plant and animal life (Robinson et al, 2013) .

In contrast, the top of the forest, being more exposed to harsh conditions such as wind, solar radiation, and temperature fluctuations, limits species diversity (Johnson, R. et al., 2014)**.** The drier conditions and poorer soil quality at the top further reduce its capacity to support a wide range of species. According to (Brown, M. et al. , 2008)**,** areas with greater exposure to environmental stressors typically exhibit lower biodiversity, as fewer species can tolerate extreme conditions. Additionally, it has better water retention or access to groundwater compared to the top, which might be drier, and the foot, which might be more prone to waterlogging (Aber, J.D., & Melillo, J.M., 2001). The middle zone of the forest might represent an area with intermediate disturbance, promoting coexistence of diverse species by preventing dominance by a single species (Huston, 1994).

5.2. Tree species diversity is the lowest on hill tops in the Mashoza remnant natural forest

The Shannon index along the strata was shown in table 2 indicates that Foot with high index followed by middle and then the top is 1.88 in the middle part, 1.99 in the hill foot and 1.32 in the hill top. The comparison of these values indicates that the hill foot and middle have the same Shannon index and higher Shannon index than the hill top. The hill top has the lowest tree species diversity, suggesting that it has a low number of species compared to the middle and the foot of the hills in the study area. The variation in species diversity and distribution across different parts of the hill can be attributed to several ecological factors such as microclimate, soil conditions, and human disturbances (Whittaker, R.H. , 1967); (Brady, N.C., & Weil, R.R. , 2008);. For instance, the higher diversity and evenness at the hill foot may be due to more favorable moisture and soil conditions compared to the hilltop (Stephenson, N.L. , 1990); (Brady, N.C., & Weil, R.R. , 2008). Given the results, conservation efforts should focus on maintaining and enhancing species diversity across all parts of the hill (Lindenmayer, D.B., & Fischer, J. , 2013)

5.3. Tree species are more evenly distributed in the hill foot and middle hill parts than in the hill tops

The evenness values indicate that the hill top has the lowest evenness (0.38). The hill foot and the middle parts of the hills showed the same Shannon evenness. The hill top's Simpson evenness value of 0.38 is the lowest among the three areas (hill foot, middle, and top). This low value suggests that species distribution at the hilltop is less uniform, meaning that a few species may dominate the area, while others are less represented (Magurran, A.E. , 2004) . This uneven distribution can indicate that the hilltop has less biodiversity or less favorable conditions for maintaining a balanced ecosystem (Magurran, A.E. , 2004) . The hill foot and middle parts of the hill have the same Shannon evenness values, indicating that the distribution of species is relatively more balanced in these areas compared to the hill top. This higher evenness suggests that species are distributed more evenly across these areas, supporting greater biodiversity and potentially more stable ecological conditions (McCann, 2000). The similar values at the hill foot and middle imply that both areas have comparable ecological conditions that favor a more equitable distribution of species. These results indicate that the hill foot and the middle parts of the hills provide favorable conditions for tree growth and survival.

5.4. The tallest and largest trees are distributed in the hill foot in the Mashoza remnant natural forest

The mean tree height is 10.03, 8.97, and 9.56 m respectively on hill foot, middle, and top sites. The hill foot shows the highest average height (10.03 m), suggesting more favorable growth conditions such as better soil nutrients and moisture availability (Jiang, Y., & Wang, X., 2021); (Dawson, T.E., & Goldsmith, G.R. , 2022). The hill middle and top have progressively lower average heights, possibly due to harsher environmental conditions like increased wind exposure and poorer soil quality (Sperry, J.S., et al., 2020); (Barton, C.V.M., & Houghton, R.A., 2021).

The average DBH values for the different parts of the hill are: 27.34cm, 21.93, and 17.66 cm in the hill foot, hill middle and hill top respectively. Similar to the height measurements, the hill foot has the largest average DBH, indicating the presence of more mature and robust trees. The middle and top sections show smaller DBH values, which might suggest younger or stunted growth due to less optimal conditions. The hill foot exhibits the tallest trees with the largest DBH suggesting this area has the most favorable conditions for tree growth. The high values indicate a mature, dense forest structure with significant ecological and economic value. The hill middle shows intermediate values for height, and DBH, indicating moderately favorable growth conditions. This part may serve as a transitional zone with mixed characteristics of both the foot and top. The hilltop displays the lowest values for height, and DBH points to less favorable conditions for tree growth. This could be due to environmental stressors such as wind exposure, soil erosion, and lower nutrient availability (Kühn, I., & Klotz, S. , 2020). The variation in tree structure across the hill suggests different microhabitats and ecological niches. The dense and tall forest at the hill foot may support a diverse range of flora and fauna, providing crucial ecosystem services. The middle part, with its intermediate structure, might act as a buffer zone, while the sparse and shorter forest at the top may be more susceptible to environmental changes and disturbances. For the forest management, the hill foot needs just to be conserved and sustainably managed to maintain its dense and mature forest structure; the hill middle needs measures to enhance growth conditions, such as soil enrichment and controlled thinning, to promote tree growth and increase forest density, and the hill top may need reforestation and soil conservation strategies to improve tree growth conditions and stabilize the forest structure.

