

**INFLUENCE OF HABITAT CHARACTERISTICS ON RODENT ABUNDANCE,
DIVERSITY AND OCCUPANCY IN A RESTORED LULANDA FOREST
RESERVE, SOUTHERN TANZANIA**

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**A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE
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ABSTRACT

Restoration of degraded natural areas to enhance genera conservation is widely gaining pace; however, effort geared at assessing response of animal community particularly in restored forests is still low. I used a CMR method to trap rodents and measured vegetation characteristics to examine the association of vegetation characteristics with rodent abundance, diversity and occupancy in a secondary forest 20 years after restoration. the results found first, five rodent genera were in the secondary forest and three genera in the primary forest and that, abundance of the most dominant genera *Praomys* sp. was significantly higher in primary than in secondary forest. In addition, results showed highest genera diversity in the secondary forest than the primary forest, supporting earlier studies in this forest reserve. Second, rodent community in the study area showed strong association with some measured local habitat characteristics in the secondary forest, suggesting the importance of forest restoration on the small mammal assembly in restored habitats. Third, in occupancy modeling, results showed detection probability strongly influenced by habitat type. In contrast, the study revealed that herbaceous cover, shrub cover and number of trees were the most important vegetation characteristics driving rodent occupancy in the studied forests. Fourth, the negative generalized linear models revealed number of saplings and percent shrub cover were the strongest predictors of rodent abundance across the study sites while the habitat types strongly predicted the *Praomys* sp. abundance in the studied area. Based on study findings, the forest restoration improves rodent genera coming back in restored areas, continuing to restore degraded areas elsewhere is an increasing priority.

DECLARATION

I, **Burton Solo**, do declare to the Senate of Sokoine University of Agriculture that, this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

Burton Solo

Date

(MSc. Candidate)

The above declaration is confirmed by

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Date

(Supervisor)

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DEDICATION

To my lovely wife Benadetha Jacob and our beloved kids Eugenia, Ian and Miguel for their prayers and moral support during the entire study at SUA. I also dedicate this work to my uncle Edson Mwene who raised me and set the base of my education up to who I am now.

TABLE OF CONTENTS

ABSTRACT.....	ii
DECLARATION.....	iii
COPYRIGHT.....	iv
ACKNOWLEDGEMENTS.....	v
DEDICATION.....	vi
TABLE OF CONTENTS.....	vii
LIST OF TABLES.....	x
LIST OF FIGURES.....	xi
LIST OF ABBREVIATIONS AND SYMBOLS.....	xii
CHAPTER ONE.....	1
 1.0 INTRODUCTION.....	1
1.1 Problem Statement and Justification.....	3
1.2 Objectives.....	4
1.2.1 Overall objective.....	4
1.2.2 Specific objectives.....	4
1.3 Research Questions.....	4
CHAPTER TWO.....	5
 2.0 LITERATURE REVIEW.....	5
2.1 Forest Restoration and Biodiversity Conservation.....	5
2.2 Importance of Rodents in Ecosystem.....	5
2.3 Drivers of Rodent Genera Abundance and Diversity.....	6
2.4 Association of Vegetation Characteristics with Rodent.....	7

2.5 Effect of Vegetation Characteristics on Rodent Abundance.....	7
2.6 The status of Rodents in Lulanda and Corridor Restoration.....	8
CHAPTER THREE.....	10
3.0 MATERIALS AND METHODS.....	10
3.1 Description of the Study Area.....	10
3.2 Research Design and Sampling Procedure.....	11
3.2.1 Rodent sampling.....	11
3.2.1.1 Rodents Data Collection.....	12
3.2.2 Vegetation characteristics sampling.....	12
3.2.2.1 Collection of vegetation characteristics.....	12
3.3 Data Analysis.....	13
CHAPTER FOUR.....	17
4.0 RESULTS.....	17
4.1 Rodent Genera Composition, Abundance and Diversity.....	17
4.1.1 Rodent genera composition.....	17
4.2.2 Rodent genus abundance.....	17
4.3.3 Rodent genera diversity.....	18
4.4 Association of Rodent Genera with Vegetation Characteristics.....	18
4.5 Rodent Detection and Occupancy Probability.....	19
4.6 Effect of Vegetation Characteristics on Rodent Abundance.....	22
CHAPTER FIVE.....	25
5.0 DISCUSSION.....	25

