

**EFFECT OF COLLABORATIVE FOREST MANAGEMENT ON CARBON  
STOCKS, SPECIES DIVERSITY AND STEM DENSITY IN MABIRA  
CENTRAL FOREST RESERVE, UGANDA**

**BY**

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## DECLARATION

I, **Phillipson Mugumya**, hereby declare that the work contained in this dissertation is a true copy of my work effort except where has been referenced and has never been submitted for any degree award at this or any other University or institution of higher learning.

**Candidate**

**Signature.**



**Date.**

29<sup>th</sup> / SEPT / 2025.

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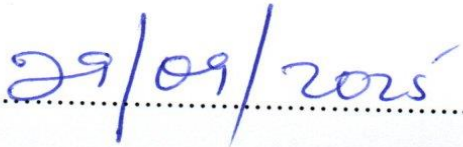
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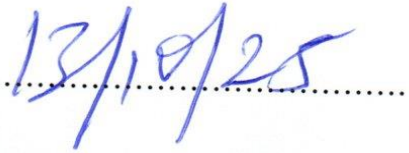
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## ACRONYMS

AGB	Above ground biomass
Asl	Above sea level
CFLRP	Collaborative forest landscape restoration program
CFM	Collaborative forest management
CFR	Central forest reserve
CO <sub>2</sub>	Carbon dioxide
CYC	Carbon yield coefficient
DBH	Diameter at breast height
<i>Et al</i>	And others
FAO	Food and Agricultural Organization
FC	Forest Certification
FTEA	Flora of Tropical East Africa
GPS	Global Positioning System
IUCN	International Union for conservation of Nature
JFM	Joint Forest Management
Km	Kilometers
Ms Excel	Microsoft excel software
MWE	Ministry of water and environment
NFA	National Forest Authority
REDD+	Reduced emission through degradation and deforestation
VYC	Volumetric yield coefficient

## ABSTRACT

Collaborative forest management (CFM) is a form of forest governance in which local communities are involved in the superintendence and administrative processes related to forest resources. It is believed that forests under such management are better in tree diversity and conservation status thus hold more carbon stocks. The study assessed the influence of CFM on carbon stocks in Mabira central forest reserve. This was achieved through measuring carbon stocks in forested areas under CFM viz a viz non-CFM areas, determining tree species diversity in forested areas under CFM viz a viz non-CFM areas, and determining tree stem-densities in areas under CFM viz a viz non-CFM areas in Mabira Central Forest Reserve. Data were collected from alternating plots laid along transects running from north to south in the different purposively selected forest areas. Field carbon stock assessment followed the procedure described by Asseffa *et al.*, (2013) Tree species diversity included species richness and species evenness as sampled among plots in the selected forest areas. Tree stem-density assessment was hinged on the method described by Eilu *et al.*, (2004). The study findings show that non-CFM areas have a greater variability and wider spread carbon stock values compared to CFM areas. CFM areas also had lower species richness compared to non-CFM areas. CFM areas however, exhibited more species diversity and variability than non-CFM areas. CFM areas had higher average stem density stands (309 stems per hectare) compared to non-CFM areas. Recommendations for improving collaborative forest management (CFM) areas include implementing targeted interventions to enhance carbon sequestration, such as promoting reforestation and afforestation with high-carbon-storing species, and strengthening monitoring and evaluation frameworks to assess carbon stock changes over time. Additionally, efforts should focus on enhancing biodiversity conservation by implementing more stringent protection measures and reducing human disturbance, while encouraging community participation in biodiversity monitoring and conservation education.

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background of the study

Collaborative Forest Management (CFM) is a participatory approach to forest management that aims to establish a mutually agreed-upon and beneficial relationship between eligible local community groups and the forest authority (NFA, 2020). CFM has been implemented in several countries, including Uganda, to promote sustainable forest management and improve the livelihoods of forest-adjacent communities (Kaggwa & Byakagaba, 2012). Over recent times, CFM has received considerable attention due to its potential in advancing sustainable forest management, enhancing livelihoods, and countering climate change by bolstering carbon stocks within woodland areas (Thammanu *et al.*, 2021; Gunawan *et al.*, 2023).

The linkage between tree stem density, species diversity, and carbon stocks is a critical area of research in forest ecology, with significant implications for carbon sequestration and ecological balance (Gebrewahid & Meressa, 2020). Tree stem density, which refers to the number of trees per unit area, influences carbon stocks as higher densities can potentially store more carbon collectively, though intense competition for resources might limit individual tree growth (Lan *et al.*, 2023). Conversely, lower densities may allow for larger individual trees, though the total carbon stock might be lower if fewer trees are present (Schaedel *et al.*, 2017). Species diversity, or the variety of species within a forest, also impacts carbon stocks by enhancing resource utilization efficiency and providing resilience against disturbances (Silva Pedro *et al.*, 2014). Diverse forests can achieve higher productivity and stability, thereby maintaining or increasing carbon storage over time (Hardiman *et al.*, 2013). The interplay between tree stem density and species diversity is complex: high density combined with high diversity can maximize carbon sequestration, while low diversity in high-density forests might lead to over competition and vulnerability to pests (Mensah *et al.*, 2023; Noulèkoun *et al.*, 2023). Research by Cavanaugh *et al.* (2014) indicates that tropical forests with high species diversity and optimal stem densities exhibit significant carbon stocks, whereas in temperate and boreal forests, the outcomes vary based on species composition and management practices.

Carbon stocks denote the volume of carbon sequestered within living and deceased vegetation, soil, and other natural materials within forests. Available evidence underscores the affirmative influence of CFM on forest carbon stocks, approximating 28,928 t C in carbon stocks impacted by CFM between 2007/2018 (Thammanu *et al.*, 2021). This points to the probable role of CFM in curtailing CO<sub>2</sub> emissions and alleviate the effects of climate change. Conserving carbon stocks can play a fundamental role in Plummeting Emissions from Deforestation and Forest Degradation (Gilani *et al.*, 2017), and engaging in the carbon market could have potentially yield approximately US \$8.66 per hectare annually (Thammanu *et al.*, 2021). A comprehensive survey encompassing global CFM experiences finds the mechanisms of CFM to be diversifying, indicating an increased acknowledgment of the necessity for collaborative partnerships in forest stewardship (Carter & Gronow, 2005).

In Uganda, Mabira Central Forest Reserve (CFR) has been the focus of CFM initiatives (Kaggwa & Byakagaba, 2012). The forest reserve is an important carbon sink and provides various ecosystem services to the neighboring communities, including wood products, non-wood forest products, and water (Nabalegwa & Tenywa, 2021; Nalwanga & Kasozi, 2023).

## **1.2 Statement of the research problem**

Representing 33% of the global land area (FAO 2011) and containing more carbon per unit area than any other land cover type (Hairiah *et al.* 2011), forests comprise the biggest percentage of biomass and play a big role in mitigating greenhouse gas emissions, especially carbon dioxide. The rate of deforestation, estimated at 0.4–0.7% per year (Parry *et al.* 2007), constitutes immense environmental stress. Uganda’s forest and woodland cover has dropped from 4.9 million hectares (20% of Uganda’s land area) in 1990 to 3.6 million (14%) in 2005, representing a 1.9% deforestation rate (NFA 2020).

To improve management in the forest reserve, several mechanisms have been devised including, Collaborative Forest Management (CFM) (MWE 2017). CFM as a participatory approach to sustainable forest stewardship, engages a diverse range of stakeholders including local communities, civil society organizations, private sector and government agencies and seeks to ensure effective planning, management and preservation of forest resources, with the ultimate goal of promoting sustainable practices (Jjagwe *et al.*, 2021; MWE, 2017).

CFM has been piloted in Mabira Central forest reserve to improve forest management given the challenges brought by surrounding population (Turyahabwe *et al.*, 2012). However, while CFM has gained traction in Uganda, its effect on different forest components such as carbon stocks, tree species diversity and stem density are inadequately understood, an issue this study sought to address.

### **1.3 Study objectives**

#### **1.3.1 General objective**

The aim of this study was to compare the effect of implementation of Collaborative forest management strategies on carbon stocks, tree diversity and stem density in Mabira central forest reserve.

#### **1.3.2 Specific objectives**

The specific objectives of the study were to;

- a. To compare carbon stocks in forested areas under CFM and non-CFM.
- b. To compare tree species diversity in forested areas under CFM and non-CFM.
- c. To compare tree stem-densities in forested areas under CFM and non-CFM.

### **1.4 Hypotheses**

The study was guided by the following hypotheses:

1. Ho: There is no significant variation in carbon stocks between CFM and non-CFM areas in Mabira Forest.
2. Ho: There is no significant variation in tree species diversity between CFM and non-CFM areas in Mabira Forest.
3. Ho: There is no significant variation in tree stem density between CFM and non-CFM areas in Mabira Forest.

### **1.5 Scope of the study**

The study was conducted in Mabira Forest, a tropical rainforest located approximately 56 km East of Kampala City along Kampala - Jinja high way in Buikwe district, central Uganda. The

study focused on the effect of Collaborative forest management on carbon stocks, tree species diversity and stem density. The study was conducted from March 2023 to May 2024.

## **1.6 Justification**

The study was essential due to the urgent need to comprehend the impacts of Collaborative Forest management (CFM) on ecological and carbon sequestration outcomes in tropical forest ecosystems. As global efforts to mitigate climate change intensify, identifying effective forest management strategies that balance conservation and local livelihoods is crucial. Uganda's Mabira Central Forest Reserve presents a unique case for examining these dynamics due to its biodiversity significance and the implementation of CFM practices aimed at involving local communities in forest stewardship. This study addresses critical gaps in existing literature by quantifying how CFM influences key ecological indicators—carbon stocks, species diversity, and stem density—thereby providing empirical evidence to inform policy and improve forest management practices. The findings are poised to offer valuable insights into optimizing forest conservation strategies, enhancing carbon sequestration, and sustaining biodiversity, which are pivotal for both local and global environmental goals.

