

Sokoine University of Agriculture



MSc Dissertation

**Above ground biomass, land cover
change and Regeneration of tree
species under different grazing
intensities in Miombo woodlands,
Tanzania**

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May 2024

**ABOVE GROUND BIOMASS, LAND COVER CHANGE AND
REGENERATION OF TREE SPECIES UNDER DIFFERENT
GRAZING INTENSITIES IN MIOMBO WOODLANDS, TANZANIA**

*Dissertation Submitted to Sokoine University of Agriculture in
Fulfilment of the Requirements of Masters of Science in
Forestry*

By

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EXTENDED ABSTRACT

Tanzania's livestock sector faces challenges due to overgrazing, threatening the ecological balance of critical habitats like Miombo woodlands. This study investigates the impact of grazing pressure on land cover changes, tree biomass, and regeneration potential in these woodlands of Kilosa, Kilombero, and Handeni districts.

Despite existing research on the damaging effects of overgrazing, a comprehensive analysis specific to Tanzanian Miombo woodlands is lacking. We address this gap by analyzing high-resolution satellite imagery (Landsat 5 TM & 8 OLI) from 1995 to 2021 to quantify land cover changes across the study areas.

Field surveys were conducted to assess grazing intensity, aboveground biomass (AGB), and tree regeneration within representative Miombo woodland sites. Allometric models estimated tree-level AGB, which was then scaled to calculate plot-level AGB (tonnes/ha). Statistical analyses explored relationships between grazing intensity and land cover change, biomass dynamics, and tree regeneration.

Results reveal a negative impact of medium and high grazing intensities on AGB compared to light grazing. Satellite image analysis indicates higher tree cover loss under medium grazing (63.5%) compared to high (61.5%) and light grazing (23.2%) between 1995 and 2022. Additionally, grazing intensity significantly affects tree regeneration (number, species richness, diversity, and evenness) ($p < 0.05$).

These findings show the damaging effects of overgrazing on Tanzanian Miombo woodlands. This knowledge can inform sustainable grazing practices, collaborative management strategies, and efforts to mitigate forest cover loss. Further research could explore optimal grazing levels and develop specific recommendations for policymakers and land managers.

IKISIRI KUU

Sekta muhimu ya mifugo nchini Tanzania inakabiliwa na changamoto kutokana na kuchungwa kwa ng'ombe kwa kiwango kikubwa, na hivyo kuhatarisha usawa wa ikolojia wa misitu kama vile misitu ya Miombo. Utafiti huu unachunguza athari za mifugo kwenye mabadiliko ya matumizi ya ardhi, wingi wa miti, na uwezo wa misitu hiyo ya Miombo kujirejesha katika wilaya za Kilosa, Kilombero, na Handeni.

Licha ya utafiti uliopo kuhusu athari mbaya za kuchungwa kwa mifugo kwenye misitu, bado hakuna uchambuzi kamili kuhusu viwango tofauti vya ufugaji kwenye misitu ya Miombo nchini Tanzania. Tunashughulikia pengo hili kwa kuchanganua picha za satelaiti (Landsat 5 TM & 8 OLI) kutoka 1995 hadi 2021 ili kupima mabadiliko ya matumizi ya ardhi katika maeneo ya utafiti.

Tafiti za ardhini zilifanywa kutathmini wingi wa mifugo, kiwango cha miti juu ya ardhi na uwezo wa miche ya miti kujirejesha katika maeneo muhimu ya misitu ya Miombo. Hesabu ilitumika kutathmini kiwango cha biomasi cha miti mmoja mmoja, ambayo kisha ikajumuishwa kuhesabu kiwango cha miti katika eneo (tonnes/ha). Uchambuzi wa takwimu uli kuchunguza uhusiano kati ya wingi wa mifugo na mabadiliko ya matumizi ya ardhi, mabadiliko ya wingi wa miti, na uwezo wa miche ya miti kujirejesha.

Matokeo yanaonyesha kuwa idadi kubwa ya mifugo ina athari mbaya kwa kiwango cha miti juu ya ardhi ikilinganishwa na idadi ndogo ya mifugo. Uchambuzi wa picha za satelaiti unaonyesha kuwa uharibifu mkubwa wa miti ulitokea kwenye maeneo yenye idadi kubwa ya mifugo (63.5%) ikilinganishwa na maeneo yenye idadi ndogo ya mifugo (23.2%) kati ya 1995 na 2022. Aidha, wingi wa mifugo kwenye misitu unaathiri kwa kiasi kikubwa uwezo wa miche ya miti kujirejesha.

Haya matokeo yanaangazia athari mbaya za kuchungwa kwa mifugo kupita kiasi kwenye misitu ya Miombo nchini Tanzania. Maarifa haya yanaweza kuarifu kuhusu mbinu endelevu za kuchunga mifugo, mikakati shirikishi ya usimamizi, na juhudi za kupunguza uharibifu wa

misitu. Utafiti zaidi unaweza kuchunguza viwango bora vya kuchunga mifugo na kutoa mapendekezo mahususi kwa watunga sera na wasimamizi wa ardhi.

DECLARATION

I, **THADEI TARCIS RUGAMBWA**, do hereby declare to the Senate of Sokoine University of Agriculture that, this thesis is my original work and that it has neither been submitted nor concurrently submitted for a degree award in any other institution

Thadei Tarcis Rugambwa
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Date

The above declaration is confirmed by;

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DEDICATION

This work is dedicated to my family and relatives for their love, constant prayers, and support which helped me to be strong through the entire period of my studies.

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LIST OF ABBREVIATIONS AND ACRONYMS

AGB	Aboveground Biomass
DBH	Diameter at Breast Height
GDP	Gross Domestic Product
GEE	Google Earth Engine

CHAPTER ONE

1.0 Introduction

1.1 Background information

Tanzania's agricultural sector heavily relies on livestock production, a critical contributor to food security, income generation and ecological balance. It accounts for roughly 30% of agricultural GDP, with beef leading the subsector (Wilson, 2019). However, uncontrolled grazing can significantly alter land-cover dynamics, potentially leading to the conversion of woodlands to grasslands (Homewood et al., 2001). This process directly impacts tree biomass, a crucial component of carbon sequestration and ecosystem health (Stephens et al., 2014). Additionally, excessive grazing pressure can hinder tree regeneration by altering seedling establishment and survival rates (Nyeko et al., 2014).

Miombo woodlands, dominated by *Brachystegia*, *Julbernardia*, and *Isoberlinia* trees, are Tanzania's most extensive vegetation type, encompassing nearly 31 million hectares (URT, 1998). Historically, factors like low soil fertility, prevalent diseases, and limited infrastructure acted as natural barriers to widespread conversion for agriculture (Ford, 1971; Munishi et al., 2004). However, recent advancements like improved soil management and disease control, coupled with a growing population, are altering land-use patterns, putting pressure on Miombo woodlands for conversion (Nduwamungu, 2015).

Land cover change, often a consequence of population and economic growth, poses a significant threat to Miombo woodlands. While historically protected by limitations like soil fertility and infrastructure, these limitations are being overcome with technological advancements. This conversion of Miombo woodlands to cropland has two major global consequences: greenhouse gas emissions from soil and biomass, and biodiversity loss.

Despite these threats, Miombo woodlands exhibit remarkable resilience through regeneration (Syampungani et al., 2016; Sangeda and Maleko, 2018). This regeneration capacity allows them to

recover from various disturbances, including livestock grazing. However, a comprehensive understanding of how grazing pressure specifically affects Miombo tree regeneration dynamics in Tanzania remains partial. The majority of available data on regeneration of Miombo woodlands is dispersed not yet assembled to relate with effects of grazing pressure.

This research dives into this critical knowledge gap by investigating the impact of grazing pressure on land-use change, aboveground biomass, and the regeneration potential of Miombo woodlands in Tanzania. The aim is to provide valuable insights for developing sustainable management practices that effectively balance the needs of livestock production with the ecological health of these vital ecosystems.

1.2 Problem statement and justification

1.2.1 Problem statement

Miombo woodlands, vital ecosystems in East and South-central Africa, face imminent threats from human activities, particularly overgrazing, leading to environmental stress and degradation (Rogers et al., 2021). The sustainability of these woodlands is critical not only for biodiversity conservation but also for the livelihoods of communities reliant on their resources. However, understanding the dynamics of Miombo woodlands sustainability requires a comprehensive study into the relationship of socio-economic, political, and environmental factors.

In particular, the Kilosa district in the Morogoro region of Eastern Tanzania serves as a touching case study. This region has a history of resource-related conflicts, epitomized by the tragic events of December 8, 2000, when pastoral Maasai warriors attacked the Rudewa Mbuyuni village, resulting in significant loss of life (Benjaminsen et al., 2009). These conflicts show the urgent need to address underlying tensions stemming from land and forest occupation, worsened by environmental degradation and socio-economic disparities.

Recent studies indicate alarming trends in land cover changes in the region. Agricultural expansion and the loss of wetland areas signify the growing pressures on natural resources, driven by population growth, market demands, and infrastructure development (Msofe et al., 2019). These changes not only threaten the ecological integrity of Miombo woodlands but also aggravate existing socio-economic differences and increase the likelihood of conflicts over resource access and management.

To address these challenges, this study offers a comprehensive assessment of land cover changes, tree above ground biomass and regeneration at different grazing intensities, and their consequences on Miombo woodlands sustainability in the Kilosa district, alongside Kilombero and Handeni districts in Tanzania. Utilizing high-resolution satellite imagery from Landsat (Landsat 5 TM and Landsat 8 OLI), we aim to analyze the patterns of land cover changes from 1995 to 2021. Specifically, we will employ the Support Vector Machine model to map land cover changes and assess the impacts of different grazing intensities on land cover change, aboveground biomass and woodland regeneration potential.