CHAPTER SIX.....	29
6.0 CONCLUSION AND RECOMMENDATION.....	29
6.1 Conclusion.....	29
6.2 Recommendations.....	29
REFERENCES.....	30

LIST OF TABLES

Table 1:	Summary of measured vegetation characteristics that influence rodent ecology as documented in the literature.....	13
Table 2:	Rodent genera composition between primary and secondary forests and its relative abundance (percent contribution) in Lulanda Forest Reserve, Southern Tanzania.....	17
Table 3:	Summary of rodent abundance based on minimum number known alive (MNKA) in primary and secondary forest types in Lulanda forest reserve....	18
Table 4:	Summary of model selection based on AIC for occupancy and detection analysis of the rodents surveyed in Lulanda Forest Reserve, Sothern Tanzania. K=number of parameters, W=AIC weight and cW= cumulative weight.....	21
Table 5:	Estimated GLM regression coefficients (β), Standard errors ($\pm SE$), Z-values and P values for the global (A) and Praomys sp. (B) models from AIC selected generalized linear models explaining effect of saplings, shrubs and restored habitat on rodent abundance.....	22

LIST OF FIGURES

- Figure 1: Map of Lulanda Forest Reserve in Mufindi District, Southern Tanzania.
 Colors; light green, light blue and pale yellow shows the natural forest patches (primary) namely Ihili, Fufu and Magwila respectively; the dotted green shows the restored corridor (secondary) uniting Fufu and Magwila; and the red squares show location of each grid sampling site.....11
- Figure 3: Ordination of rodent genera (capitalized) composition in Lulanda Forest Reserve based on vegetation characteristics indicated by green lines.
 Where shrub percent cover (%Shrub.Cov), number of trees (No.Trees), number of dead woods (No.DeadW) percent crown cover (%Crown.Cov) Canopy height (Canopy.hei), percent herbaceous cover (%Herb.Cov), Diameter at Breast Height (DBH), number of climbers (No.Climbers), percent leaf litter cover (%Litter.Cov) and leaf litter depth (Litter.Dep).
 The axis corresponds to the genera scores scaled by Eigenvalues.
 The Eigenvalues of axis 1 and axis 2 are 0.78 and 0.03, respectively
 and the Eigenvalue of the axis 3 is 0.02 (not displayed).....19
- Figure 4: A global model graph showing shrubs and saplings as strongest predictors of rodent abundance across the natural and restored sites in Lulanda Forest Reserve. Rodent abundance increased with both percent cover and number of saplings in the reserve.....23
- Figure 5: Effect of three predictors on Praomys sp. abundance in Lulanda Forest Reserve. Shrub cover and restored forest negatively affected the Praomys sp. abundance (top), while saplings positively predicted increase in Praomys sp. abundance in the study area (bottom).....24

LIST OF ABBREVIATIONS AND SYMBOLS

BS	Bustani
CCA	Canonical Correspondence Analysis
CD	Corridor
EAM	Eastern Arc Mountains
EAMCEF	Eastern Arc Mountains Conservation Endowment Fund
Fig	Figure
FU	Fufu
IUCN	International Union for Conservation of Nature
MG	Magwila
SUA	Sokoine University of Agriculture
WWF	World Wildlife Fund

CHAPTER ONE

1.0 INTRODUCTION

Rodents are one of the ubiquitous vertebrate taxa that inhabit a wide range of habitats from dry land to wetland. Habitat degradation and fragmentation are well known to affect resources needed by several animals including rodents (Blaum *et al.*, 2007; Yang *et al.*, 2018). For example, several studies have revealed that degraded and fragmented habitats are associated with decrease in rodent diversity and richness (Johnson and Karels, 2016; Mortelliti *et al.*, 2010). Fragmented habitats also affect animal dispersal and recolonization of patches since they influence habitat cover and quality (Mulligan *et al.*, 2013). The habitat structure and vegetation characteristics at a site can affect the structure of the rodent populations, through influencing which rodent community colonizes a particular habitat (Shiels and Ramirez de Arellano, 2018).