## **1.7 Significance**

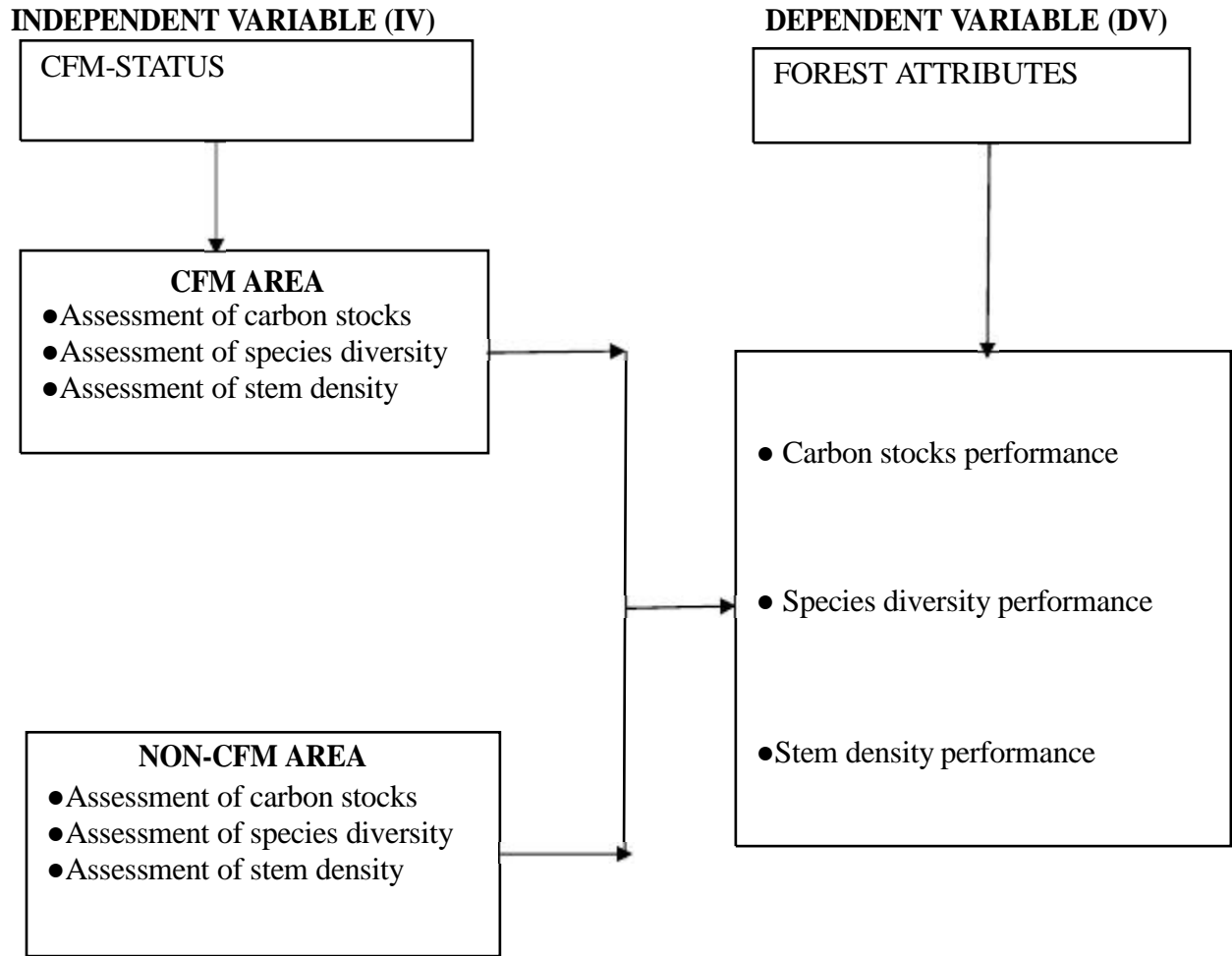
The exceptionalness of the study lies in its alignment with several Sustainable Development Goals (SDGs) and Uganda's National Development Plan III (NDP III). By evaluating the influence of collaborative forest management (CFM) on carbon stocks, the study contributes to SDG 13 (Climate Action) through its focus on enhancing carbon sequestration to combat climate change. It also addresses SDG 15 (Life on Land) by examining species diversity, thus supporting efforts to conserve biodiversity and manage forests sustainably. Additionally, the study aligns with SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth) by promoting sustainable livelihoods and economic opportunities for local communities involved in forest management. In terms of NDP III, the study supports environmental sustainability by providing data to inform better forest management practices, enhances household incomes through sustainable forest-based activities, contributes to biodiversity management, and aids in climate change mitigation & adaptation strategies.

## **1.8 Conceptual framework**

The study employed a conceptual framework to examine how forest management style influences key ecological forest attributes. It explains the relationship between two variables under study, management style being the independent variable (IV) and the forest attributes being the dependent variable (DV). In this case forest attributes were measured in terms of carbon stocks, species diversity & stem density while Management style was conceptualized into two dimensions of; CFM areas and NON-CFM Areas. CFM areas are those blocks/compartments dual managed with community while Non-CFM are those exclusively managed by National Forestry Authority (NFA). Conventionally all the two predictors (either CFM or Non-CFM) are hypothesized as having positive significant impact of forest attributes. For example, CFM areas are expected to be having fewer illegal activities hence increase in carbon stocks and stem density than Non-CFM areas.

CFM, which involves the shared management of forest reserves between local communities and governmental. This management approach includes joint decision-making, benefit-sharing, sustainable resource use, and active community participation in forest governance. The dependent variables in this framework are carbon stocks, species diversity, and stem density. Carbon stocks is the amount of carbon stored in forest biomass, which is crucial for climate change mitigation. Species diversity measures the variety and abundance of different species within the forest, essential for ecosystem resilience and health. Stem density is the number of tree stems per unit area, affecting forest structure, light penetration, and competition among trees.

FIGURE 1: A CONCEPTUAL FRAMEWORK OF THE STUDY



**Source:** adapted from Argyris (2002) and modified by the researcher.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Introduction

Collaborative Forest Management (CFM) has emerged as a significant approach in the stewardship of forests, particularly in tropical regions where biodiversity is high but under threat from deforestation, climate change, and unsustainable practices. CFM involves partnerships between government agencies, local communities, NGOs, and private stakeholders to manage forest resources sustainably. This literature review investigates the impact of CFM on three critical ecological parameters: carbon stocks, species diversity, and stem density in tropical forests.

#### 2.2 Theoretical Review

The study was underpinned by the niche construction theory. The theory was advanced by Oxford biologist John Odling-Smee (1988). Niche construction refers to the modification of selective environments by organisms (Laland et al.,2011) explores niche construction theory and its implications for biodiversity and ecology, highlighting how organisms modify their environment, which is critical in understanding forest dynamics. Collaborative forest management (CFM) is a governance approach that involves multiple stakeholders such as local communities, government agencies working together to manage forest resources sustainably. When viewed through the lens of niche construction theory (NCT), CFM can influence carbon stocks, species diversity, and stem density in tropical forests in various meaningful ways: Gilmour, D. A. (2016) urges that CFM encourages local communities to take an active role in forest management, leading to better stewardship practices. Stakeholders may employ techniques that promote forest protection hence reduce deforestation, and enhance carbon storage. More so, a diverse array of practices and knowledge from different stakeholders can lead to the use of diverse tree species, which can enhance carbon stocks due to differing growth rates, biomass accumulation, and resilience to pests and diseases. Species-appropriate management encourages the planting and preservation of trees that sequester more carbon. CFM can promote sustainable practices that improve soil quality and reduce erosion, which are important for long-term carbon

stocks. The involvement of local communities often leads to the adoption of agroecology and mixed-use strategies that enhance carbon sequestration.

Communities often possess traditional ecological knowledge that can be critical in understanding how to manage species diversity effectively (Mori *et al.*,2017). He postulates that this knowledge can guide the selection of diverse plant species that thrive in specific ecological niches, maintaining a broad spectrum of biodiversity. CFM allows for adaptive management where practices are adjusted based on ecological feedback. This flexibility enables stakeholders to experiment with different management strategies, which can help maintain or increase species diversity as environmental conditions change. Harrison *et al.*, 2016 sums it all that collaborative approaches can help identify and protect critical microhabitats that promote diverse species assemblages.

In a CFM context, stakeholders can agree on sustainable harvesting practices that consider the ecological and social dimensions of forest use (Perez *et al.*,2018). These practices can influence stem density by allowing certain species to thrive while managing the density of others to prevent overcrowding. More so, when communities are given a stake in the management of forest resources, they may be incentivized to conserve and regrow forests rather than deplete them. This can lead to improved stem density as forests regenerate and species composition shifts favorably over time. With a collaborative approach, stakeholders can participate in forest monitoring, leading to a better understanding of how management interventions affect stem density (Barton *et al.*,2020). This could include community-led assessments of regrowth or species health, thereby increasing the likelihood of implementing adaptive management strategies.

In conclusion, collaborative forest management, when viewed through the lens of niche construction theory, illustrates how human interactions with forests can modify ecological niches, thereby influencing carbon stocks, species diversity, and stem density. By engaging diverse stakeholders and leveraging local ecological knowledge, CFM can promote sustainable practices that enhance ecological resilience. This interconnected approach fosters biodiversity, optimizes carbon capture, and shapes forest structures that reflect a commitment to sustainability and ecological stewardship. In doing so, CFM can play a vital role in addressing climate change and maintaining vital ecosystem services in tropical forests.

### 2.3 Collaborative Forest Management and Carbon Stocks

One of the most substantial benefits of CFM is its contribution to maintaining and enhancing carbon stocks in tropical forests. Tropical forests are paramount in global carbon storage; hence, understanding how CFM practices influence these stocks is critical. Involvement of forest surrounding communities in forest management can improve the status of different forest components through change in conservation mindset and restricted access to forest utilities (Turyahabwe *et al.*, 2012). Forests play a critical role in mitigating climate change by capturing carbon dioxide and storing carbon within soils and forest biomass (Waring *et al.*, 2020). The importance of forest carbon stocks in climate change mitigation cannot be overstated. Forest ecosystems are essential natural resources that provide a wide range of ecosystem services such as moderating atmospheric carbon balance and thus, climate change (Solomon *et al.*, 2018). Carbon emissions from deforestation and forest degradation are the second-largest source of anthropogenic carbon emissions (IUCN, 2021). Therefore, reducing carbon emissions is of great importance in this era of climate change.

Carbon stocks in forest ecosystems are affected by changes in land use, forest clearance for agriculture, settlement, and industrial expansion. These changes have contributed about 136 ( $\pm$  55) Gt carbon or one-third of total anthropogenic emissions of carbon dioxide to the atmosphere over the past 150 years (Solomon *et al.*, 2018). The quantification and estimation of forest carbon stock is essential for monitoring carbon sinks and climate change mitigation efforts. Measurement and estimation methods for forest carbon stocks include remote sensing, ground-based inventory, and modeling approaches (Njana *et al.*, 2021).