This study aims to help make better decisions about protecting and managing Miombo woodlands by showing how grazing affects the land cover and the ability of the woodlands to regenerate. The findings will not only contribute to the academic understanding of ecosystem dynamics but also provide actionable insights for policymakers and local communities. Ultimately, this research endeavors to foster sustainable land use practices that balance ecological conservation with socio-economic development in Miombo woodland landscapes

1.3 Research objectives

1.3.1 General objective

The main objective is to determine the effects of grazing pressure on land cover and land-use change in the districts of Kilosa, Kilombero and Handeni.

1.3.2 Specific objectives

The specific objectives of this study were to:

- i. To assess the effect of grazing pressure on land cover and land use changes of the Miombo woodlands over a period of thirty years.
- ii. To estimate the effect of grazing pressure on above-ground biomass and the regeneration limitation of the Miombo woodlands.

1.4 Limitations of the Study

We acknowledge the limitations of this research. Our study primarily focuses on grazing intensity as a singular factor, although an important one. The complex nature of ecosystems implies that other variables, such as climate, soil conditions, and fire regimes, may influence grazing effects. After accomplishing reliable estimates of forest cover change using Landsat 5 TM and 8 OLI remote sensing data, several limitations remain. Future studies should consider these interactions to provide a more comprehensive understanding of ecosystem dynamics.

- i. The first Manuscript looks into the tree cover change from 1995 to 2022 where there was a difficulty in obtaining cloud free images. We used composite images, which do not accurately represent features of a particular time point.
- ii. In the field dataset used, prediction errors may have occurred because a general allometric equation was used to obtain plot-level AGB from individual tree

attributes (DBH) while the study sites had a relatively large number of tree species.

1.5 Dissertation Structure

This dissertation is divided into five chapters and is structured as a series of publishable manuscripts. The first chapter introduces the study, including background information, the problem statement, study objectives, and limitations. Chapter 2 assesses tree cover change and aboveground biomass of forests under different grazing intensities Chapter three looks into the regeneration of tree species under grazing pressure in Miombo woodlands. Chapter 4 is a general discussion of the study's findings, and Chapter 5 provides a summary of the key contributions, conclusions, and recommendations for future research.

CHAPTER TWO

Manuscript One

Tree cover change and aboveground biomass of forests under different grazing intensities in Miombo woodlands, Tanzania

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2.1 Abstract

Miombo woodlands are important for biodiversity conservation, carbon sequestration, and community sustenance but face a severe threat from anthropogenic activities including increased intensity of livestock grazing. This study assessed variation in tree above ground biomass (AGB) and change in tree cover of Miombo woodlands under low, medium and high grazing intensities. The AGB was assessed in 181 rectangular (20 m x 50 m) sample plots randomly distributed in nine forests located in three districts covering diverse climate and landform in Miombo. Tree cover changes was assessed through the analysis of Landsat Satellite images between 1995 and 2022. Results show that medium and high grazing intensities have a negative effect on AGB when compared to light grazing intensity. The analysis of Satellite imagery showed that between 1995 and 2022, tree cover loss was higher in woodlands under medium grazing intensity (63.5%) than high (61.5%) and light (23.2%) grazing intensities. The findings of this study suggest that medium and high grazing intensities could accelerate forest degradation. Urgent interventions, contributing awareness for sustainable management and conservation, are required to counter the increasing loss of AGB and forest cover in Miombo woodlands.

Keywords: Biomass; Grazing; Remote sensing; Land cover

2.2 Introduction

Miombo woodlands, covering approximately 2.7 million km² across southern Africa, play a critical role in ecosystem health. These woodlands provide essential services like carbon sequestration, soil conservation, and biodiversity conservation (Frost, 1996). In Tanzania, Miombo woodlands are the dominant vegetation type, covering about 90% of the mainland's woodlands (Campbell et al., 1996). Characterized by species like *Brachystegia*, *Julbernardia*, and *Isoberlinia*, these woodlands support a diverse network of life (White, 1983). They serve as a habitat for African fauna like elephants, lions, leopards, and various antelope species. Millions of people rely on Miombo woodlands for their livelihoods, as they

support agricultural practices; provide timber for construction, fuelwood, non-timber forest products for food, and a variety of other ecosystem services (Gambiza et al., 2000). Additionally, Miombo woodlands play a crucial role in regulating water flow, particularly during dry seasons, acting as important sources for groundwater recharge and maintaining streamflow (Syampungani et al., 2009).

However, Miombo woodlands in Tanzania, like those across Africa, face a multitude of threats. These challenges include wildfires, overharvesting of trees, shifting cultivation practices, and agricultural expansion (Mwarura et al., 2020; Mugasha & Zahabu, 2014; Kilawe et al., 2018; FAO, 2020). The growing livestock population also poses a significant threat, potentially leading to deforestation and degradation of Miombo woodland flora (Mugasha et al., 2013). Deforestation and land-use changes directly remove mature trees and hinder the establishment of new ones (Maginnis & Jackson, 2005). If left unaddressed, these challenges can disrupt natural regeneration processes of Miombo trees, jeopardizing the long-term sustainability of these vital ecosystems.

Livestock production plays a significant role in Tanzania's agricultural sector, contributing substantially to food security, income generation, and asset accumulation (Mdoe et al., 2021). However, this growth in livestock production comes at an environmental cost, particularly for Tanzania's dominant ecosystem, the Miombo woodlands (Jew et al., 2016). As the demand for livestock products rises, so too does the pressure exerted on Miombo woodlands by grazing activities. This pressure can lead to changes in vegetation composition, declining productivity, and increased soil erosion (Nyirenda et al., 2019). Grazing can alter vegetation structure by decreasing tree density and canopy cover, while increasing the abundance of herbaceous plants (Pettit et al., 1995). These changes can have cascading effects, affecting the availability of forage for both livestock and wildlife, as well as altering the microclimate and soil properties of the Miombo woodlands.

Existing research on the effects of grazing on tree cover and biomass primarily focuses on comparisons between grazed and ungrazed forests (Noy-Meir, 1978; Pettit et al., 1995; Todd et al., 1998; Zumo & Hashim, 2020). Studies conducted in Tanzania on the impacts of grazing on Miombo woodland biomass observed differences in biomass between grazed and ungrazed forests (Ruvuga et al., 2020, 2021). However, the intensity of grazing likely influences the extent of its impact on biomass. To address this knowledge gap, this study investigates the effects of grazing at different intensities (low, medium, and high) on the tree cover and aboveground biomass (AGB) of Miombo woodlands in Tanzania. Understanding these variations is crucial for developing sustainable management strategies that can balance the needs of livestock production with the conservation of Miombo woodlands. By promoting sustainable grazing practices through integrated approaches, we can mitigate the negative impacts of grazing on these ecosystems while supporting the livelihoods of local communities.

2.3 Methodology

2.3.1 Study area

The study was conducted in nine villages located in Kilombero District, Kilosa District, and Handeni District in Tanzania (Fig. 1). Kilosa District is situated at (8.2215° S, 36.3498° E), Kilombero District is at (8.2215° S, 36.3498° E) both within the Morogoro region, and Handeni District at (5.4236° S, 38.0261° E), located in the Tanga region. The districts have a tropical climate with warm temperatures. There are three main groups of communities performing different livestock management practices in these districts including farming communities dealing with agricultural activities and sedentary grazing, agro-pastoralist communities practising both extensive livestock keeping and farming, and pastoralist communities engaged in livestock keeping only. Grazing is an important activity in all three districts. Cattle, goats, and sheep

are the most common livestock. The grazing land is often communal, which leads to frequent conflicts over land use..

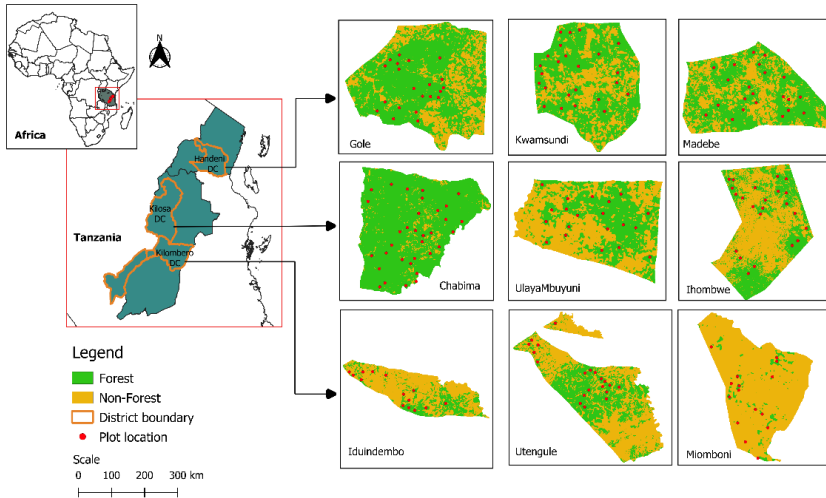


Figure 2.1: Study area map

Source: Own Construct, (2022)

2.4 Research design and Data collection

2.4.1 Field measurements

Field data collection was conducted in November 2022 in the Kilosa and Handeni Districts and in April 2023 in the Kilombero District. A stratified random sampling method was used, with a minimum of 20 sample plots per study village. A total of 188 rectangular (20 m x 50 m) sample plots were randomly placed in forest regions using QGIS software (Fig. 1) with some villages having more than 20 plots. Only 181 plots provided the data used because some plots had no trees at all. In each plot, the diameter of all trees with diameter at breast height, $dbh > 5$ cm was measured using a 65cm Haglof aluminium tree calliper and OCM open reel fibreglass 100m measuring tape for larger trees exceeding the calliper dimensions. A diameter of greater than 5 cm is a criterion used for identifying adult trees from regenerants

(Ghanbari et al., 2021). Additional information on the respective plot was recorded such as the GPS coordinates and elevation for a clear understanding of the environment.