Important vegetation characteristics in this regards include vegetation density, basal cover, canopy height, canopy cover and leaf litter (Thompson and Gese, 2013). In areas of thick vegetation and litter are typically characterized by small, seed eating rodents (Reed *et al.*, 2005). Vegetation cover provides rodents protection, food resources and offers suitable microclimate for rodent population (Moro and Gadal, 2006). Thus, to understand how vegetation characteristics affect the ecology of rodent genera, it is necessary to design and implement strategies at local scale such as restoration in order to conserve them (Flores-Peredo and Vazquez-Dominguez, 2016).

Restoring forest aims to reestablish a degraded forest to its original or near original state so as to enhance its ecological integrity to deliver forest products, enhance biodiversity

and services (Maginnis and Jackson, 2007; Chazdon *et al.*, 2016). Restoring deforested habitats is thus increasingly advocated for as a mitigation measure against habitat degradation and fragmentation (Mérő *et al.*, 2015) and to alleviate the ongoing biodiversity loss (Montoya *et al.*, 2012; MacDicken, 2015). In addition, restoration has the potential for encouraging the arrival of animal genera that may have been displaced in response to disturbance pressure.

On the other hand, animal genera occupancy is a variable of interest on biodiversity management particularly in evaluating the impacts of management actions such as restoration (Mazerolle *et al.*, 2005). Occupancy of a particular genera helps to understand changes in genera distributions and considered as an important measure of extinction risk (IUCN 2012). Occupancy is modeled as a function of site measured habitat characteristics therefore, helps to explain factors that affect genera distributions (Karama *et al.*, 2020). There is increasing effort in Tanzania to restore degraded and deforested areas (WWF, 2018). For example, the government through AFR100 project has announced its commitment to restore 5.2 million hectares by 2030 (The Guardian, 2018). Some restoration projects have taken place in several parts of Tanzania including Uluguru, Usambara and Kilimanjaro mountains (Doody, 2002; Doggart *et al.*, 2008; Mansourian, and Vallauri, 2012; WWF, 2018).

Monitoring of secondary forests following restoration is imperative to respond to the threats posed by deforestation and degradation, which is important in order to keep track of the restoration trajectory (Mérő *et al.*, 2015). Further, rodents are an ideal case to investigate in restored forest because they recolonize restored areas relatively fast and are regarded as excellent bio indicators (Avenant, 2011).

1.1 Problem Statement and Justification

While restoration effort is gaining pace in Tanzania, a matched effort in monitoring animals in secondary restored forest is still rare. Elsewhere outside Tanzania, most studies that have monitored animal recolonization in secondary forests were conducted at an early stage of restoration, less than 10 years (e.g. Patten, 1997; Kezar and Jenks, 2004; Mérő *et al.*, 2015; Lazarus, 2017). This duration may be insufficient to fully evaluate restoration aftermath (Cortina *et al.*, 2011). These studies reported that, secondary forests improved connectivity of habitats and that; abundance and diversity of studied genera were positively affected by vegetation characteristics. Similarly, studies by Doody (2002) and Kisingo *et al.* (2005) conducted in the Lulanda forest reserve in southern Tanzania covered only short time span (i.e. 6 years) since restoration occurred. They also reported that, rodent recolonization after restoration was associated with habitat mosaics, and they found high diversity in the restored forest patch than the primary control forest. These studies improve our understanding of how reassembling of lost habitats can have a huge impact on the genera assemblage and structuring. It is not clear however, how vegetation characteristics in a secondary forest after relatively longer time e.g. 20 years since restoration have affected rodent abundance, diversity and occupancy in the area.

Further, the Lulanda forest patches and restored corridors are an interesting case to examine how small mammal recolonization because of existing baseline information that is useful for comparison twenty years after forest restoration. The information generated by this study will provide forest managers with recommendations on monitoring strategies that may be applicable across Tanzania to improving conservation management. Further, the findings will also help in planning of restoration in other degraded sites elsewhere.

1.2 Objectives

1.2.1 Overall objective

The general objective of this study was to understand how habitat characteristics influence rodent biodiversity in Lulanda secondary forest, Mufindi district Tanzania.