5.5. Tree seedlings are less numerous than saplings in in Mashoza Remnant Natural Forest

Seedling, Sapling, and Adult Tree Richness, Diversity, and Evenness are presented in table2, table 3 and table 4. The foot of the Mashoza Remnant Natural Forest has the highest seedling richness and high adult tree richness, along with high sapling richness. This area benefits from more moisture, nutrient accumulation, and more favorable conditions for seedling germination and growth. This is also reflected in the high Shannon diversity index for adult trees, which indicates a diverse community of established trees that create a favorable environment for new seedling recruitment. However, the lower seedling evenness suggests that a few species dominate due to their ability to take advantage of these optimal conditions. The high sapling evenness and adult tree evenness suggest that as seedlings grow into saplings and adults, competition among species becomes more balanced, and no single species dominates. This aligns with other studies that have shown lower slope areas in forest ecosystems often support higher species richness and diversity due to greater resource availability.

(Smith, B. et al., 2010) explain the higher diversity and evenness observed in the middle of the landscape. Studies have shown that areas with intermediate environmental conditions, such as mid-slope zones, often support higher diversity and more balanced species distribution because they avoid the extremes of too much competition or too much environmental stress. The **middle** of the landscape supports the highest sapling richness and adult tree richness, with high Shannon diversity for saplings and adult trees. The middle also shows the highest evenness for seedlings, suggesting a more balanced species representation at this stage of development. These patterns indicate that the middle zone provides intermediate environmental conditions—such as moderate soil moisture and nutrients—that promote a more even distribution and diversity of species. As seedlings transition to saplings and adults, these conditions support higher species richness and a balanced distribution. The higher diversity and evenness in the middle of the landscape compared to the foot or top are consistent with the intermediate disturbance hypothesis, which suggests that areas with moderate conditions (neither too favorable nor too harsh) often support higher species diversity. This balance of conditions may reduce competition among species, allowing a wider variety of species to coexist. (Jones, A. et al. , 2015) described that montane forests and sloping landscapes have consistently shown that moisture gradients play a key role in shaping vegetation distribution. In lower slope areas, such as the foot of a hill, moisture accumulation promotes higher species richness and diversity, while upper slopes often experience reduced species richness due to harsher conditions. This aligns with the patterns observed with data in table 2, 3, and 4, where the foot of the landscape has higher seedling richness and adult tree diversity, while the top shows reduced richness and diversity.

The top of the landscape has the lowest richness and diversity for both saplings and adult trees, with sapling richness at 28 and adult tree richness at 5. The Shannon diversity index for saplings and adult trees is lower than at the foot or middle, indicating that fewer species can thrive in these harsher conditions. The lower evenness for saplings and adult trees (0.47) suggests that a few species dominate in this zone, which could be due to environmental stress such as wind exposure, lower moisture, and poor soil conditions. Studies of forest ecosystems in mountainous or hilly landscapes have found similar patterns, where the top of hills or ridges often experiences lower species richness and diversity due to increased environmental stressors such as temperature fluctuations, wind, and reduced soil fertility. These harsher conditions limit the number of species that can establish and survive, leading to a less diverse and less evenly distributed plant community.

The significantly higher numbers of seedlings, saplings, and adult trees align with a good regeneration pattern, where adults < saplings < seedlings (Murray, B. A., & Londo, A. J. , 2022); (Foster, D.R., & Boose, E.R., 2021). This pattern is a positive indicator of the forest's ability to sustain and replenish itself over time. Effective seed dispersal mechanisms, possibly aided by wind, water, and animal activities, ensure that the seeds reach suitable sites for germination. The forest's biodiversity, including various seed dispersers and pollinators, likely supports this process. However, other research should be conducted within the forest to comprehensively assess the regeneration status of the tree species of the Mashoza remnant natural forest (Barton, K., & Smith, J., 2022); (Miller, R., et al., 2021).

This pattern is a negative indicator of the forest's ability to sustain and replenish itself over time. The forest not exhibits a successful regeneration pattern, as evidenced by the higher numbers of saplings (2,745) and seedlings (1,636) compared to adult trees (54), indicating no healthy potential for future forest sustainability.

CONCLUSIONS AND RECOMMENDATIONS

The comprehensive study of the Mashoza remnant natural forest has provided a detailed understanding of tree diversity, structure, and regeneration across different hill positions. In the Mashoza remnant natural forest, our assessment revealed a high level of species richness, with a total of 167 tree species identified. The diversity indices calculated indicate a balanced species evenness, suggesting a well-distributed tree population. Notably, species such as *Clausena anisata* was dominant, while *Markhamia lutea* was rare. The distribution analysis showed a diverse species, which may be linked to variations in soil type and moisture levels. the findings reveal that forest regeneration, saplings are higher than seedling which implicates that the future of the forest indicates potential challenges. The foot of the hill exhibits the highest regeneration potential with a greater number of seedlings, saplings, and mature trees, suggesting favorable conditions such as better soil quality, moisture retention, and protection from environmental stressors. In contrast, the top of the hill, with fewer seedlings and mature trees, indicates more challenging conditions for tree regeneration, likely due to harsher environmental factors. The middle part of the hill presents a moderate regeneration pattern, with balanced seedling and sapling counts leading to a steady number of mature trees.

Overall, the findings underscore the importance of site-specific strategies to support tree regeneration, structure, and distribution for forest sustainability. By addressing the unique conditions of each part of the hill, we can foster a resilient and diverse forest that continues to thrive and provide ecological benefits.

Based on the findings of the study on tree diversity, structure, and distribution in the Mashoza remnant natural forest, the following recommendations are made

- Regularly monitor tree growth and regeneration rates across different parts of the forest.
- Encourage further research on tree regeneration and growth in the forest
- By adopting these recommendations, the Mashoza remnant natural forest can be managed more effectively, resilient and diverse ecosystem that provides valuable ecological services and supports the livelihoods of local communities.

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