2.4.2 Remote sensing

Thirty-six cloud-free Landsat 5 TM and Landsat 8 OLI composite images were acquired from Google Earth Engine's Landsat catalog (<https://developers.google.com/earth-engine/datasets/catalog/landsat>). The characteristics of the images are presented in Table S1 (in Electronic Supplementary Materials, EMS). In Google Earth Engine, the Landsat Surface Reflectance Tier 1 products are already atmospherically corrected. Remote sensing and geospatial analysis used Google Earth Engine, which is a powerful platform for accessing and processing satellite imagery. This involved the utilization of Landsat 5 and Landsat 8 collection imagery, which are renowned for their 30m pixels high quality images with and freely available data (Ridwan et al., 2018). To improve the accuracy and precision of the analysis process, the Landsat imagery was filtered by date, focusing on capturing data during dry season (Li et al., 2022). This temporal filtering ensures that the imagery corresponds to a specific time relevant to the study objectives, thereby enhancing the accuracy and relevance of the following analyses.

2.4.3 Grazing intensity

Grazing intensity was calculated based on officially registered livestock in villages per available village forest grazing area and expressed in Tropical Livestock Units (TLU)/ha/yr (Table 1). One TLU is based on an animal of 250 kg. We used the conversion factors 0.7 for cattle and 0.1 for goats and sheep (Ruvuga et al., 2021). Grazing intensity was classified into three levels: light grazing, medium grazing, and high grazing, corresponding to the stocking rate (SR): Light GI if $SR \leq 0.2 \text{ TLU/ha/yr}$, medium GI if $0.3 < SR < 0.4 \text{ TLU/ha/yr}$, and high GI if $SR \geq 0.5 \text{ TLU/ha/yr}$. The calculations were modified from Kikoti and Mligo (2015) by adjusting

the available grazing area to 75% of the total forest area, a modification made to better suit the environmental characteristics of the study area.

Table 2.1: Measurement of Variables (Categorization and definitions of explanatory factors)

Village	Grazing Area (ha)	Number of Cattle	Number of Shoots	Total TLU	Stocking Rate (SR) (TLU/ha/yr)	Grazing Intensity
Madebe	8526.42	3179	4212	2647	0.3	Medium
Gole	13367.43	1132	1362	929	0.1	Light
Kwamsundi	3593.16	2381	403	1707	0.5	High
Utengule	4986.36	2937	1557	2212	0.4	Medium
Iduindembo	943.2	1903	1118	1444	1.5	High
Miomboni	61.02	6468	2416	4769	1.9	High
Ihombwe	15986.88	6211	3435	4691	0.3	Medium
Chabima	13264.74	1158	30	814	0.1	Light
Ulaya	2433.33	1812	730	1341	0.6	High
Mbuyuni						

2.5 Data Analysis

2.5.1 Variation of tree Above-Ground Biomass across grazing intensities

Tree AGB was estimated using allometric models for Miombo woodlands developed by Mugasha et al 2013. The AGB estimates of the individual trees were then summed for each plot, and scaled to per-hectare values according to their respective plot area. Given the presence of unequal sample sizes, a Welch's Analysis of Variance (ANOVA) from R package "stats" was selected to evaluate the differences in AGB means among grazing intensities while accounting for variations in sample sizes and variances. A Dunn's post hoc analysis was undertaken to study pairwise differences in aboveground biomass between the grazing intensity levels.

2.5.2 Change in tree cover across various grazing intensities

The protocols followed during image classification is presented in in Fig.2.2 The Landsat images were clipped to the study area geometry using the 'ee.Image.clip()' function, which helped to reduce processing time and memory requirements. The clipped Landsat composite image was classified into forest and non-forest classes. Forest class included a continuous stand of trees with no evidence of farming or settlement where non forest included farmlands, bare lands, grasslands and settlements (Kilawe et al., 2018). To improve the accuracy of classification about 80 training samples for each class were selected from the images. The training samples were selected based on tone, texture and color (RGB band composition 5, 4, 3 for Landsat 8 and 4, 3, 2 for Landsat 5). Under these band combination forest areas appear red and non-forest areas appear grey to whitish. Google earth engine base maps were used for reference of geometry and recent (2022) land cover map. Classification used Support Vector Machine (SVM) classifier with an RBF kernel for image classification to produce land cover maps for each image. Parameters such as kernel type, gamma (0.5), and cost (10) were configured to optimize the classification.

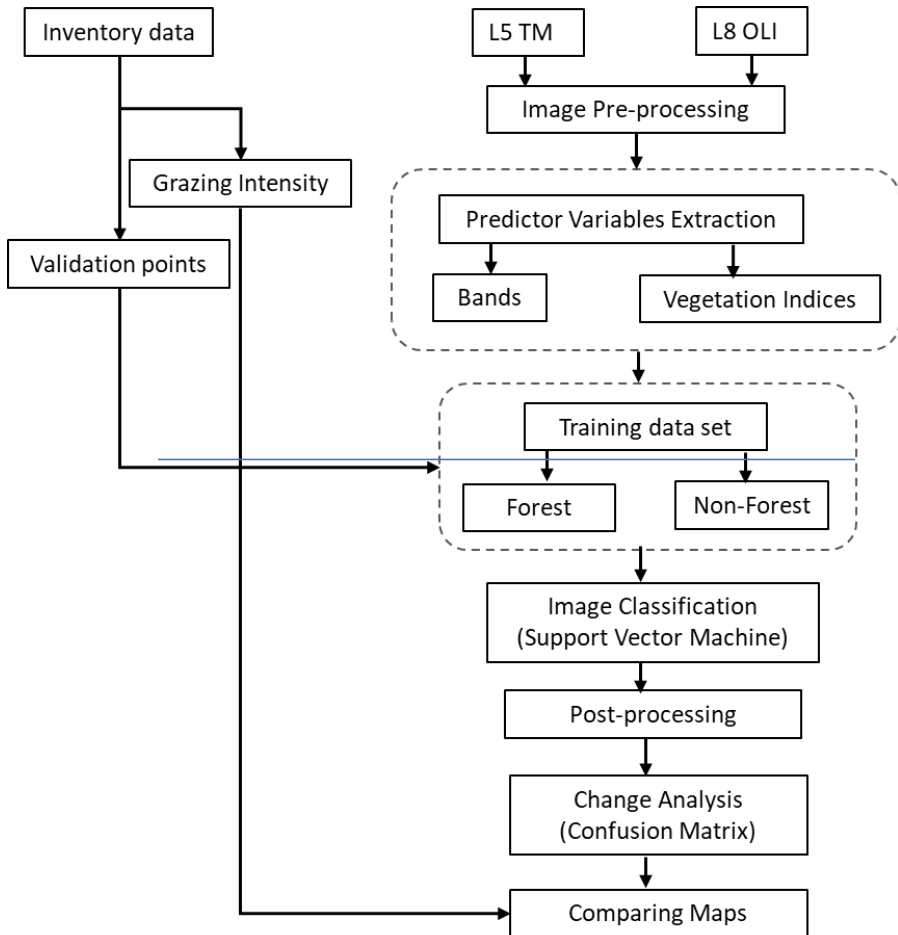


Figure 2.2: Methodological framework of Tree cover classification using images from Landsat 5 TM and Landsat 8 OLI performed in Google earth engine.

2.5.3 Accuracy assessment

Accuracy assessment of the classification model used a confusion matrix created from the Support Vector Machine (SVM) classified forest cover maps. First, the training sample was split into training dataset (80%) and validating dataset (20%). The SVM classifier was then applied to the separated validation dataset and calculated the

error matrix of the classification results. The error matrix provided detailed information on the classification errors, including user accuracy, producer accuracy, and overall accuracy (Lewis & Brown, 2001). Cohen's Kappa coefficient was then used to measure the agreement between the classification results and the ground truth (Google satellite base map), considering the possibility of agreement occurring by chance (Abdollahi et al., 2023).

2.6 Results

2.6.1 Accuracy Assessment

The summary of overall accuracy of the classified 2022 maps is presented in Table 2.2. Visual interpretation of the Landsat images gave total of 1680 training samples for forest class and 3437 samples for non-forest class. Accuracy assessment utilized 80% of the training samples as training points and 20% as validation points. The overall accuracy was 95.2%, which was more than 70%, meaning that the classification was of acceptable reliability (Congalton & Green, 2009).

Table 2.2: Accuracy assessment of tree cover maps

Class	Validation training points	Producer Accuracy %	User Accuracy
Forest	336	95.12	95.2
Non-forest	687	93.73	95.2
Overall Accuracy = 95.2			

2.6.2 Variation of tree Above-Ground Biomass across grazing intensities

Results from Welch's Analysis of Variance show that grazing intensity has a significant effect on the AGB at ($p < 0.1$). Tuckey's HSD test shows tree aboveground biomass in forests under light grazing intensity was significantly higher at ($P < 0.05$) than tree AGB in forests under medium and high grazing intensities (Fig. 3).

However, no significant difference between medium and high grazing intensities was observed.