The role of forest management practices in carbon sequestration is crucial. Forest administration practices can augment carbon sequestration by promoting forest growth and plummeting carbon emissions from deforestation and forest degradation. Forest management based on carbon capture and sequestration capacity includes carbon conservation, carbon storage, and carbon substitution models (Nunes *et al.*, 2020). These models aim to increase carbon sequestration by dropping carbon discharges and swelling carbon storage in forest ecosystems.

Numerous studies have explored the effect of Community Forest Management (CFM) on carbon stocks, employing diverse methodologies and yielding important insights. Studies indicate that CFM can lead to increased carbon sequestration compared to conventional management

approaches. Schmitt *et al.* (2018) found that areas under CFM exhibited up to 30% higher carbon stocks due to improved forest growth and reduced deforestation rates. Thammanu *et al.* (2021) further observed that CFM led to increased carbon sequestration, with an annual growth rate of 2.89% in northern Thailand. Their projections for 2028 indicated continued carbon stock growth, underscoring the potential of CFM in augmenting carbon sequestration and plummeting CO<sub>2</sub> emissions. Larrazábal *et al.* (2012) stressed the advantages of community-based forest monitoring for REDD+ implementation, including cost reduction and improved governance through community participation. However, they also highlighted challenges related to data accuracy and the need for further research. The positive impacts on carbon stocks are often attributed to enhanced forest protection, improved governance, and the allocation of resources towards forest management activities that promote growth and regeneration (Müller *et al.*, 2019).

Di Girolami *et al.* (2023) found varying impacts of Forest Certification (FC) and CFM on deforestation, underscoring the necessity for additional investigation. Successful CFM initiatives in Indonesia and Brazil have demonstrated significant carbon retention. For instance, a community-managed forest in Acre, Brazil, reported an increase in above-ground biomass due to participatory monitoring and sustainable harvesting practices (Rico *et al.*, 2020). In Brazil, Romero *et al.* (2020) identified timber species with high carbon storage, emphasizing the influence of wood density in carbon storage and justifiable forest management. Dennis (2016) conducted a comprehensive valuation of carbon stocks in the Northern Region and Custer Gallatin National Forest, revealing trends of increasing total carbon storage but with varying outcomes in different forest areas. Birungi *et al.* (2023) focused on dry tropical forests and reported higher carbon estimates, providing valuable understandings into the potentiality of these ecosystems for carbon storage. Hilmi *et al.* (2021) discussed the significance of Blue Carbon ecosystems in climate change mitigation, highlighting the need for sustainable management and international cooperation to safeguard these vital resources. Collectively, these studies contribute to our understanding of CFM, carbon stocks, and environmental conservation.

## **2.4 CFM and Species Diversity**

Species diversity is vital for ecosystem resilience and functionality. CFM has been shown to positively impact biodiversity in tropical forests through various mechanisms. Several studies underscore that CFM can enhance species diversity by promoting sustainable harvesting

practices, reducing illegal logging, and enabling local communities to manage species according to ecological principles (Locke & Dearden, 2020). A meta-analysis by Chazdon (2014) highlights that CFM areas often retain higher species richness compared to those under exclusive state or private management. CFM practices encourage the sustainable use of diverse species and the conservation of underutilized ones, which is crucial in biodiversity-rich regions. Empowering local communities contributes to better monitoring and protection of diverse habitats. For instance, Poudyal *et al.*, (2019) assessed the influence of different forest management approaches on tree species richness and composition within Nepal's Tarai landscape, and found that regularly harvested community forests exhibited a higher capacity to support tree species richness and composition compared to other management approaches. The findings underscored the importance of active local-level forest management in aligning with global conservation initiatives, such as sustainable forest management, REDD+ and biodiversity preservation.

Lamsal *et al.*, (2023) assessed carbon stocks, plant diversity, and other ecological attributes between two different forest types managed under varying management approaches in Nepal's Surkhet district, and found that Kakrebihar protection forest exhibited higher levels of carbon stock, plant species richness, and abundance at the landscape level than Sano Surkhet community forest

Monarrez-Gonzalez *et al.*, (2020) examined the impact of silvicultural treatments on tree diversity within a temperate forest in northern Mexico, and found both conservative and semi-intensive treatments having minimal impact on tree diversity. These findings contribute valuable insights into the effects of silvicultural practices on species composition and provide a nuanced perspective on their implications.

## **2.5 CFM and Tree Density**

CFM has been associated with increased stem density, particularly when local communities are incentivized to protect and manage forests sustainably. A study in Cameroon indicated that CFM led to a nearly 25% increase in stem density over five years, attributed to reduced extraction rates and active reforestation efforts (Nkamleu *et al.*, 2018). More so, Mawa *et al.* (2020) demonstrates that CFM has a positive effect on tree densities, with a noticeable increase in basal area. The study also found that the CFM compartment exhibited higher stem density of specific tree species used for timber and charcoal production. CFM is therefore beneficial for maintaining

favorable tree densities, particularly concerning basal area and stem density of key tree species, thereby enhancing the forest's overall health and sustainability.

Research shows that regulated and participatory management of harvesting practices under CFM models can mitigate the adverse impacts of selective logging, thereby maintaining higher stem densities compared to unmanaged forests (Bode et al., 2019). A study by Bir Bista (2013) in Nepal, highlights the positive outcomes of investing in collaborative forestry management (CFM). Activities such as tree management and protection have led to an increase in tree density within community forests. Conversely, poorly implemented CFM can lead to overharvesting if not accompanied by effective governance, which can negatively impact stem density. Therefore, monitoring and robust community engagement play a critical role in realizing positive outcomes (Martin et al., 2020). The study suggests that the efforts made by local communities in CFM initiatives are directly correlated with the growth, density, and coverage of trees.

A study by Turyahabwe *et al.* (2013) in Budongo Central Forest Reserve in Uganda supports the notion that CFM contributes to higher tree densities. CFM compartments within the forest reserve demonstrated greater quantities of live stems for both timber and pole tree species. This finding indicates an improvement in forest condition and supports the argument that CFM facilitates sustainable forest management and leads to more responsible utilization of forest resources.

The identified knowledge gaps underscore the significance of conducting further research in these domains. Addressing these gaps is not only essential for advancing our understanding of the impact of CFM on carbon stocks, tree species diversity and stem density but also for providing crucial insights that can inform policy decisions and implementation of effective strategies for environmental preservation.

## CHAPTER THREE

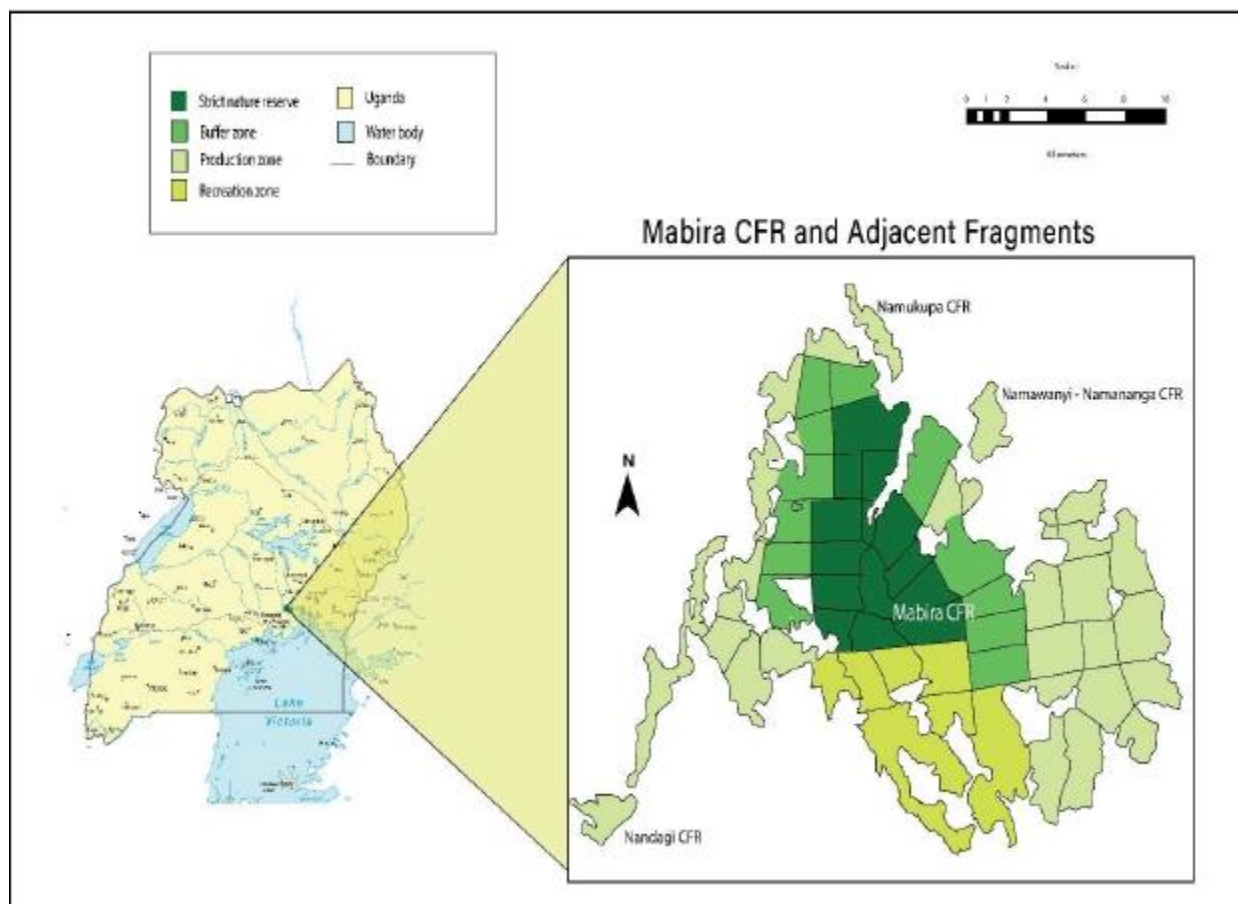
### MATERIALS AND METHODS

#### 3.1 Study area description

The study was conducted in Mabira Central Forest Reserve situated between 0° 24' - 0° 35' N and 32° 52' - 33° 07' E (Uganda Forest Department, 1996). The forest was selected due to; its critical ecological roles, vital biodiversity conservation functions, support to the maintenances of resident communities, and implementation of CFM programs (citation). The entire forest is managed by National Forestry Authority (NFA) under one Forest Management Plan. The forest reserve and fragments cover a total area of 31,293 hectares, are situated in the Lake Victoria basin and are a water catchment area for Lake Kyoga and the Victoria Nile. The forest lies north of Kampala along Jinja road, about 45 km from Kampala City and 28 km from Jinja City. Mabira CFR covers an area of 29,974 hectares and is located in Buikwe and Mukono Districts (citation). According to the management plan of 1994/95, the forest is subdivided into 65 compartments numbered from 171 to 235, and four management zones: buffer zone; recreation zone; production zone; and strict nature reserve (Nabanoga et. al., 2010).