1.2.2 Specific objectives

- i. To compare rodent genera composition, abundance and diversity between secondary and primary forest patches in the study area
- ii. To examine association of rodent genera with vegetation characteristics in the two forest types
- iii. To determine rodent detection and occupancy probability in a secondary and primary forest patches
- iv. To assess effect of vegetation characteristics on the abundance of rodents in a secondary and primary forest patches.

1.3 Research Questions

- i. Does the secondary forest support abundance, composition and diversity of rodents similar to the primary forest?
- ii. Is there any difference in rodent occupancy probability between secondary and primary forest in the study area?
- iii. Is there any association between rodent assemblages with local vegetation characteristics in the area?
- iv. What is the effect of vegetation characteristics on the rodent abundance?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Forest Restoration and Biodiversity Conservation

Forest restoration is an intentional process that aims to accelerate the recovery of an ecosystem with respect to its structure (Lamb *et al.*, 2012). Restored forests facilitate the attainment of sustainable development and help in the mitigation of climate change (Roberts *et al.*, 2009). For example, restoration can support livelihoods and enhance biodiversity and ecosystem services such as the provision of clean water, reducing soil erosion, providing wildlife habitat, biofuels and other forest products (Benaya *et al.*, 2009). Restoration results in improving population size and hence, viability because of increased available habitats and quality (Hylander and Ehrlén 2013; Newmark *et al.*, 2017). Restoring degraded landscapes is difficult and success is not assured (Hobbs *et al.*, 2007). It is difficult also to predict successional outcomes and changes in the population of wildlife as forests are restored (Lamb *et al.*, 2012). Both ecological and economic circumstances can alter the restoration process. Gerlach *et al.* (2013) proposed the use of bioindicator genera in monitoring restored sites of which Avenant (2011) recommended rodent taxa as a cost-effective bio-indicator since it is sensitive to ecosystem changes.

2.2 Importance of Rodents in Ecosystem

About 44% of all mammal genera are rodents, implying that rodents have high numbers than any other orders of mammals (Wolff and Sherman, 2008). Their distribution is worldwide due to their highly diversified habitats (Kingdon, 1997). They are interesting

to study because of their influence on ecosystem characteristics, their presence or absence can influence other genera success (Bradley and Marzluff, 2003). This is due to their high reproductive ability and use of small area and sensitivity to habitat change (Morales-Díaz *et al.*, 2019). Studying rodents is ideal for understanding short term effects in an ecosystem since it is clear and easy to observe reproductive seasons and variation in densities (Avenant, 2000). Rodents are also used as models for testing hypotheses to infer other taxa (Wolff and Sherman, 2008). They are regarded as bioindicators of ecosystem integrity since they respond quickly to habitat changes due to their high breeding rate, short generation time, and necessity of microhabitat settings to survive (Avenant and Cavallini 2007; Avenant, 2011). Due to these reasons, rodents are considered to be useful and adequate biological models mostly for habitat conservation strategies (Afonso, 2019).

2.3 Drivers of Rodent Genera Abundance and Diversity

Rodent abundance is influenced by several factors including availability of food sources, shelter, vegetation cover, and other ecological requirements (Datiko and Bekele, 2014). Vegetation cover affects rodent abundance, distribution and diversity; because these areas are perceived to be safe, hence rodents spent more time foraging in these areas (Shiels and de Arellano, 2018). Vegetation cover for example, has been reported to show a positive relationship with rodent genera richness and abundance (Yarnell *et al.*, 2007). This suggests that availability of food resources can be used to determine relative abundance of rodents in a particular area (Madden *et al.*, 2019). Apart from vegetation characteristics, abiotic factors including precipitation and seasonal variations have influence on abundance and diversity of rodents (Mulungu *et al.*, 2014; Sipos *et al.*, 2017). Changes in precipitation regimes and temperature influence the production, and availability of food, which in turn, can influence the dominance of certain genera (Pardini

et al., 2005). Furthermore, the abundance and diversity of rodents may vary with the degree of their specialization. Usually, specialist genera are mostly likely affected by habitat change than generalists, which are very flexible to switch to other resources (Coda *et al.*, 2015).

Thus, to understand how biotic factors such as vegetation characteristics affect the ecology of rodent genera, it is necessary to design and implement strategies at local scale such as restoration in order to conserve them (Flores-Peredo and Vazquez-Dominguez, 2016).