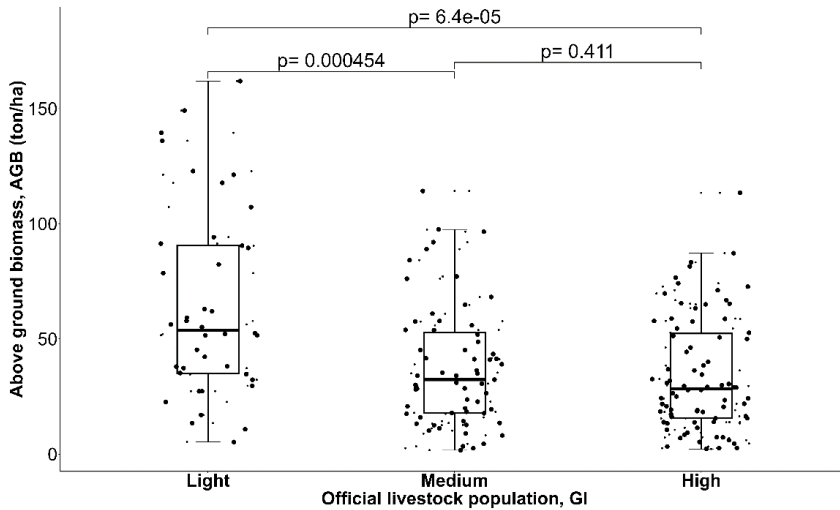


Figure 2.3. Boxplot showing the variations in tree aboveground biomass with grazing intensity.

2.6.3 Change in tree cover across various grazing intensities

Table 2.3 summarizes the changes in tree cover within Miombo woodlands between 1995 and 2022, categorized by grazing intensity. Detailed land cover classifications for the corresponding years are further illustrated in Figure 2.4. This analysis shows a trend where tree cover loss has been significantly higher in areas experiencing high and medium grazing intensities compared to those with light grazing. This suggests a direct correlation between grazing intensity and the decline of tree cover within Miombo woodlands.

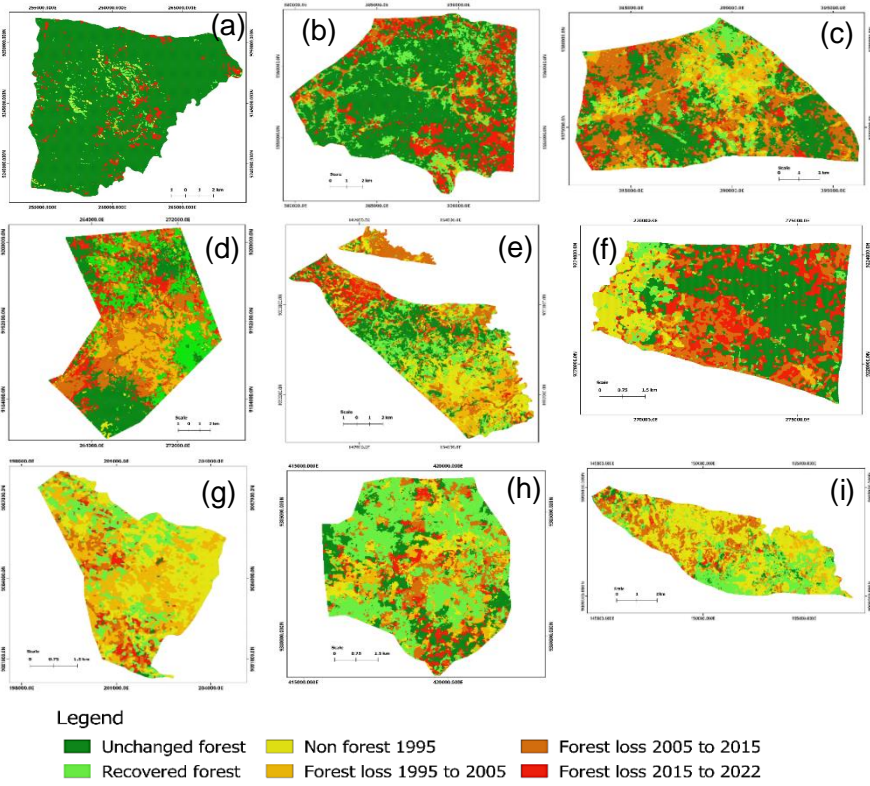


Figure 2.4. Land Cover maps

Table 2.3. Change in tree cover for woodlands under different grazing intensities.

Grazing Intensity	Total village area (ha)	Total cover loss 1995 to 2022 (ha)	Tree cover loss (ha)	Cumulative Forest Loss (%)	Tree cover loss rate (ha/year)
Light	26633.81	5802.57		23.2	214.91
Medium	42458.43	27704.85		63.5	1026.11
High	12995.90	7969.91		61.5	295.14

Figure 2.5 shows the temporal trends in tree cover loss for villages categorized by grazing intensity. A distinct pattern emerges where villages experiencing high and medium grazing intensity had the most significant tree cover loss between 2005 and 2015, followed by a decline in the rate of loss between 2015 and 2022. This suggests a potential shift in grazing practices or environmental factors during this later period. Whereby, villages with light grazing intensity exhibit a more consistent pattern of tree cover loss, with the highest rate occurring between 2015 and 2022.



Figure 2.5. Line graph showing cumulative forest loss and gain between 1995 and 2022 for all Miombo woodlands under Light, Medium and High grazing intensities.

2.7 Discussion

2.7.1 Grazing Intensity and Tree Above-Ground Biomass

Findings support a negative correlation between grazing intensity and AGB in Miombo woodlands. Villages experiencing light grazing pressure exhibited significantly higher AGB compared to those under medium and high grazing pressure. This aligns with previous research by Manyanda et al. (2021) and Zumo & Hashim (2020), showing the damaging impact of grazing on tree biomass. The observed differences in AGB can likely be attributed to the varying levels of damage caused by livestock across grazing intensities.

Light grazing villages often have lower population densities and limited accessibility for livestock, leading to less disturbance and higher AGB. Additionally, functional forest management plans in light grazing villages designate specific grazing areas, further reducing pressure on existing forests (Kilemo et al., 2014; Uisso et al., 2019). Villages with lower livestock populations, like Chabima and Gole, show this positive association between light grazing intensity and higher AGB. These findings suggest the potential benefits of local control practices, community-led initiatives, and lower livestock density for sustainable woodland management.

The absence of a significant difference in AGB between medium and high grazing intensity areas could be explained by comparable cattle-to-forest ratios, implying a consistent level of pressure affecting tree aboveground biomass. This highlights the need for establishing an equilibrium between grazing activities and Miombo woodland preservation. Studies by Munishi et al. (2011) and Mtimbanjaye & Sangede (2018) suggest potential for light grazing to foster positive interactions between pastoralism and forest ecosystems. In contrast, areas with more intense grazing require meticulous planning to protect biodiversity and overall ecosystem health.

2.7.2 Tree Cover Change and Grazing Intensity

This study showed a clear association between increasing grazing intensity and tree cover loss. Light grazing villages displayed a lower rate of loss compared to medium and high grazing areas. Interestingly, while medium and high grazing areas experienced the highest forest loss between 2005 and 2015, the rate of loss declined towards 2022. This decline likely reflects a combined effect of reduced grazing pressure due to limited remaining tree cover and limited accessibility of remaining forests. Additionally, testimonies from village elders suggest an influx of pastoral communities after 2005, contributing to the initial spike in tree cover loss. These

findings show the interactions between grazing activities and forest ecosystem dynamics.

Other factors influencing tree cover loss, as mentioned by Lulandala et al. (2023), Mullan et al. (2018), Phiri et al. (2023), and Taylor & Schoo (2018), include agricultural expansion, settlement growth, and charcoal production. These factors likely interact with grazing pressure to determine the overall rate of tree cover loss. Figure 2.4 visually reinforces these trends, providing a comprehensive view of cumulative forest loss across different grazing intensities.

Light grazing areas generally experienced the lowest rate of loss due to less grazing pressure. Notably, within light grazing areas, Gole village exhibited a higher rate of loss compared to Chabima, likely due to its gentler terrain, offering easier access for livestock.

The observed recovery of tree cover in all study villages suggests resilience within the Miombo woodlands. The level of recovery varied across grazing intensities, with Kwamsundi village (high grazing) showing the highest recovery attributed to a government-introduced land-use plan restricting grazing and charcoal production. Similarly, Ihombwe village (medium grazing) displayed significant recovery due to the combined efforts of land-use plans and village patrols protecting deforested areas. Efforts by village governments and the Tanzanian Forestry Service Agency (TFS) likely contributed to the observed recovery in Gole village within the light grazing category.

2.8 Conclusion and Recommendations

2.8.1 Conclusion

The identified relationship between grazing intensity and above-ground biomass is most significant between light and high grazing areas, as well as light and medium grazing areas. In light grazing areas, characterized by less deforestation activities, above-ground biomass is particularly higher compared to medium and high grazing

areas. On the contrary, areas experiencing medium and high grazing show no significant differences in tree above-ground biomass. High and medium grazing intensities show a similar trend with the highest forest loss, particularly between years 2005 and 2015, with gradually declining rates towards 2022. The decline in the rate of forest loss towards 2022 is attributed to both the depletion of available forest cover and the inaccessibility of remaining patches to villagers. Miomboni village emerged as the most severely deforested village, experiencing large-scale conversion of forest land to rice plantations and the fragmentation of remaining forests into small forests.

2.8.2 Recommendation

Sustainable grazing practices should be a priority, promoting collaboration among stakeholders, including forest managers, policymakers, and local communities. Mitigating forest cover loss demands addressing root causes such as agricultural and settlement expansion, managing pastoralist migrations, and promoting sustainable land use practices. Future research should look into ecological mechanisms and the relationship between grazing intensity, environmental variables, and the long-term resilience of Miombo woodlands.

Engaging local communities through educational programs can encourage sustainable land management practices, fostering a sense of ownership. Policymakers should reassess land allocation decisions to align with Miombo woodlands' conservation imperatives. Implementing these recommendations will significantly contribute to preserving the vitality and ecological equilibrium of these critical ecosystems.