Mabira CFR is a medium altitude forest, with elevations ranging from 1070 to 1340 m above sea level. The topography is characterized by an undulating plateau from flat-topped hills to wide shallow valleys occupied by swamps sloping gently northwards. The reserve is isolated from other protected areas by agricultural land and is characterized by the ferritic soil type of the Buganda catena ranging from loamy to sandy clay loams with isolated cases of waterlogged clays and grey sands in the valley bottoms. The area receives between 1375 and 1524 mm of rainfall annually. Rainfall is well distributed throughout the year, with peaks in April-May and October- November. The highest rainfall occurs in the southern part of the reserve. The annual mean minimum and maximum temperatures range between 16°C to 17°C and 28°C to 29°C respectively (MWE, 2017). The forest has a dense undergrowth of various shrubs, lianas, climbers and herbs with a closed canopy. It is rich in biota harboring 47% of Uganda's total plant species including 151 species of forest birds, 2 species of diurnal forest primates, 39 species of forest swallow tail and 218 species of butterflies. Many of these are on the list of globally endangered species (Baranga, 2007).

Collaborative Forest management (CFM) is defined as a working relationship between key stakeholders in management of a given forest in this case, Mabira Central forest reserve. The key stakeholders being the local forest users and National Forestry Authority (NFA). In this case, certain compartments of the forest are put under dual management by the Authority and community for mutual benefits like improved forest protection and increased community livelihood benefits. CFM program was adopted in mabira Cfr for improved forest protection on the side of National Forestry Authority. Its against this background that the study was conducted.



**Figure 2: A Map of Mabira CFR (NFA, 2022)**

### 3.2 Research design

The study adopted a quasi-experimental research design. Apart from being less expensive, the design was chosen because its conducted in the real-world conditions with few controls hence can establish the effectiveness of interventions. However, the design has a disadvantage that it lacks randomization hence increasing the risk of bias. The study measured, quantified and

compared amounts of carbon stocks and tree species diversity within forested areas under CFM with those in non-CFM areas. The study also measured tree stem-densities in areas under different forest management strategies. The study involved both quantitative *in-situ* and herbarium *ex situ* tree species identification. The tree species diversity was best determined at three tree growth levels that seedling, sapling and pole (mature) levels. This aided understanding of the crucial state at which tree growth level the most carbon is stored in the forest and which tree species are key at doing so at the different stages of tree growth.

### **3.3 Materials**

The study involved use of modern technology equipment where possible and these were supplemented by manual operated hand tools so as to capture the required data. The Global Positioning System (GPS) was used to map study sites as well as direct the directions and flow of transects drawn in the different sample sites studied. The panga was used to clear vegetative obstacles in the way of the transect and also clearing the lines along which study plots were followed. The panga was also used in clearing climbers from trees to be identified as well as to make small slashes to better accurate tree identification. Marked ranging rods and colored tapes were used to mark different corners of the plots and the nested plots for seedling identification.

A forest tree guide and a book titled important trees and shrubs of Uganda by Katende (2000) was used to clearly and correctly identify the trees encountered in the different plots. A marked tree pole was used to mark the DBH height on every tree where the diameter of each tree was always taken. A graduated pole was used to estimate the height of different trees as this was ground-trothed by the tree height measuring software on the smart phone. Parts of unidentified field trees were stored in a press then transported to the Makerere University Herbarium for accurate identification with the help of a botanist. All details from the field and supplementary data were recorded in the note book as the field data was directly entered in the pre-designed data collection sheets.

### **3.4 Methods**

#### **3.4.1 Selection and access to study sites**

Study sites within Mabira CFR were purposefully selected based on their CFM status. At each site, transects oriented north to south, determined using a compass and GPS, with alternating

plots were demarcated. Within these plots, assessments of tree species diversity and carbon stocks were conducted. Tree stem-density assessment was based on the procedure described by Eilu *et al.*, (2004). This entailed sampling trees in each area to measure parameters like DBH and tree height, which were then converted into estimates of carbon stocks, tree species diversity, and tree-stem density using standard conversion factors and allometric equations. All study the sites were under the management of the NFA and are governed by a single forest management plan. Therefore, permits were secured from the NFA to ensure an authorized and safe research environment during data collection.

### **3.4.2 Carbon stocks assessment**

Field carbon stock assessment adhered to Asseffa *et al.* (2013)'s procedure for sustainable forest management and REDD+. A hybrid Tier-3 approach combining modeling with on-site sampling and verification was employed. This included the following key steps: defining project boundaries and mapping; stratifying the project area; selecting the forest carbon pool to measure; determining sample plot type, shape, and size; establishing the number of sample plots; setting measurement frequency; preparing for fieldwork and logistics; conducting carbon stock assessment.

Assessment of carbon stocks was done using field inventory techniques, establishing 2 evenly spaced 2km-long transects running north to south across each management area.

Along each transect, 20m by 20m study plots was designated at 100m intervals, with an initial 10m buffer to account for edge effects. Forty square plots, each 400m<sup>2</sup> in size were used where Measurements of diameter at breast height (DBH), and Height were done recorded in each management area.

Carbon stocks primarily comprised above-ground biomass, including woody stems, branches, leaves, and undergrowth of living trees, creepers, climbers, and epiphytes. The mean carbon stock per hectare from field measurements in fixed forest sample plots, chosen systematically along transects was estimated. All live plants  $\geq 2$  cm DBH were considered above-ground woody plants. For trees  $\geq 2$  cm DBH in sample plots, DBH at breast height or 1.3 meters or above buttresses was measured. All stems  $>10$  cm DBH at 1.3 meters was measured, along with collar diameter for multiple stems below 1.3 meters. Corrections for buttressed or grooved trees was

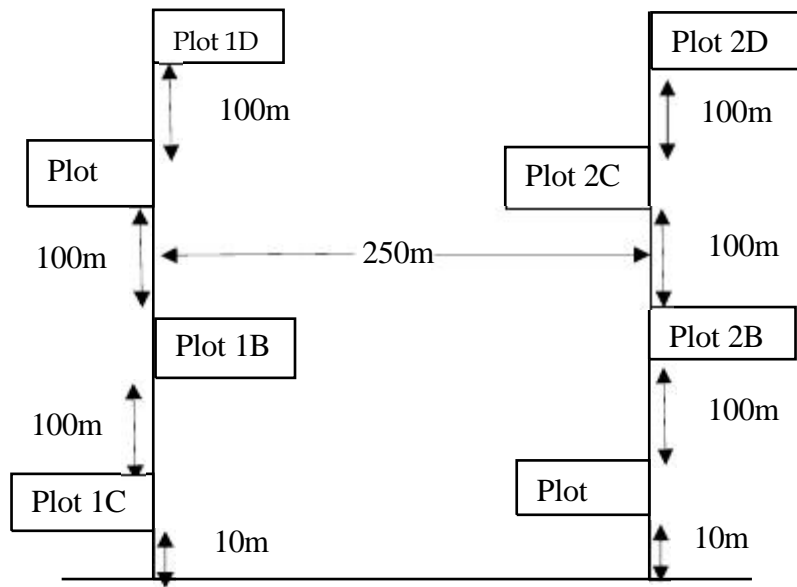
made as appropriate. If stranglers, lianas, or climbers were present, their DBH was recorded. The height of up to 15 dominant canopy trees was measured and used to establish a diameter-height regression equation for biomass calculation. Valid allometric equations for forest type, species, or family, checking for biomass under/overestimation were selected. Alternative allometric equations were applied to estimate above-ground biomass (kg/tree) when needed.

### **3.4.3 Tree species diversity assessment**

In this study, tree species diversity encompassed the number and distribution of different species within selected forest areas under varying management. To assess tree species diversity field inventory techniques, establishing 2 evenly spaced 2km-long transects running north to south across each management area.

Along each transect, 20m by 20m study plots was designated at 100m intervals, with an initial 10m buffer to account for edge effects. Within these plots, all encountered tree species were identified and recorded, noting their frequency, diameter at breast height (DBH), and the presence of seedlings, saplings, poles, and mature trees. The slope of each plot was also measured. For larger trees (DBH >20cm) and poles (DBH 10-19.9cm), were further identified, counted, and measured diameter. Within each plot, smaller nested plots of 5m by 5m and 7.5m by 10m were used to sample seedlings (diameter <5cm) and saplings (diameter 5-9.9cm), respectively.

Identification of tree species followed Katende (2000). In cases where botanical names were unknown, local names provided by the area's inhabitants were used. Species density and composition (trees with stem diameter  $\geq$  5cm) across all plots were also recorded.



**Figure 3:Field layout of the tree species diversity assessment**

#### **3.4.4 Tree stem-densities assessment**

Tree stem-density assessment was based on the procedure described by Eilu *et al.*, (2004). Three plots of 20 × 500 m (1 ha) in a relative intact forest were subjectively established in each management area (CFM and Non-CFM) making a total of 6 plots. Assessments were carried out systematically in 20 × 50 m (0.1 ha) sub plots. Trees of DBH (1.3 m) ≥ 10 cm were enumerated, and identified based on the FTEA (Polhill, 1952). Individuals that would not be identified were included in the samples under one family named ‘unknown’. A representative voucher was collected from each species in each plot and from each site for identification and for deposition in Makerere University Herbarium.

#### **3.5 Data collection**

The inventories were taken in Mabira CFR over a three-month period from October to December 2023. Data were collected by a team of five field assistants guided by the principal investigator. Data on above-ground carbon stocks, tree diversity, and stem density were collected.