2.4 Association of Vegetation Characteristics with Rodent

Rodents favor areas with relatively high plant cover to reduce their risk of predation (Shiels and Ramírez, 2018). The shrub covers for example can provide shelter from weather and aerial predators (Vickery and Rivest 1992). In this regard, available food resources are associated with vegetation characteristics. This in turn, can influence rodent genera abundance and diversity of a particular landscape. Some rodents either prefer areas with high vertical density and structural complexity of the understory or abundant multiflora, or dense ground cover, and or abundant trees since they are semi-arboreal (Manson *et al.*, 1999). Vegetation may vary among forest patches because of differences in microclimate (e.g. in denser vegetation, sparse vegetation, bare ground, or areas free of vegetative litter) near edges (Saunders *et al.*, 1991). Thus, the high ecological diversity of any habitat suggests that the area could be inhabited by a wide variety of rodent genera (Venance, 2009).

2.5 Effect of Vegetation Characteristics on Rodent Abundance and Occupancy

The structure of vegetation, and how it varies across a forest landscape, is crucial to understanding the distribution of wildlife genera (Thompson and Gese, 2013). Vegetation

structure and food availability influence pattern of distribution of rodents in different habitats (Ahmad *et al.*, 2002). According to Thompson and Gese, (2013) the important vegetation structures include vegetation density, basal cover, canopy height, canopy cover and leaf litter. Similarly, dead wood such as stumps and logs found on the forest floor play a great role in determining rodent abundance and occupancy (Fauteux *et al.*, 2012). Rodents are sensitive to changes in vegetation cover due to their energy demands, foraging efficiency and security (Reed *et al.*, 2005). Vegetation cover provides rodents protection, food resources and offers suitable microclimate (Moro and Gadál 2007). The amount of cover and food affects rodent density, i.e. influence which rodents are present in a community (Kotler *et al.*, 1988; Manson *et al.*, 1999).

2.6 The status of Rodents in Lulanda and Corridor Restoration

Early in the 1990s, the Tanzania Forest Conservation Group (TFCG) established a restoration programme in Lulanda Forest Reserve following fragmentation due to farming activities (Doody, 2002). A number of scientists visited the reserve and highlighted its high biodiversity value (Woodcock, 1998). Despite being small, endemism has been recorded in the reserve (Lovett and Pócs, 1992). For instance, endemic and near-endemic genera of birds (*Apalis chapini*, *Batis mixta*, *Modulatrix stictigula*), amphibians (*Scolecomorphus vittatus*, *Phlyctimantis keithae*) and plants (*Pavetta lynesii*, *Aframomum alpinum*, *Psychotria megalopus* and *Keetia lulandensis*) were recorded in the reserve (Doody, 2002; EAMCEF, 2008).

Six years following corridor restoration Kisingo *et al.*, 2005 found seven genera of rodents in the study area. *Grammomys* sp. was represented in higher numbers within the corridor while was not recorded at all in either forest patch. *Praomys* sp. appeared to be the dominant small mammal genus in both forest patches. However, *Mus* sp. was the

most frequently encountered genus in the restored corridor. Some genera *Hylomyscus* sp. and *Beamys* sp. have been caught in the two forest patches. These are common in EAM because, previous studies e.g., Stanley *et al.* (1998) have documented a composition of rodent genera that was comparable across the Eastern Arc archipelago. They found that *Praomys* sp. was the most common in East and West Usambara except in the Udzungwa where *Lophuromys* was slightly more abundant while *Beamys* sp. and *Grammomys* sp. were less common similar to Kisingo *et al.* (2005). Hayhow *et al.* (2003) recommended a periodic survey of Lulanda forest reserve e.g. in five or ten years to discover how genera composition has changed with changing restored forest.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

This study was conducted in Lulanda Forest Reserve in Mufindi District about 75 km southeast of Mafinga town in Iringa Region, Tanzania (Fig. 1). The forest is situated in the southern Udzungwa Mountains, 5 km east of Mufindi Scarp East Forest Reserve from 1480-1640 m above sea level. Lulanda is a government Forest Reserve managed by the villages (Hayhow *et al.*, 2003). The reserve consists of three forest patches namely Magwila, Fufu and Ihili with a total area approximately 235 ha. A corridor known as Lulanda Forest Corridor (54 ha) connects Fufu and Magwila forest patches (Fig. 1). The reserve is montane, dominated by *Parinari excelsa* trees with a canopy up to 30m (Doody, 2002).