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CHAPTER THREE

Manuscript Two

Regeneration of Tree Species under Grazing Intensities in Miombo Woodlands, Tanzania

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3.1 Abstract

This study examines the impact of grazing intensity on the regeneration of Miombo woodlands in Tanzania. Field surveys were conducted in nine villages across three districts encompassing various grazing intensities (light, medium and high). The results suggest a significant correlation between grazing intensity and the abundance of regenerating seedlings, particularly for non-Miombo species. While no significant difference was observed in the diversity of adult trees, species diversity of regenerating trees showed an increase with higher grazing intensity for both Miombo and non-Miombo species. These results challenge the presumption of a universally negative grazing impact on regeneration of Miombo woodlands. The research suggests a relationship between grazing and regeneration, justifying further exploration into long-term effects and incorporating diverse tree species' regeneration dynamics into sustainable management practices.

Keywords: Species, Diversity, Richness, Evenness

3.2 Introduction

Miombo woodlands, vast swaths of dry woodlands covering an impressive 2.7 million km² across southern Africa, are a vital ecological treasure trove (Moyo et al., 2019). Miombo woodlands are dominated by genera *Brachystegia*, *Julbernardia*, and *Isoberlinia* (Campanello et al., 2008). These co-dominant trees typically reach heights of 15-25 meters, their crowns forming a distinctive open canopy that allows dappled sunlight to reach the woodland floor (Shoro et al., 2002). However, the richness of Miombo woodlands extends far beyond these dominant species.

Thriving alongside *Brachystegia*, *Julbernardia*, and *Isoberlinia* is a rich mosaic of life known as associated species. This diverse group includes numerous shrubs, grasses, and other tree species that contribute significantly to the overall biodiversity and ecological function of the Miombo ecosystem (Shoro et al., 2002). Some common examples of associated tree species include *Uapaca kirkiana*, *Burkea africana*, *Terminalia sericea*, and *Pterocarpus angolensis* (Monela et al., 2017). These associated species provide food and habitat for a variety of animals, helping to create a complex and interconnected web of life. The understory vegetation, often dominated by grasses and herbaceous plants, plays a crucial role in nutrient cycling, fire management, and soil health (Staver et al., 1996).

Livestock production is a foundation of Tanzania's agricultural sector, providing food security, income, and a buffer against inflation (Wilson, 2019). As demand for livestock products increases, the sector expands, placing escalating pressure on Miombo woodlands. This translates to changes in plant communities, decreased productivity, and increased soil erosion (Nyirenda et al., 2019). Districts like Kilosa, Kilombero, and Handeni in Tanzania have witnessed particularly intense grazing pressure on their Miombo woodlands. Studies by Mbilinyi et al. (2019), Mwambene et al. (2020), and Mkandamilo et al. (2021) highlight the rising pressure in

these areas, attributing it to population growth, climate change, agricultural expansion, and infrastructure development (Mbilinyi et al., 2019; Mwambene et al., 2020; Mkandamilo et al., 2021).

Livestock grazing can severely affect Miombo woodland regeneration by reducing seedling and sapling numbers, hindering natural regrowth (Mugasha et al., 2010; Nyanga et al., 2020). The intensity of grazing in a particular area plays a significant role, influencing seedling survival and growth, often leading to stunted development or mortality (Nyanga et al., 2020). Additionally, grazing pressure disrupts the diversity of Miombo ecosystems, leading to a decline in both woody and herbaceous plant species (Benard et al., 2021). This loss of biodiversity can ultimately weaken the ecosystem's ability to provide essential services. However, the severity and extent of these impacts vary depending on factors like grazing intensity and duration, vegetation type, and specific characteristics of the Miombo woodlands themselves (Nyirenda et al., 2019). Therefore, a nuanced understanding of how grazing pressure affects Miombo woodlands across various locations is crucial. This will allow us to uncover the underlying mechanisms at play and develop appropriate management strategies.

This research aims to analyze the effects of varying grazing intensities on the regeneration of Miombo woodlands in Tanzania's Kilosa, Kilombero, and Handeni Districts. We will specifically assess how grazing pressure impacts tree regeneration within these woodlands. We hypothesize that heavy grazing will have a significantly more negative impact on regeneration compared to medium and light grazing intensities, across all study areas.

3.3 Methodology

3.3.1 Study Area

The study was conducted in nine villages across three districts in Tanzania: Kilosa and Kilombero Districts (Morogoro Region) and Handeni District (Tanga Region) (Fig. 1). These districts share a

tropical climate with warm temperatures and high rainfall, ideal for the growth of Miombo woodlands, the target ecosystem of this study. Kilosa District, with a population exceeding 300,000, has a thriving agricultural sector focused on maize and livestock keeping (cattle, goats, and sheep). Kilombero District, even more populated at over 400,000, reflects this agricultural focus, including the crucial addition of fishing to its economic activities. Handeni District, the largest of the three with a population surpassing 600,000, includes a similar agricultural base but stands out for its active trade sector. Importantly, all three districts rely on communal grazing land for their livestock, and managing this shared resource can sometimes lead to conflicts over land use. This aspect of land use management is particularly relevant to our research focus on tree regeneration under varying grazing pressures within miombo woodlands.

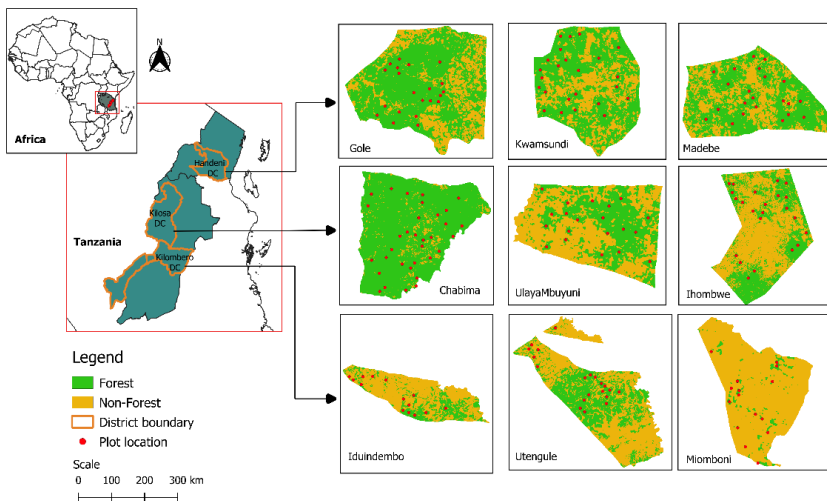


Figure 3.2: Study Area Map
Source: Own Construct (2023)

3.3.2 Sampling Design

This study on tree regeneration under varying grazing pressures employed a stratified random sampling design across nine villages

in Tanzania. To ensure representativeness, villages were chosen based on the presence of Miombo woodlands and categorized by grazing intensity (light, medium, and high). The design used was stratified random sampling. Preliminary surveys and land cover maps were used to identify forest and non-forest areas within each village. A total of 188 sampling plots were then proportionally allocated to forest areas, ensuring coverage of different vegetation types. Within the forest stratum, plots measuring 20m x 50m were randomly placed, and smaller sub-plots of 5 x 5m were positioned at the corners and centre for detailed observation of regenerants. To minimize data homogeneity between plots, a minimum separation distance of 250 meters was maintained.

3.3.3 Data collection

Field data collection for this study was conducted in two phases. Data from villages in Kilosa and Handeni Districts was collected in November 2022, while villages in Kilombero District were surveyed in April 2023. To ensure consistency across all nine villages, rectangular plots measuring 50 x 20 meters were established in each study location. A total of 188 sample plots were laid out across the study area.

Regeneration assessment focused on counting all individual tree regenerants within the study sample plots. Within the main plots of 50 x 2m, sub-plots measuring 5 x 5m were established at the corners and center to allow for a more focused evaluation of regeneration. Regeneration data was successfully collected in 156 of the 188 plots, indicating the presence of regenerating trees in those specific locations. The scientific name and local name were recorded for each tree regenerant. For any plant species where field identification remained uncertain, plant parts were collected and stored for further confirmation at the Tanzania National Herbarium.

3.3.4 Grazing Intensity

To assess grazing intensity within each study plot, a scoring method was used based on readily observable signs of cattle grazing

activity. Trained observers evaluated indicators such as the presence of livestock dung, animal trails, visibility of hoof prints on the soil surface, and the degree of vegetation grazed. Each indicator received a score between 0 (no sign), 1 (light), 2 (medium) and 3 (most severe condition). The individual plot scores were then calculated by summing the scores for each indicator, resulting in a total score ranging from 0 to 9. Based on this score, grazing intensity was categorized into four classes, light grazing (scores 1-3), moderate grazing (scores 4-6), and heavy grazing (scores 7-9). To ensure accurate and consistent evaluation, an average of three independent assessments were conducted for each plot by the trained observers. This approach provides a standardized and reliable method for characterizing grazing pressure within the study area.

3.4 Data Analysis

3.4.1 Abundance of tree regenerants

Due to the non-normal distribution of the data (Shapiro-Wilk test; p -value < 0.05) a non-parametric Kruskal-Wallis test from the "PMCMRplus" package in R software was used to assess the variation in regenerant abundance across different grazing intensities (light, medium, high). The sample size for this analysis was 4362 trees and 2081 regenerants. To determine the difference in regeneration patterns, we further categorized regenerant species into two species groups, Miombo species (characteristic trees genera, *Brachystegia*, *Julbernardia*, and *Isoberlinia*) and Non-Miombo species. The Kruskal-Wallis test was used to determine the difference in the abundance of regenerants across the grazing intensity categories for each species group. If a significant difference was found, a post-hoc Tuckey's HSD test was used to pinpoint which specific grazing intensity categories differ significantly from each other in terms of regeneration abundance within each group.