A systematic random sampling approach with a 0.5% sampling intensity were applied within forty study plots. The plots were georeferenced on the study map using GPS coordinates and ArcGIS software. Forty square plots, each 400m<sup>2</sup> in size, were used for trees (>10 cm DBH), while 50m<sup>2</sup> plots were designated for saplings. DBH measurements were taken with a Diameter

tape, tree and sapling heights were measured using Abney's level, and seedlings were counted and measured with a measuring tape. Rigorous quality assurance was upheld to ensure the collection and management of accurate data both in the field and post-collection.

### 3.6 Data analysis

Collected data were entered and processed in MS Excel, then exported and analyzed in R software. A one-sample K-S normality test was used to assess data distribution. Levene-tests was used to analyze variations in species diversity, stem density and carbon stocks between CFM and non-CFM area, all at a significance level ( $\alpha$ ) of 0.05.

#### 3.6.1 Carbon stock estimation

After estimation of the above-ground biomass of a tree (DBH>10 cm). Carbon stocks from the Above Ground Biomass (AGB) was calculated using allometric equations (Chave et.al, 2005).

$$AGB = \rho * \exp(-0.667 + 1.784 * \ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3)$$

Where:  $\rho$  = wood specific gravity = oven-dry wood over green volume (g/cm<sup>3</sup>). The mean  $\rho$  for tropical forests Africa is estimated to be 0.5 g/cm<sup>3</sup>. D = tree diameter at breast height (1.3 m). Similarly, to estimate the carbon stock of a single tree species, density values of the entire forest for that species were summed. The percentage contribution on carbon stock of each tree species was estimated by dividing the amount of carbon stock of a specific species in a forest by the sum of carbon stock/ha of all species in the same forest.

#### 3.6.2 Tree diversity estimation

Shannon-Wiener index was calculated for estimation of species diversity. Species dominance was calculated using the Simpson index. Species richness was determined using the Margalefs' richness index. Species Diversity was quantified using the Shannon-Wiener Diversity Index ( $H'$ ) according to the following equation.

$$SD = - \sum_{i=1}^S P_i \ln P_i$$

where SD = Shannon - Wiener Diversity ( $H'$ ), S = the number of species at that site,  $P_i = n_i/N$ , that is, proportion of the individual trees of the  $i^{\text{th}}$  species to the total,  $n_i$  = total number of individuals in the  $i^{\text{th}}$  species, N = total number of individuals of all species, ln= Natural logarithm

to base  $e$ ,  $\Sigma =$  is the sum of the calculations, and  $S$  is the number of species. The values of Shannon's diversity index,  $H'$  typically lie between 1.5 and 3.5, although in exceptional cases, they may exceed 4.5.

**Tree Species Richness** was determined by summing up the number of species identified within the CFM compartments and non-CFM area (Magurran, 2003).

**Species Evenness/Equitability (J)** was determined using the following equation in accordance to (Tumuhe et. al., 2018).

$$J = H' / H'_{max}$$

where;  $J$ = Evenness,  $H'$  = Shannon-Wiener diversity index and,  $H'_{max} = \ln S$  where  $S$  is the number of species.

### 3.6.3 Tree stem density estimation

CFM compartment sizes encompassed both the CFM area and the intact Mabira CFR area (MWE, 2017). Tree-stem density, calculated as the total stems per unit land area, was determined by direct counting within size classes and extrapolation using (Etigale *et al.*, 2014) formula.

$$N = \frac{h}{a} \times c$$

Where;  $h$  = one hectare,  $a$ = Area of plot measured in hectares

$c$ =Number of trees in plot,  $N$  = estimated number of trees per hectare

**CHAPTER FOUR**  
**RESULTS**

**4.1 Carbon Stocks in Forested Areas**

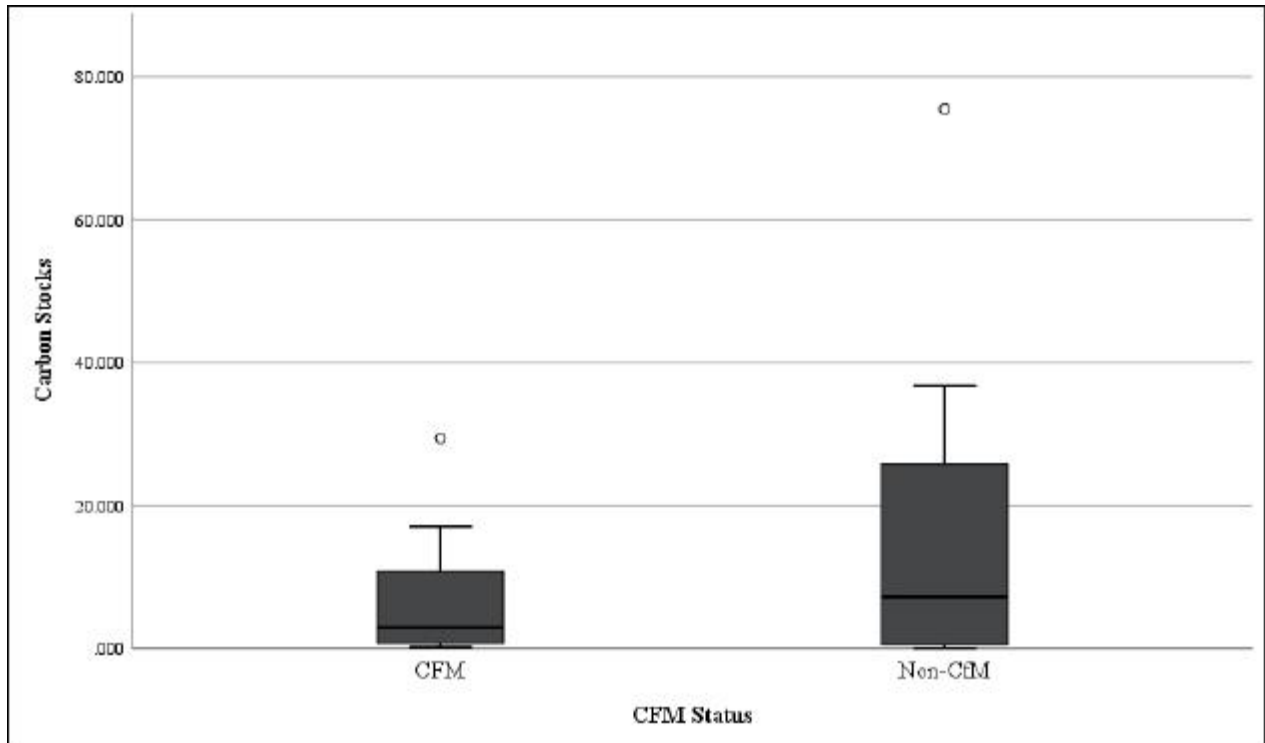
**4.1.1 Overview of the Carbon Stocks in the Study Areas**

To understand the distribution of carbon stocks in the Mabira Central Forest Reserve, descriptive statistics were computed. The study findings reveal higher mean carbon stock in non-CFM areas compared to CFM areas (Table 1). These distinctive metrics highlight substantial variability in carbon stocks between the two management statuses, signifying potential differing influences on carbon sequestration and storage.

**Table 1: Carbon stocks in CFM and non-CFM areas**

CFM Status	Mean	N	Std. Deviation	Minimum	Maximum	Std. Error of Kurtosis	Kurtosis	Skewness	Std. Error of Skewness
CFM	6026703.05	371	34160679.95		379571595.09		76.57	8.22	.13
Non-CFM	7666878.15	284	37858303.56		327996992.89		35.17	5.78	.15

The study findings further reveal notable distinctions in carbon stock distributions. The box plot (Figure 4) shows a wider Interquartile Range (IQR) for non-CFM areas compared to CFM areas, indicating a more dispersed middle 50% of the Carbon Stocks data in the former. Both CFM and non-CFM areas showcase outliers, signifying extreme values in carbon stocks within the two areas. Moreover, the whiskers in the non-CFM areas appear longer than those in CFM areas, implying a greater variability and wider spread of carbon stocks values in the non-CFM territories. Notably, the position of the median in both sets of areas is situated on the lower side of the IQR, suggesting a potential skewness towards lower carbon stocks values in both CFM and Non-CFM areas. This analysis underscores the differences in variability and distribution patterns of carbon stocks between the two areas, with non-CFM areas displaying greater variability and a wider range of values compared to CFM areas.



**Figure 4: Variation in carbon stocks between the CFM and non-CFM areas**

#### 4.1.2 Variation in Carbon Stocks according to CFM status

The Levene test was used to assess the equality of variances in carbon stocks between CFM and non-CFM areas within the Mabira CFR. The results indicate that the variances in carbon stocks display consistency across the different statistical approaches (Table 2). Specifically, the Levene tests based on mean values demonstrated a marginal difference in variances between CFM and non-CFM areas ( $p = 0.051$ ), suggesting a potential but not statistically significant variance disparity. Similarly, tests utilizing median, adjusted degrees of freedom with median, and trimmed mean values all indicated no significant differences in variances ( $p > 0.05$ ). These findings consistently imply a lack of substantial evidence supporting unequal variances in carbon stocks between CFM and non-CFM areas. Therefore, the data suggest relative similarity in the variability of carbon stocks across CFM and non-CFM areas.

**Table 2: Test of Homogeneity of Variances of Carbon stocks**

		Levene Statistic	df1	df2	Sig.
Carbon Stock	Based on Mean	4.25	1	22	.051
	Based on Median	1.16	1	22	.294
	Based on Median and with adjusted df	1.16	1	11.03	.305
	Based on trimmed mean	1.89	1	22	.183

## 4.2 Floral composition in the Forested Areas

### 4.2.1 Species Richness in the Study Area

The study findings indicate a lower observed species richness in CFM compared to non-CFM areas (Figure 5). The non-CFM area shows rapid species discovery from plots 1 to 3, followed by a slower increase in species count from plots 3 to 6, and a subsequent rapid rise from plots 6 to 12. In contrast, the CFM area demonstrates a quick discovery of species from plots 1 to 4, a slower increase from plots 4 to 5, and a stable, significant increase in species count from plots 5 to 12. Both curves exhibit continuous ascent, suggesting ongoing species discovery, with convergence at plot 12, implying similar observed species richness in both areas at this sampling effort. This comparison underscores distinct patterns of species discovery and richness between CFM and non-CFM areas.