Precipitation in Lulanda forest averages 1800 mm per annum with temperatures between 17.1 °C to 19° C max in November and 14° C min. in July. Dry season is between June and November (Lovett and Pócs, 1993). Early in the 1960s, Lulanda forest reserve was a continuous forest area (Doody, 2002), but later in 1970s, the reserve was fragmented into smaller patches due to agricultural activities. In 1990s, the Tanzania Forest Conservation Group (TFCG) established a restoration project at the site (Doody, 2002). The TFCG restored a forest corridor that connects Fufu and Magwila forest patches by replanting indigenous tree genera such as *Vepris sp.*, *Canthium lulandalensis* and *Parinari excelsa*. More details about the reserve can be found in Lovett and Pócs (1993), Woodcock (1998), Hayhow *et al.* (2003) and Kisingo *et al.* (2005).

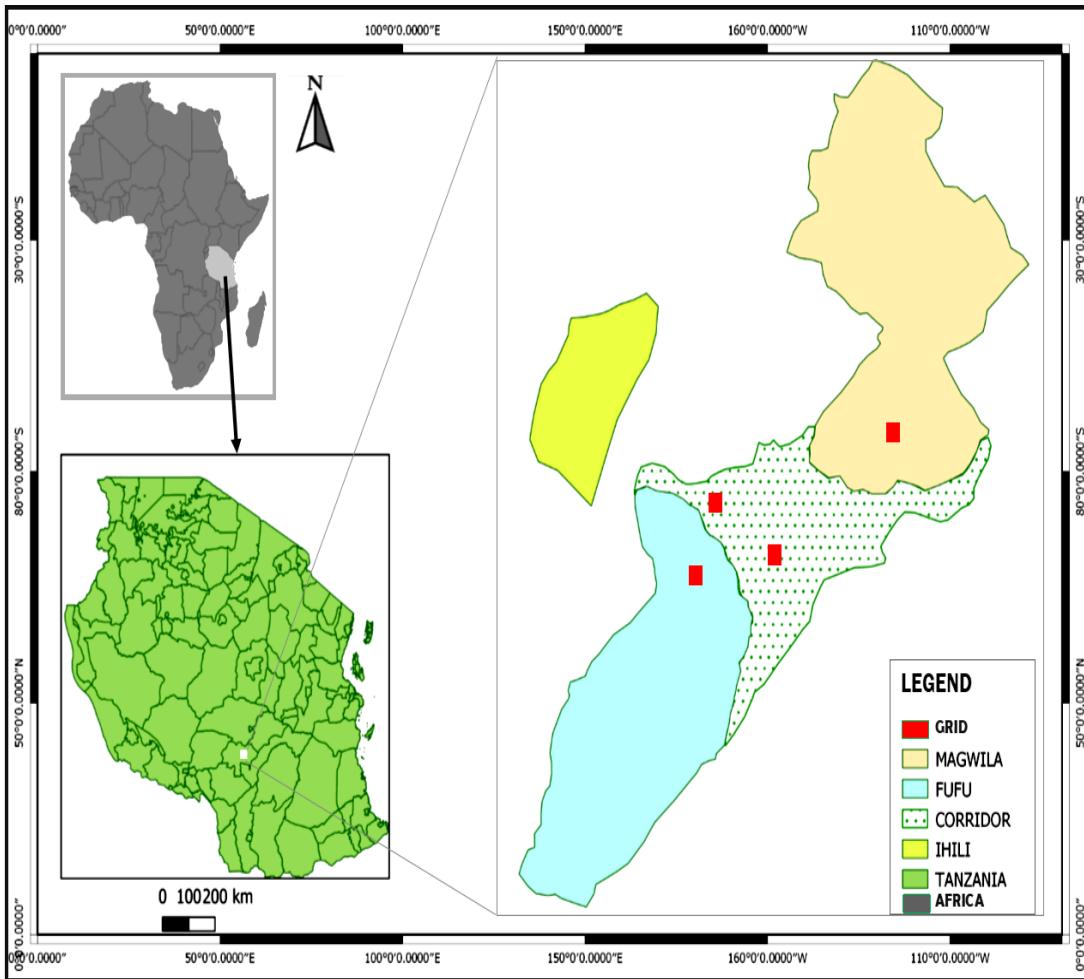


Figure 1: Map of Lulanda Forest Reserve in Mufindi District, Southern Tanzania. Colors; light green, light blue and pale yellow shows the natural forest patches (primary) namely Ihili, Fufu and Magwila respectively; the dotted green shows the restored corridor (secondary) uniting Fufu and Magwila; and the red squares show location of each grid sampling site.