3.4.2 Species Diversity of tree regenerants

To assess the influence of grazing intensity (GI) on tree species diversity within the Miombo woodland, diversity was calculated using the Shannon Index. The analysis focused on Species Abundance for calculating diversity (Shannon Index) for both Miombo and Non-Miombo species within each grazing intensity category. This approach provides information on the influence of grazing intensity on species diversity within Miombo and non-Miombo groups. The results of this analysis, including the specific Shannon Diversity values for each grazing intensity category and group (Miombo, Non-Miombo), will be presented in the following sections.

3.5 Results

3.5.1 Grazing Intensity on the Regeneration abundance of Miombo woodland

Kruskal-Willis analysis of Miombo species regenerants showed no statistically significant difference in abundance across the grazing intensity gradient. However, non-Miombo species regenerant abundance showed significant difference across grazing intensities ($p < 0.05$). Tuckey's HSD test post-hoc analysis revealed significant differences between light and high grazing intensities ($p < 0.05$), and medium and high grazing intensities ($p < 0.05$). These findings suggest that higher grazing intensity may have a detrimental effect on the regeneration of non-Miombo species within the Miombo woodland.

Similar to the regenerants, Miombo adult tree species abundance did not differ significantly across the grazing intensity gradient. Non-Miombo adult trees abundance showed significant differences between grazing intensities at ($p = 0.0015$). A post-hoc test using Tuckey's HSD test identified a significant difference between medium and high grazing intensities.

Table 3.1: Abundance of tree regenerants at different grazing intensities

Grazing Intensity	Miombo species		Non-Miombo species	
	Regenerants	Tree	Regenerants	Tree
Light	40	387	447	922
Medium	64	291	473	774
High	70	401	994	1587

3.5.2 Grazing Intensity on the Regeneration Species Diversity

The analysis showed a potential relationship between grazing intensity and Miombo tree regeneration species diversity (Table 3.2). Non-Miombo species consistently exhibited the highest diversity indices (ranging from 4.81 to 5.69), suggesting a potentially more complex and resilient tree community compared to Miombo species (ranging from 2.73 to 3.02). This observation shows the ability of these Non-Miombo species to cover a broader range of ecological tolerances. A trend towards increasing diversity with increasing grazing intensity (Light to Medium to High) was observed across both Miombo and Non-Miombo species. However, the magnitude of this potential increase appears to be more obvious for Non-Miombo species.

Table 3.2. Species diversity of trees and regenerants species

Grazing Intensity	Miombo species		Non-Miombo species	
	Regenerants	Tree	Regenerants	Tree
Light	2.73	3.53	4.96	3.97
Medium	2.75	3.58	4.81	3.93
High	3.02	3.30	5.69	3.82

3.6 Discussions

3.6.1 Grazing Intensity on the Regeneration abundance

The results showed a positive correlation between grazing intensity and the abundance of both Miombo and Non-Miombo regenerants. This contradicts previous studies that documented negative impacts of grazing on seedling establishment and survival (Nyanga et al., 2020). Several potential explanations can be made for this difference. Firstly, heavy grazing by livestock can lead to the addition of regenerating seedlings through two mechanisms. Livestock manure can act as a fertilizer for germinating seeds, promoting seedling growth. Additionally, grazing on undergrowth (grasses, herbs, and climbers) reduces competition for light, water, and nutrients for the regenerating Miombo seedlings.

However, it is important to acknowledge the potential downsides of high grazing intensity. While it may increase the number of regenerants in the short term, it can also lead to a reduction in overall plant biomass, hindering the growth and survival of young trees (Wang et al., 2007). Furthermore, long-term exposure to high grazing pressure can have detrimental effects on the health and survival of adult Miombo trees (Asner et al., 2004). Therefore, while increased regeneration abundance might be observed initially, sustainable management practices are necessary to ensure the long-term health of the Miombo forest.

Interestingly, the abundance of regenerating Non-Miombo species showed a significant difference across grazing intensities, with the highest abundance observed under high grazing pressure suggesting that Non-Miombo species might be more opportunistic and better adapted to thrive in disturbed environments created by grazing. On the contrary, there was no statistically significant difference in the abundance of Miombo regenerating seedlings across grazing intensities suggesting that factors other than grazing intensity might be playing a more prominent role in Miombo species regeneration.

3.6.2 Grazing Intensity on the Regeneration Species Diversity

The analysis of species richness, evenness, and diversity across grazing intensities for both Miombo and Non-Miombo species yielded intriguing results. Contrary to studies reporting reduced species diversity under grazing pressure (Benard et al., 2021), this study found the highest species diversity in areas with heavy grazing intensity for both categories. This increase in species diversity could be attributed to the creation of open spaces and disturbances through grazing activities. These disturbances promote the establishment of a diverse range of plant species, including both fast-growing pioneer species and shade-tolerant species that can thrive in the newly created gaps (Moyo et al., 2019). Additionally, medium grazing intensity might promote nutrient cycling through the decomposition of grazed vegetation, potentially alleviating competition among plant species and contributing to an increase in species diversity.

The pattern of species diversity highlights the complexity of grazing impacts on Miombo ecosystems. While heavy grazing may promote species diversity in the short term, it could also lead to changes in community composition, particularly for Miombo species. Further investigations are recommended to explore the specific factors driving the observed patterns of species diversity. This could involve studying the impact of grazing on specific regeneration stages (seedling and sapling) for both Miombo and Non-Miombo species, exploring the influence of different livestock types (cattle and goats), or investigating the long-term effects on soil properties and nutrient cycling. Understanding these factors will be crucial for informing targeted management strategies that promote both regeneration abundance and diverse, resilient Miombo woodlands.

The observed lack of significant difference in adult tree species diversity for both Miombo and Non-Miombo categories reinforces the notion that the effects of grazing pressure on tree communities manifest over extended timescales. This finding aligns with previous studies on woodland ecosystems, which suggest that shifts in tree

species composition and diversity due to disturbances like grazing often occur gradually over several decades (White & Reich, 1999). In the context of this study, the absence of a clear diversity signal in adult trees might be because the observed variations in regeneration abundance, particularly for Non-Miombo species, are a relatively recent phenomenon driven by the implemented grazing intensities. These changes in regeneration patterns may not have had sufficient time to translate into a detectable shift in adult tree species diversity.

Long-term monitoring of these woodlands is crucial to capture these gradual shifts. By establishing permanent sampling plots and revisiting them at regular intervals, researchers can track changes in species composition, abundance, and diversity of both regenerating seedlings and adult trees across the grazing intensity gradient. This long-term data will be helpful in understanding the full impact of grazing pressure on the dynamics and resilience of Miombo woodlands. Additionally, incorporating demographic information on adult trees such as growth rates and mortality into the monitoring program can provide valuable insights into how grazing intensity might be affecting the population dynamics of mature trees and shaping the future structure and composition of the Miombo woodlands.

3.7 Conclusions and Recommendations

3.7.1 Conclusions

This study investigated the effects of grazing intensity on the regeneration of Miombo woodlands, examining both Miombo and Non-Miombo tree species. While we expected a negative impact on regeneration, the abundance of Miombo regenerating seedlings did not differ significantly across the grazing intensity gradient. This suggests factors beyond grazing pressure, such as seed dispersal limitations or specific ecological requirements, might be more critical for Miombo regeneration. In contrast, Non-Miombo regenerating seedlings showed a significant increase with higher grazing intensity, suggesting they are more opportunistic and thrive in

disturbed environments. However, the lack of significant difference in adult tree species diversity for both Miombo and Non-Miombo categories highlights a potential time lag between grazing's effects on regeneration and adult tree populations. Long-term monitoring is crucial to capture these gradual shifts in species composition and diversity.

These findings challenge the notion of a universally negative grazing impact on Miombo woodland regeneration. While some Non-Miombo species might benefit in the short term, the long-term consequences for both Miombo and Non-Miombo tree populations remain unclear and require further investigation.

This research has significant implications for sustainable management and conservation of Miombo woodlands. While grazing may not always have a clear negative impact on regeneration, particularly for Non-Miombo species, a holistic approach is essential. This approach should consider not only the aboveground components but also the vital dynamics of regeneration across different tree species. Sustainable grazing practices, like controlled and rotational grazing, must be prioritized in conservation efforts. Collaboration among stakeholders, from forest managers and policymakers to local communities, is key to achieving this.

We acknowledge limitations in focusing solely on grazing intensity. The complex nature of ecosystems suggests other variables like climate, soil conditions, fire regimes, and interactions with other herbivores might influence regeneration dynamics. Future studies should consider these interactions for a more comprehensive understanding.

3.7.2 Recommendations

To clarify the observed patterns, future research could investigate deeper into Comparative studies through examining the regeneration ecology of specific Miombo and Non-Miombo species

under controlled grazing could provide insights into their germination requirements, light tolerance, and competitive abilities. Seed dispersal mechanisms by investigating the role of livestock in seed dispersal, particularly for Non-Miombo species, could quantify the potential contribution of grazing to their regeneration. Long-term effects through monitoring regeneration plots over extended timeframes can reveal the lasting impacts of grazing intensity on the survival and growth of both Miombo and Non-Miombo seedlings, ultimately influencing the future forest composition and diversity. In addition, adult tree demographics through incorporating demographic information on adult trees (e.g., growth rates, mortality) into long-term monitoring can provide valuable insights into how grazing intensity might be affecting the population dynamics of mature trees and shaping the future structure and composition of the Miombo woodlands.

Comprehensive investigations into the interplay between grazing, other environmental variables, and long-term forest resilience are paramount to a holistic understanding.