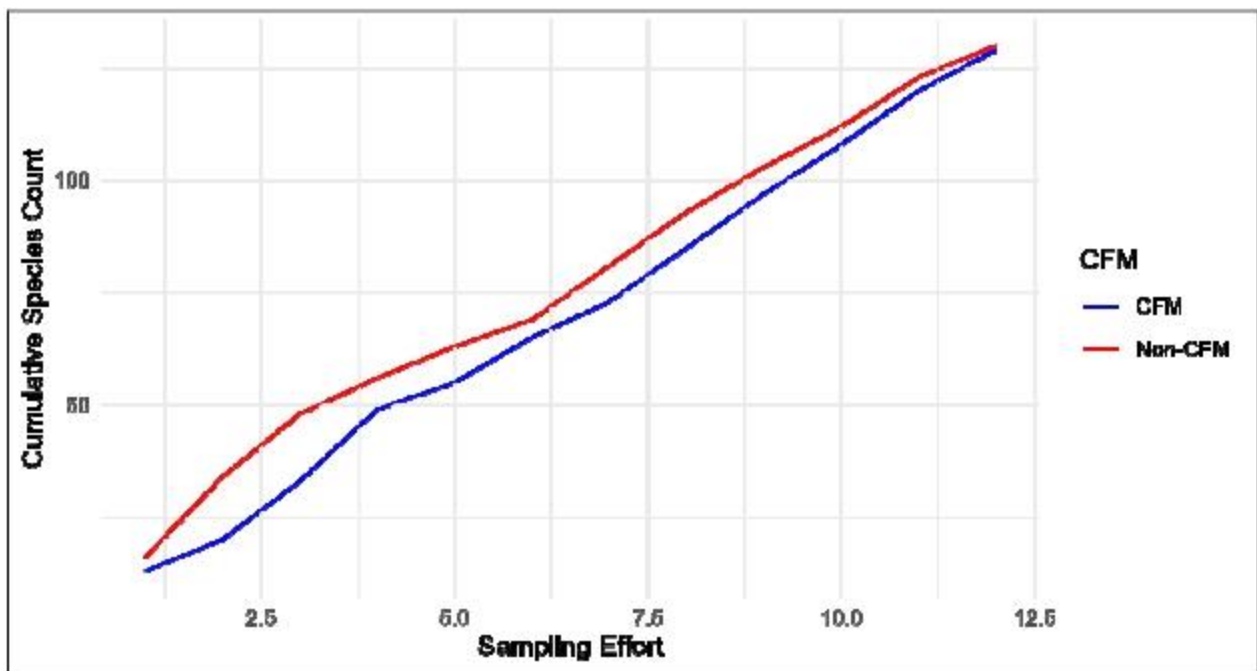


Figure 5: Rarefaction Curve showing the Species Richness in CFM and non-CFM Areas

### 4.2.2 Species Diversity

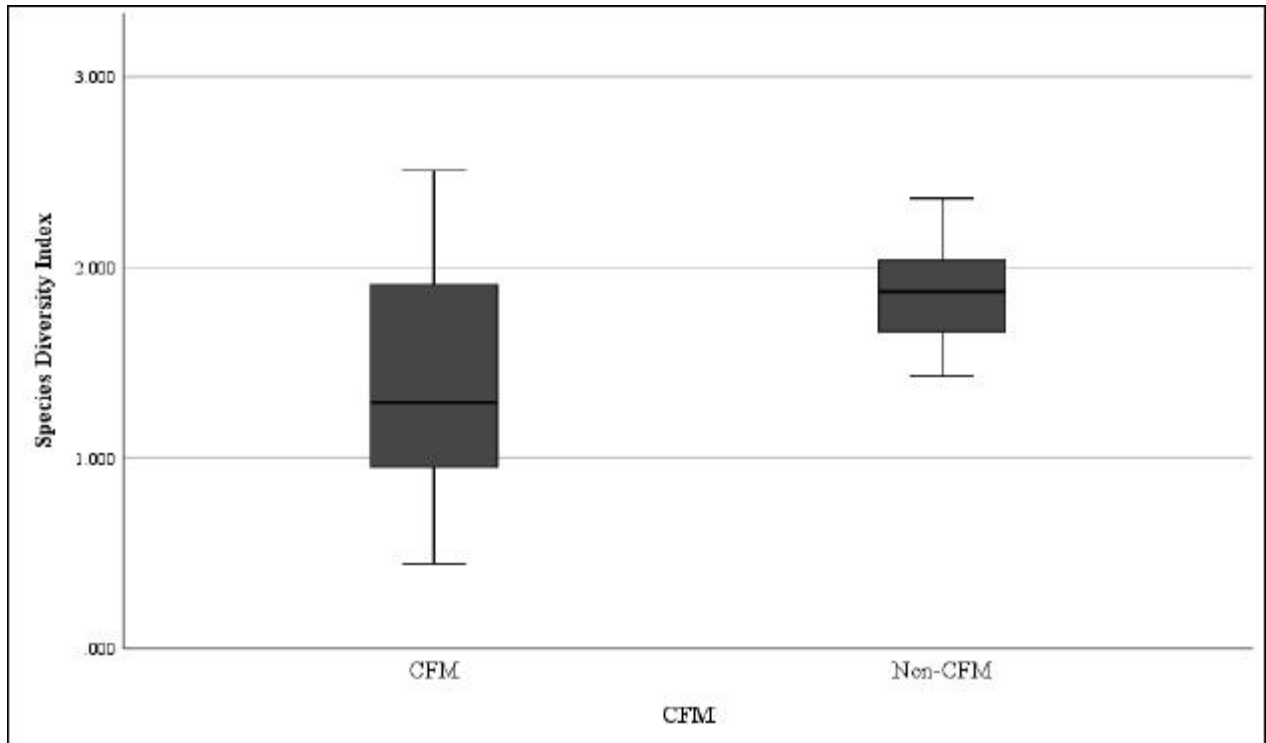
The study findings reveal a lower mean species diversity index ( $H$ ) in CFM areas ( $1.41 \pm 0.58$ ) compared to non-CFM areas ( $1.86 \pm 0.28$ ) (Table 3). This discrepancy implies a potential association between forest management strategies and species diversity within the reserve. Moreover, the wider range of species diversity values in CFM areas, as indicated by the larger

standard deviation, implies greater variability in species composition within these managed zones.

**Table 3: Species Diversity in CFM and non-CFM Areas**

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
CFM	22	1.41	.58	.12	1.15	1.67	.44	2.51
Non-CFM	15	1.86	.28	.07	1.70	2.01	1.43	2.36
Total	37	1.60	.53	.09	1.42	1.77	.44	2.51

The study findings further reveal that contrary to typical trend, CFM areas have more varied Species Diversity than non-CFM areas (Figure 6). The middle 50% of Species Diversity data in CFM areas exhibit a broader central portion, denoted by a wider Interquartile Range (IQR), compared to the Non-CFM areas. Additionally, CFM areas are characterized by longer whiskers compared to the non-CFM areas, suggesting a greater variability and wider spread of Species Diversity values in CFM areas. Notably, the median in the non-CFM areas is higher than that in the CFM areas, indicating that the middle value of Species Diversity data is positioned at a higher level in non-CFM regions. This comparison highlights the contrasting patterns of Species Diversity between CFM and Non-CFM areas, with CFM areas demonstrating a broader central range and greater variability, while non-CFM areas showcase a higher median value, potentially indicating a more concentrated or elevated species richness in those regions.



**Figure 6: Variation in Species Diversity between the CFM and non-CFM Areas**

#### 4.2.3 Variation in Species Diversity

Table 4, To assess the homogeneity of variances for the Species Diversity Index between different groups within the study area, Levene test was performed. The findings reveal statistically significant differences in variances across groups, as indicated by the low p-values ( $p < 0.01$ ) for all tested methods (mean, median, adjusted median). The results suggest that the variances of species diversity indices significantly vary between the examined groups, potentially influencing the reliability of certain statistical analyses and emphasizing the need for cautious interpretation when comparing species diversity across CFM and non-CFM areas.

**Table 4: Levene Test of Homogeneity of Variances**

		Levene Statistic	df1	df2	Sig.
Species Diversity Index	Based on Mean	10.70	1	35	.002
	Based on Median	8.16	1	35	.007
	Based on Median and with adjusted df	8.16	1	26.32	.008
	Based on trimmed mean	10.56	1	35	.003

#### 4.2.4 Species Evenness Analysis in CFM and non-CFM Areas

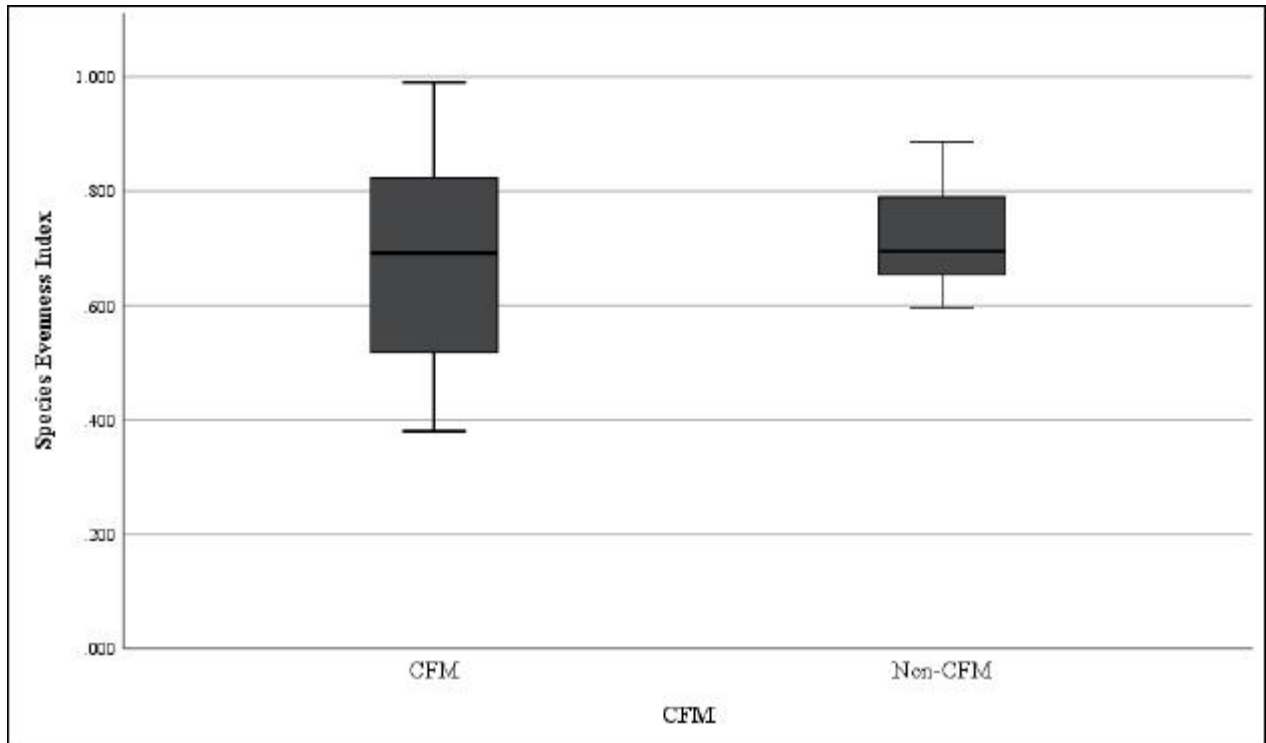
The results further indicate a slightly lower average Species Evenness (J) in CFM areas (0.69) compared to non-CFM areas (0.73). (Table 5). However, the observed standard deviations

suggest greater variability in evenness within CFM areas. The findings point to a potential disparity in evenness levels between CFM and non-CFM areas, warranting further investigation to discern the significance of this difference and its ecological implications within the study area.