This study advances our knowledge of the Miombo forest ecosystem, highlighting the need for adaptable and sustainable management strategies. By embracing the complexity of grazing effects and incorporating them into management practices, stakeholders in Tanzania can proactively protect the biodiversity and ecosystem services provided by Miombo woodlands. The lessons gleaned from this research show the importance of balancing human activities with ecological preservation to ensure the lasting health and vitality of the Miombo woodlands.

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CHAPTER FOUR

GENERAL DISCUSSIONS

4.1 Summary of Major Findings

This study investigated the effects of grazing intensity on Miombo woodlands in Tanzania. We observed both aboveground biomass and tree regeneration dynamics for Miombo and Non-Miombo species. Our findings challenge the simplistic view of grazing always having a negative impact.

4.1.1 Variation of tree cover change and above-ground biomass across grazing intensities

The relationship between grazing intensity and aboveground biomass was negative, particularly between light and high grazing areas. Interestingly, medium and high grazing intensities showed no significant difference in aboveground biomass, suggesting a potential threshold effect. Additionally, high and medium grazing intensities exhibited the highest rates of forest loss, particularly between 2005 and 2015, with a decline towards 2022 due to both resource depletion and inaccessibility.

4.1.2 Regenerants abundance

For regeneration, grazing intensity did not significantly affect the abundance of regenerating Miombo seedlings. This suggests factors beyond grazing, like seed dispersal limitations or specific ecological requirements, might be more critical for their renewal. In contrast, Non-Miombo regenerating seedlings increased with higher grazing intensity, indicating they thrive in disturbed environments. However, the lack of a significant difference in adult tree species diversity for both categories highlights a potential time gap between grazing's effects on regeneration and adult tree populations. Long-term monitoring is crucial to capture these gradual shifts in species composition and diversity.

CHAPTER FIVE

5.0 Conclusion and Recommendations

5.1 Conclusion

The identified relationship between grazing intensity and above-ground biomass is most significant between light and high grazing areas, as well as between light and medium grazing areas. In light grazing areas, characterized by less deforestation activities, above-ground biomass is particularly higher compared to medium and high grazing areas. On the contrary, areas experiencing medium and high grazing show no significant differences in tree above-ground biomass. High and medium grazing intensities show a similar trend with the highest forest loss, particularly between years 2005 and 2015, with gradually declining rates towards 2022. The decline in the rate of forest loss towards 2022 is attributed to both the depletion of available forest cover and the inaccessibility of remaining patches to villagers. Regeneration of Miombo trees is significantly affected by the grazing intensity but in a different context. High grazing areas contain the highest species count and diversity compared to light and medium while species richness is highest in light grazing areas than in medium and high grazing areas.

5.2 Recommendations

Based on the results and conclusions of this study, it is recommended that:

- i. Sustainable grazing practices such as controlled and rotational grazing should be a priority, promoting collaboration among stakeholders, including forest managers, policymakers, and local communities.
- ii. Mitigating forest cover loss demands addressing root causes such as agricultural and settlement expansion, managing pastoralist migrations, and promoting sustainable land use practices.

- iii. Future research should look into ecological mechanisms, the relationship between grazing intensity, environmental variables, and the long-term resilience of Miombo woodlands.

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APPENDICES

Appendix 1: Table showing Miombo and Non-Miombo species

Miombo species	Non-Miombo species
<i>Brachystegia boehmii</i>	<i>Acalypha fruticosa</i>
<i>Brachystegia bussei</i>	<i>Afzelia quanzensis</i>
<i>Julbernardia globiflora</i>	<i>Albizia grablesens</i>
<i>Brachylaena huillensis</i>	<i>Albizia gummifera</i>
<i>Brachystegia longifolia</i>	<i>Albizia harveyi</i>
<i>Brachystegia microphylla</i>	<i>Albizia petersiana</i>
<i>Brachystegia spiciformis</i>	<i>Albizia versicolor</i>
	<i>Allophylus calophyllus</i>
	<i>Angueria tomentosa</i>
	<i>Annona senegalensis</i>
	<i>Antiaris toxicaria</i>
	<i>Antidesma venosum</i>
	<i>Balanites aegyptiaca</i>
	<i>Blighia unijugata</i>
	<i>Boscia salicifolia</i>
	<i>Brachylaena huillensis</i>
	<i>Brackenregia bussei</i>
	<i>Bridelia cathartica</i>
	<i>Burkea africana</i>
	<i>Byrsocarpus orientalis</i>
	<i>Cajanus cajan</i>
	<i>Cassia abbreviata</i>
	<i>Catunaregam spinosa</i>

Miombo species	Non-Miombo species
	<i>Cedrela odorata</i>
	<i>Combretum collinum</i>
	<i>Combretum fragrans</i>
	<i>Combretum imberbe</i>
	<i>Combretum molle</i>
	<i>Combretum zeyheri</i>
	<i>Commiphora africana</i>
	<i>Cordia ovalis</i>
	<i>Croton jatrophioides</i>
	<i>Cussonia arborea</i>
	<i>Dalbergia boehmii</i>
	<i>Dalbergia melanoxylon</i>
	<i>Dalbergia nitidula</i>
	<i>Deinbollia borbonica</i>
	<i>Dichapetalum stuhlmanii</i>
	<i>Dichrostachys cinerea</i>
	<i>Diospyros kirkii</i>
	<i>Diospyros natalensis</i>
	<i>Diospyros squarrosa</i>
	<i>Diplorhynchus</i>
	<i>condylocarpon</i>
	<i>Dombeya rotundifolia</i>
	<i>Dombeya shupangae</i>
	<i>Ehretia cymosa</i>
	<i>Elaeodendron</i>
	<i>buchananii</i>

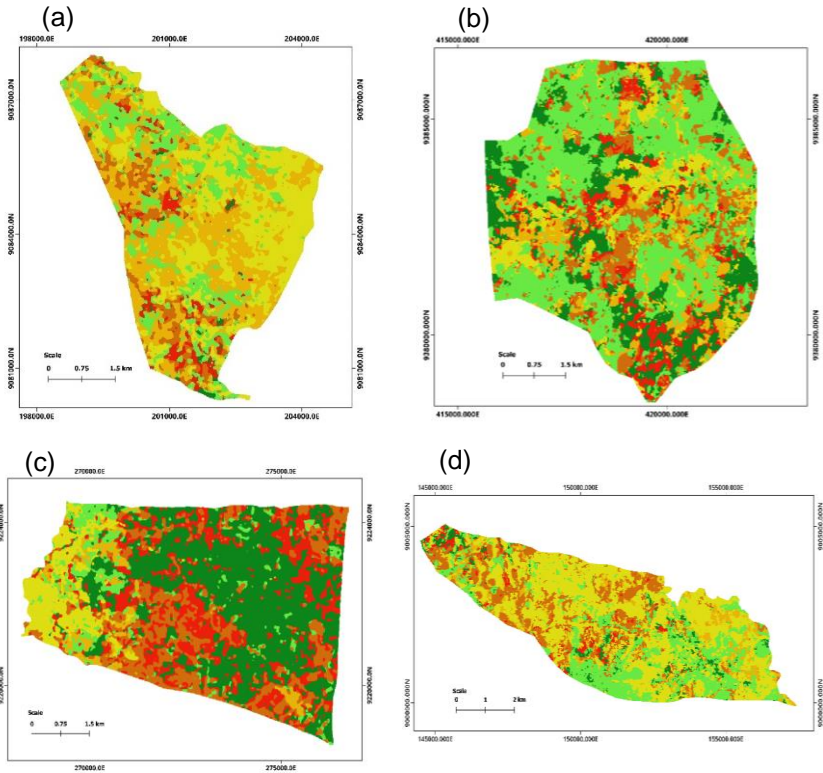
Miombo species	Non-Miombo species
	<i>Erythrina abyssinica</i>
	<i>Erythrococca fischeri</i>
	<i>Erythroxyllum coca</i>
	<i>Euclea natalensis</i>
	<i>Flacotia indica</i>
	<i>Flacourtia indica</i>
	<i>Flueggea virosa</i>
	<i>Garcinia stuhlmanii</i>
	<i>Gardenia jovis-tonantis</i>
	<i>Grewia bicolor</i>
	<i>Haplocoelum foliolosum</i>
	<i>Harrisonia abyssinica</i>
	<i>Heinsia zanzibarica</i>
	<i>Holarrhena pubescens</i>
	<i>Hymenocardia acida</i>
	<i>Hymenocardia ulmoides</i>
	<i>Hymenodicton floribunda</i>
	<i>Keetia gueinzii</i>
	<i>Lanea humilis</i>
	<i>Lanea humilis</i>
	<i>Lanea welwitschii</i>
	<i>Lecaniodiscus</i>
	<i>fraxinifolius</i>
	<i>Maerua kirkii</i>
	<i>Maerua triphylla</i>

Miombo species	Non-Miombo species
	<i>Margaritaria discoidea</i>
	<i>Markhamia hildebrandtii</i>
	<i>Markhamia lutea</i>
	<i>Maytenus senegalensis</i>
	<i>Millettia dura</i>
	<i>Monodora minor</i>
	<i>Ochina culatelifolia</i>
	<i>Ochna longipes</i>
	<i>Opilia desiflora</i>
	<i>Opilia desiflora</i>
	<i>Ormocarpum orientalis</i>
	<i>Parinari culatelifolia</i>
	<i>Parinari culatelifolia</i>
	<i>Paveta schumanniana</i>
	<i>Philenoptera bussei</i>
	<i>Philenoptera violacea</i>
	<i>Phyllocosmus</i>
	<i>lemaireanus</i>
	<i>Piliostigma thoningii</i>
	<i>Piliostigma thonningii</i>
	<i>Premna chrysoclada</i>
	<i>Pseudolachnostylis</i>
	<i>maprouneifolia</i>
	<i>Psidium guajava</i>
	<i>Psorospermum</i>
	<i>febrifugum</i>

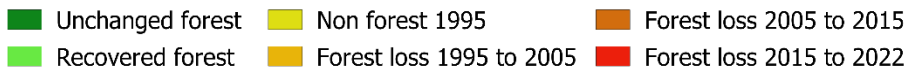
Miombo species	Non-Miombo species
	<i>Psychotria peter</i>
	<i>Pteleopsis myrtifolia</i>
	<i>Pterocarpus angolensis</i>
	<i>Pterocarpus mildbraedii</i>
	<i>Pterocarpus tinctorius</i>
	<i>Rhus natalensis</i>
	<i>Rhus vulgaris</i>
	<i>Sclerocarya birrea</i>
	<i>Securina kwinkwiloba</i>
	<i>Senna didymobotrya</i>
	<i>Senna singueana</i>
	<i>Sorindeia</i>
	<i>madagascariensis</i>
	<i>Spiralstachis cinerea</i>
	<i>Spirostachys africana</i>
	<i>Steganothaenia araliacea</i>
	<i>Stereospermum</i>
	<i>kunthianum</i>
	<i>Strychnos cocculoides</i>
	<i>Strychnos inocua</i>
	<i>Strychnos usambarensis</i>
	<i>Suregada zanzibarica</i>
	<i>Swartzia</i>
	<i>madagascariensis</i>
	<i>Tepesia garkeana</i>
	<i>Terminalia sericea</i>

Miombo species	Non-Miombo species
	<i>Tricalysia mirtiflora</i>
	<i>Trilepisium</i>
	<i>madagascariense</i>
	<i>Turraea floribunda</i>
	<i>Vachellia brevispica</i>
	<i>Vachellia hockii</i>
	<i>Vachellia mellifera</i>
	<i>Vachellia nigrescens</i>
	<i>Vachellia nilotica</i>
	<i>Vachellia robusta</i>
	<i>Vachellia royumae</i>
	<i>Vachellia xanthophloea</i>
	<i>Vangueria tomentosa</i>
	<i>Vangueropsis lanciflora</i>
	<i>Vepris nobilis</i>
	<i>Vepris simplicifolia</i>
	<i>Xeroderris stuhlmannii</i>
	<i>Ximenia americana</i>
	<i>Ximenia caffra</i>
	<i>Xylopia parviflora</i>
	<i>Zanha africana</i>

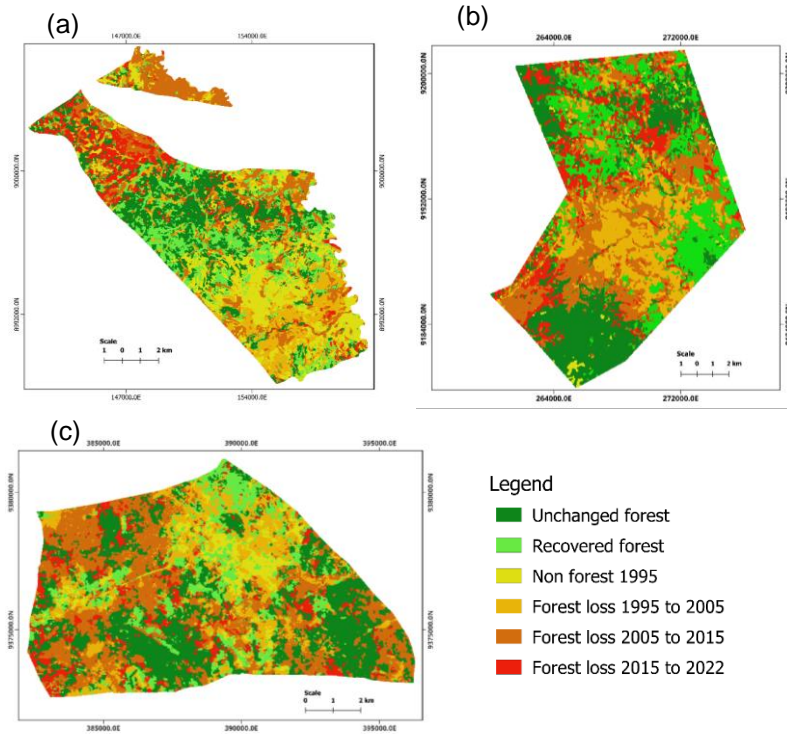
Appendix 2: Cover maps of forests with high grazing intensities villages (a) Miomboni, (b) Kwamsundi, (c) Ulaya Mbuyuni and (d) Iduindembo showing extent of tree cover loss from 1995 to 2022.



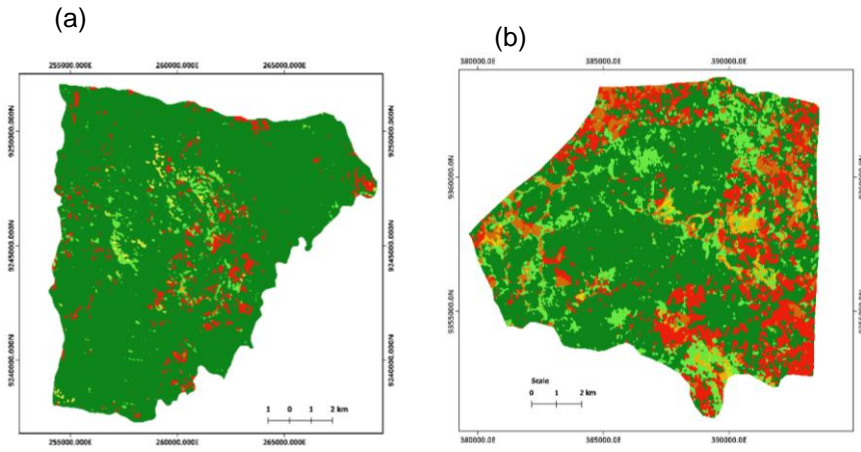
Legend



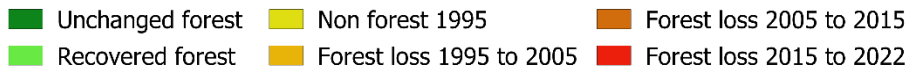
Appendix 3: Cover maps of forests with medium grazing intensities villages (a) Utengule, (b) Ihombwe, (c) Madebe showing extent of tree cover loss from 1995 to 2022.



Appendix 4: Cover maps of forests with light grazing intensities villages (a) Chabima, (b) Gole showing extent of tree cover loss from 1995 to 2022.



Legend



Appendix 5: Characteristics of the satellite images covering study villages

Woodland	Image	Composite Image acquisition date	Cloud cover	Path/Row
Chabima	Landsat 5 TM	1995-07-01 to 1995-10-30	2%	167/65
	Landsat 5 TM	2005-07-01 to 2005-10-30	1%	
	Landsat 8 ETM	2016-07-01 to 2016-10-30	2%	
	Landsat 8 ETM	2021-07-01 to 2021-10-30	1%	
Ihombwe	Landsat 5 TM	1995-07-01 to 1995-10-30	1%	167/65
	Landsat 5 TM	2005-07-01 to 2005-10-30	1%	
	Landsat 8 ETM	2016-07-01 to 2016-10-30	1%	
	Landsat 8 ETM	2021-07-01 to 2021-10-30	1%	
Ulaya Mbuyuni	Landsat 5 TM	1998-07-01 to 1998-10-30	1%	167/64
	Landsat 5 TM	2005-07-01 to 2005-10-30	1%	
	Landsat 8 ETM	2016-07-01 to 2016-10-30	1%	
	Landsat 8 ETM	2020-07-01', '2020-10-30	1%	

Woodland	Image	Composite Image acquisition date	Cloud cover	Path/Row
Iduindembo	Landsat 5 TM	1996-07-01 to 1996-10-30	1%	168/66
	Landsat 5 TM	2006-07-01 to 2006-10-30	1%	
	Landsat 8 ETM	2016-07-01 to 2016-10-30	1%	
	Landsat 8 ETM	2022-07-01 to 2022-10-30	1%	
Utengule	Landsat 5 TM	1995-07-01 to 1995-10-30	1%	168/66
	Landsat 5 TM	2006-07-01 to 2006-10-30	1%	
	Landsat 8 ETM	2016-07-01 to 2016-10-30	1%	
	Landsat 8 ETM	2022-07-01 to 2022-10-30	1%	
Miomboni	Landsat 5 TM	1995-07-01 to 1995-10-30	1%	168/66
	Landsat 5 TM	2006-07-01 to 2006-10-30	1%	
	Landsat 8 ETM	2015-07-01 to 2015-10-30	1%	
	Landsat 8 ETM	2022-07-01 to 2022-10-30	1%	
Gole	Landsat 5 TM	1998-07-01 to 1998-10-30	1%	167/64
	Landsat 5 TM	2005-07-01 to 2005-10-30	2%	
	Landsat 8 ETM	2016-07-01 to 2016-10-30	1%	
	Landsat 8 ETM	2021-07-01 to 2021-10-30	1%	

Woodland	Image	Composite Image acquisition date	Cloud cover	Path/Row
Kwamsundi	Landsat 5 TM	1995-07-01 to 1995-10-30	2%	167/64
	Landsat 5 TM	2005-07-01 to 2005-10-30	1%	
	Landsat 8 ETM	2015-07-01 to 2015-10-30	0%	
	Landsat 8 ETM	2021-07-01 to 2021-10-30	1%	
Madebe	Landsat 5 TM	1995-07-01 to 1995-10-30	1%	167/64
	Landsat 5 TM	2005-07-01 to 2005-10-30	1%	
	Landsat 8 ETM	2016-07-01 to 2016-10-30	1%	
	Landsat 8 ETM	2021-07-01 to 2021-10-30	1%	