**Table 5: Species Evenness (J)**

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
CFM	22	.69	.19	.04	.61	.77	.38	.99
Non-CFM	15	.73	.09	.02	.68	.77	.60	.89
Total	37	.70	.15	.03	.65	.75	.38	.99

The findings on variation in Species Evenness, reveal distinct characteristics in their distributions. CFM areas showcase a broader Interquartile Range (IQR) compared to non-CFM areas, indicating a wider spread of Species Evenness values within the middle 50% of data in CFM areas (Figure 7). Moreover, the whiskers in CFM areas are notably longer than those in non-CFM areas, suggesting a greater variability and wider range of Species Evenness values. Interestingly, both CFM and non-CFM areas display almost equal median values, indicating a similar central tendency in Species Evenness between the two areas. Furthermore, the box plot demonstrates that the lower whiskers in both areas are shorter than the upper whiskers, suggesting a potential asymmetry in the distribution, where the lower end of the data range is more restricted compared to the upper end in both CFM and Non-CFM areas. This comparison highlights the differences in variability and spread of Species Evenness between CFM and Non-CFM areas, with CFM areas showcasing a broader range and greater variability despite similar median values, while both areas exhibit a restriction in the lower end of their data ranges.



**Figure 7: Showing Variation in the Species Evenness between the CFM non-CFM Areas**

#### 4.2.5 Variation in the Species Evenness

To assess the variances in the Species Evenness Index across different groups within the studied area, a Levene test was performed. The results demonstrate statistically significant differences in variances for the Species Evenness Index among the examined groups (Table 6). This suggests that the homogeneity of variances assumption required for certain statistical analyses may not hold among these distinct groups, potentially influencing the reliability and interpretation of statistical comparisons involving the Species Evenness Index among these categories within the study area.

**Table 6: Levene Test of Homogeneity of Variances**

		Levene Statistic	df1	df2	Sig.
Species Evenness Index	Based on Mean	6.62	1	35	.015
	Based on Median	6.57	1	35	.015
	Based on Median and with adjusted df	6.57	1	29.98	.016
	Based on trimmed mean	6.65	1	35	.014

### 4.3 Stem Density Variation

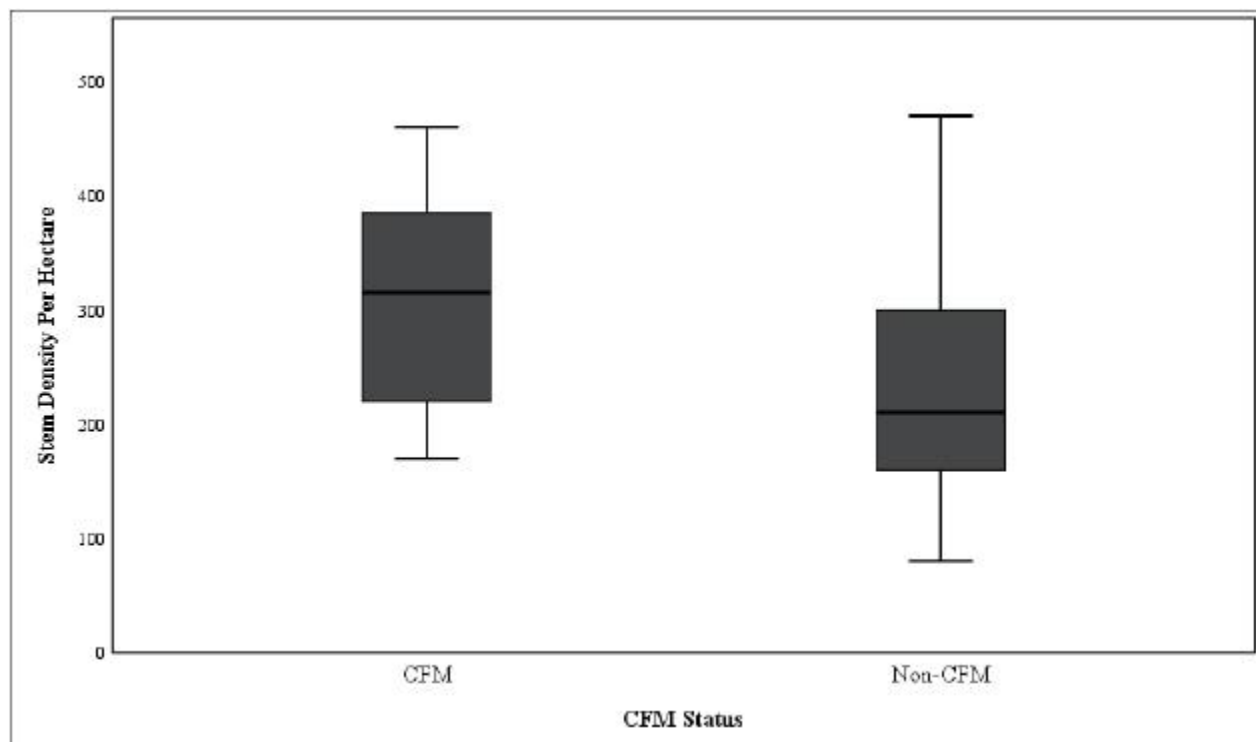
#### 4.3.1 Stem Density Distribution in the Study Area

The descriptive statistics from the study findings reveal that the average stem density in CFM areas was higher (309 stems per hectare) compared to non-CFM areas (239 stems per hectare) (Table 7). This difference in mean values suggests a potential difference in forest structure and composition between CFM and non-CFM areas. The variability within CFM areas, denoted by a standard deviation of 103 stems, appears slightly lower than that within non-CFM areas. The confidence intervals for the mean densities illustrate a range within which the true population mean is likely to fall, emphasizing the need for further analysis to discern any significant differences between the CFM and non-CFM statuses in terms of stem density distribution and forest health.

**Table 7: Stem Density in CFM and non-CFM areas**

Stem Density Per Hectare								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
CFM	12	309	102.9	29.7	243.8	374.5	170	460
Non-CFM	12	239	114.3	33.0	166.5	311.8	80	470
Total	24	274	112.2	22.9	226.8	321.5	80	470

In terms of variation in Stem Density, both CFM and non-CFM areas exhibit nearly the same Interquartile Range (IQR), with the non-CFM areas displaying a narrower IQR (Figure 8). This suggests that while the middle 50% of Stem Density values are similar between both types of areas, the non-CFM areas have a more concentrated range of data within this middle portion. Moreover, the whiskers in the non-CFM areas are longer than those in the CFM areas, indicating a greater variability and wider spread of Stem Density values in non-CFM areas. Notably, the CFM areas exhibit a higher median compared to non-CFM areas, suggesting that the middle value of Stem Density data is positioned at a higher level in CFM regions. This comparison underscores the differences in variability and central tendency of Stem Density between CFM and non-CFM areas, with non-CFM areas displaying a narrower range but greater variability, while CFM areas demonstrate a higher median value, potentially indicating a more concentrated or elevated Stem Density.



**Figure 8: Box Plot showing the Variation in the Stem Density in CFM and non-CFM Areas**

#### 4.3.2 Variation in Stem Density in CFM and non-CFM Areas

Table 8 presents various statistics to assess the homogeneity of variances for stem density, a Levene test was performed. The findings indicate equal variances for stem density per hectare between CFM and non-CFM areas (Table 8). This suggests a relative similarity in the variability of stem density values in CFM and non-CFM areas, irrespective of the measure used to assess variance homogeneity.

**Table 8: Levene Test of Homogeneity of Variances in Stem Density**

		Levene Statistic	df1	df2	Sig.
Stem Density Per Hectare	Based on Mean	.005	1	22	.946
	Based on Median	.004	1	22	.948
	Based on Median and with adjusted df	.004	1	17.806	.948
	Based on trimmed mean	.001	1	22	.970

## CHAPTER FIVE

### DISCUSSIONS

#### 5.1 Effect of CFM on Carbon Stocks

The first objective of the study was to compare carbon stocks in CFM and non-CFM areas within the area of study. The study findings revealed notable differences in the distribution of carbon stocks between CFM and non-CFM areas. Non-CFM areas exhibited a wider range and greater variability in carbon stocks compared to CFM areas, suggesting a broader spectrum of carbon storage levels within the non-CFM territories. Additionally, both CFM and non-CFM areas showed outliers, indicating extreme values in carbon stocks, regardless of management type. Descriptive statistics further highlighted distinct differences between CFM and non-CFM areas. The mean carbon stock in non-CFM areas was notably higher than in CFM zones, pointing towards a potential difference in average carbon storage between these management statuses. Moreover, the larger standard deviation in non-CFM areas emphasized greater variability and dispersion of carbon stock values within these regions. However, statistical tests like the Levene test did not provide substantial evidence supporting clear-cut differences in carbon stocks between CFM and non-CFM areas. While variability and mean values varied, there was no statistically significant distinction between CFM and Non-CFM management approaches.

The similarity in the overall variability of carbon stocks, as indicated by the Levene test results, suggests that both management regimes face similar environmental conditions and ecological processes that influence carbon storage (Braga et al., 2024). This includes factors like soil fertility, climate conditions, and natural disturbances, which can affect carbon sequestration regardless of management practices (Ekoungoulou et al., 2018).

The findings from the analysis of carbon stocks in the Mabira CFR, comparing CFM and non-CFM areas, bring out distinct differences with existing literature. Numerous studies have suggested that CFM can positively impact carbon stocks by promoting sustainable forest practices and enhancing carbon storage (Wood et al., 2019). Mandal *et al.* (2012) found that CFM areas exhibited higher carbon stocks compared to non-CFM areas, echoing the positive influence of community participation in forest stewardship.

The divergence of findings from some literature that suggests CFM areas tend to consistently maintain higher carbon stocks, resonates with the broader understanding that the impact of CFM on carbon stocks can vary significantly based on contextual factors, as highlighted by Melikov *et al.* (2023). The insignificance in carbon stocks in both areas could be attributed to similar impacts from illegalities from the surrounding communities based on the fact that both areas are in proximate to key highly populated communities and enclaves that have a greater demand for forest products. In addition, these studied areas were close to each other perhaps mirroring the same spatial difference.

The diverse effects of forest management practices on carbon stocks are highlighted in the literature, emphasizing the significance of factors beyond the management status alone. For instance, studies have indicated that CFM doesn't always guarantee higher carbon stocks compared to other management practices like Protection Forest management (PFM), as seen in Nepal (Lamsal *et al.*, 2023). Additionally, local conditions, species selection, time since practice, and previous land use significantly influence the impact of CFM on carbon stocks, echoing the complexities observed in the Mabira CFR analysis.

Overall, whereas the findings from the Mabira CFR don't support the notion that CFM can positively influence carbon stocks, the observed variability between CFM and non-CFM areas underscore the complex interplay of management practices, local conditions, and other factors that collectively shape carbon stock dynamics. This comprehensive understanding emphasizes the need for holistic approaches considering multifaceted factors beyond management status alone to effectively manage and enhance carbon stocks in forested areas.

## **5.2 Effect of CFM on Tree Species Diversity**

The second objective of the study was to investigate tree species diversity in forested areas under CFM and non-CFM. The study reveals that non-CFM areas exhibit higher species richness and diversity compared to CFM areas. The rarefaction curve indicates more rapid species discovery in non-CFM plots, suggesting less human disturbance. In terms of species diversity, non-CFM areas have a higher mean diversity index (1.86) than CFM areas (1.41), with non-CFM areas showing less variability in species composition. The Levene test confirms significant differences in variances across groups, underscoring the influence of management strategies on diversity outcomes. Additionally, species evenness is slightly lower in CFM areas (0.688) compared to

non-CFM areas (0.726), with greater variability observed in CFM areas, as evidenced by broader interquartile ranges and longer whiskers. This suggests that human activities in CFM areas contribute to greater variability in species distribution and abundance, whereas non-CFM areas benefit from more stable and higher species diversity due to reduced disturbance.

The disparity in species diversity between CFM and non-CFM areas is largely attributed to the varying levels of human disturbance and resource utilization (Turyahabwe et al., 2012). CFM areas, which involve active human engagement through sustainable harvesting and utilization of forest resources, experience habitat disruption that can reduce species richness and diversity (Boton et al., 2021). In contrast, non-CFM areas, with less direct human interference, maintain more stable and diverse ecosystems (Sassen & Sheil, 2013). Furthermore, the distinct management practices play a crucial role; CFM areas often balance conservation with economic benefits for local communities, leading to selective logging and other practices that negatively impact species diversity (Ellis et al., 2019). On the other hand, non-CFM areas, governed by stricter conservation policies, prioritize ecosystem preservation, resulting in higher species richness and diversity (Fleishman et al., 2006). Additionally, non-CFM areas are at more advanced stages of ecological succession, providing more mature forests that support a greater number of species due to increased habitat complexity and resource availability (Chazdon, 2017). This advanced ecological succession is evidenced by the quicker species discovery in non-CFM plots, suggesting well-established habitats that support diverse flora (Brazier et al., 2020).

Monarrez-Gonzalez et al. (2020) indicate that intensive management interventions can decrease tree diversity. This aligns with the study's findings showing lower observed species richness in CFM areas compared to Non-CFM areas. Both sources highlight the potential impact of management interventions on reducing floral diversity. The spatial comparison in the study showcases distinct patterns between CFM and Non-CFM areas. Despite convergence at the 12th plot in terms of observed species richness, the spatial analysis reveals a consistently lower observed species richness in CFM areas compared to Non-CFM areas, emphasizing spatial disparities in floral composition influenced by management practices.

Despite differences in management practices, both CFM and non-CFM areas exhibit similarities in species richness and diversity due to shared ecological characteristics, for instance climate,

topography & soil type, which influence species composition (Thammanu et al., 2020). These common ecological features can result in similar baseline species richness and diversity over time, as shown by the convergence of species richness curves at plot 12. Additionally, increased community engagement and conservation awareness in CFM areas can lead to protective measures that enhance biodiversity (Fielding et al., 2023). Community members, recognizing the long-term benefits of biodiversity, may engage in activities like planting native species and protecting key habitats, which mitigate some negative impacts of resource utilization and promote species richness (Salmi et al., 2023). Furthermore, both CFM and non-CFM areas benefit from natural regeneration processes, where natural disturbances create opportunities for new species to establish, maintaining a dynamic equilibrium in species diversity (Shono et al., 2007). This natural resilience allows ecosystems to recover from disturbances, leading to similar levels of species richness over time.

Wood *et al.* (2019) and Ramos *et al.* (2019) support the idea that CFM positively impacts biodiversity conservation. The study findings align with this perspective by showcasing CFM's role in mitigating forest loss and maintaining biodiversity, albeit at lower species diversity indices in the spatial analysis. Despite lower observed species richness in CFM areas, the study indicates a convergence in diversity at the 12th plot, suggesting CFM's role in mitigating forest loss and maintaining certain aspects of biodiversity. This highlights CFM's spatial impact on overall floral composition, reinforcing its positive contribution to biodiversity conservation within specific spatially managed zones.

### **5.3 Effect of CFM on Stem Density**

The third objective of the study was to determine tree stem-densities in forested areas under CFM and non-CFM. The study reveals that CFM areas have a higher average stem density (309 stems per hectare) compared to non-CFM areas (239 stems per hectare). Despite this difference, the variability within CFM areas is slightly lower, with a standard deviation of 103 stems compared to 114 in non-CFM areas. Both areas exhibit similar interquartile ranges, but non-CFM areas show a more concentrated range of stem density values within the middle portion, and greater overall variability. The higher median stem density in CFM areas indicates a higher central tendency of stem density in these regions. A Levene test confirms that the variances in

stem density between CFM and non-CFM areas are equal, suggesting similar variability in stem density values across both forest management types.

The disparities and similarities in stem density between CFM and non-CFM areas can be attributed to several factors. In CFM areas, active human engagement through sustainable harvesting and resource utilization often leads to higher stem densities; these practices encourage planting and maintaining more trees to support both communities needs and conservation goals (Boton et al., 2021). Conversely, non-CFM areas, with less direct human interference, may experience lower stem density due to natural thinning processes and less interventionist management practices (Giuggiola et al., 2012). Additionally, CFM areas typically balance forest utilization with protection, resulting in a managed increase in stem density; Community-led initiatives often include reforestation and afforestation efforts, enhancing stem density (Bowler et al., 2010). In contrast, non-CFM areas, which prioritize conservation, might not have the same level of active reforestation, leading to a more natural but lower stem density.

However, the similarity in stem densities as shown by the Levene-test could point to similar patterns of disturbances in both CFM and no-CFM areas. More so, both CFM and non-CFM areas share similar ecological characteristics such as climate, soil type, and topography, contributing to baseline similarities in stem density.

## CHAPTER SIX

### CONCLUSIONS AND RECOMMENDATIONS

#### 6.1 Conclusions

This study aimed to evaluate the impact of CFM on carbon stocks, species diversity, and stem density in the Mabira CFR. Despite CFM's goal to balance forest conservation with community benefits, there is limited empirical evidence on its ecological outcomes. The study addressed this gap by comparing these variables between CFM and non-CFM areas. The objectives were to compare carbon stocks, species diversity, and stem density between these management types. Key findings revealed that CFM significantly influences species diversity while having no significant influence on carbon stocks and stem density.

#### 6.2 Recommendations

The study highlighted notable differences between CFM and non-CFM areas in the Mabira CFR. The study was justified by the need to empirically assess the ecological effects of CFM, a strategy intended to balance forest conservation with community benefits. Understanding these impacts is crucial for informing forest management policies and practices that can effectively sustain forest ecosystems while supporting local communities.

- Whereas the studies didn't support CFM in influencing carbon stocks, there is need to capture baseline conditions before implementing CFM to help in future comparative studies. Despite, there should be targeted interventions in CFM such as promoting reforestation and afforestation with high-carbon-storing species. Additionally, strengthen monitoring and evaluation frameworks to assess carbon stock changes over time.
- Enhance biodiversity conservation efforts in CFM areas by incorporating more stringent protection measures and reducing human disturbance. Encourage community participation in biodiversity monitoring and conservation education to raise awareness and support for preserving species diversity.
- Promote sustainable forest management practices in both CFM and non-CFM areas to maintain balanced stem density.

### **6.2.1 Areas for Further Research:**

- Investigate more on impact of CFM on carbon stocks and stem density in other ecologically similar forests by capturing baseline conditions before implementation of CFM.
- Explore the socio-economic advantage of CFM to resident communities and how these relate to ecological outcomes.
- Conduct comparative studies on CFM practices in different regions to understand contextual factors influencing their effectiveness.
- Examine the significance of different tree species in carbon sequestration and biodiversity enhancement within CFM areas.

By addressing these recommendations and areas for further research, future forest management strategies can be better aligned with both conservation goals and community needs, ensuring sustainable and resilient forest ecosystems.

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## APPENDIX 1 ANTIPLAGARISM REPORT

# Phillipson Mugumya

## EFFECT OF COLLABORATIVE FOREST MANAGEMENT ON CARBON STOCKS%2C SPECIES DIVERSITY AND STEM DENSI...

 Uganda Management Institute

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- 10% Submitted works (Student Papers)

## Integrity Flags

### 0 Integrity Flags for Review

Our system's algorithms look deeply at a document for any inconsistencies that would set it apart from a normal submission. If we notice something strange, we flag it for you to review.