3.2 Research Design and Sampling Procedure

3.2.1 Rodent sampling

In this study Capture-Mark-Recapture (CMR), technique was used to sample rodent data. Two 70 x 70 m grids were set each in Fufu (FU) and Magwila (MG) primary forest patches and the other two grids at Bustani (BS) and Corridor (CD) in a secondary.

These grids were randomly assigned and had a minimum of 500m apart from each other. Each grid consisted of seven parallel lines spaced 10 m apart, with seven trapping stations per line also spaced 10 m apart, making 49 trapping stations per grid. One Sherman LFA live trap (H.B Sherman Traps Inc., Tallahassee, FL) was positioned at each trapping station to trap rodent. To improve catch, the traps were baited with peanut butter mixed with maize flour (Sabuni *et al.*, 2018). Traps were left for three consecutive days each month for five months (March 2020 to July 2020) and were checked twice a day; in early morning (between 06:00 and 07:00h) and late afternoon (between 17:00 and 18:00h).

3.2.1.1 Rodents Data Collection

To understand rodent abundance, diversity and occupancy, a range of data were collected in the study area. From each trap catch; genus name, body mass, sex and reproductive status were recorded. The identification of rodents to genus level was done using Happold (2013) field guide. Identification of animals to genera level was not possible, thus only genus name was used and is reported in this study. When data recording was complete from any captured individual, two toes were clipped and the animal was released at the trapped site to facilitate monitoring of subsequent recaptured individuals.

3.2.2 Vegetation characteristics sampling

To obtain unique habitat characteristics for each trap site, sampling of vegetation characteristics was done around each site where rodent trapping occurred. At each trapping site, a 1-m² quadrat and 5-m² plot were established.

3.2.2.1 Collection of vegetation characteristics

To understand the role of habitat characteristics on the rodent abundance diversity and. In a 1 m² quadrat, percent ground cover of herbaceous layer was visually estimated and leaf litter depth (cm) was measured using one feet ruler. In a 5 m² plot, percent cover of shrubs number of trees, canopy height (m) and canopy cover were recorded using Clinometer (Suunto) and HabitApp v. 1.1 (Deichmann *et al.*, 2017; Suchiang *et al.*, 2020) installed in Samsung Galaxy J7 Pro mobile phone. In addition, diameter at breast height (DBH) of all trees ≥10cm was measured using Caliper. Finally, all the saplings, climbers and dead woods within the 5 m² subplot were counted and recorded. A total of 196 (5 m²) plots and 196 (1 m²) subplots were sampled.

Table 1: Summary of measured vegetation characteristics that influence rodent ecology as documented in the literature

Variable/Life form	Unit of measure	Means of measurement	Reference
Shrub cover	%	Eye/Visual	Van Andel <i>et al.</i> , 2016
Litter cover	%	Eye/Visual	Cox <i>et al.</i> , 2000
Canopy cover	%	Habitapp v. 1.1	Fauteux <i>et al.</i> , 2012; Suchiang <i>et al.</i> , 2020
Litter depth	cm	Ruler	Madden <i>et al.</i> , 2019
Trees	number	Count	Van Andel <i>et al.</i> , 2016
DBH	cm	Caliper	Gregory <i>et al.</i> , 1999
Canopy height	m	Suunto	Fauteux <i>et al.</i> , 2012
Dead wood	number	Count	Rhim and Lee, 2001; Madden <i>et al.</i> , 2019
Climbers/liana			
s	number	Count	Lehtonen <i>et al.</i> , 2001
Saplings	number	Count	van Ginkel <i>et al.</i> , 2013
Herbs cover	%	Eye/Visual	Lehtonen <i>et al.</i> , 2001

3.3 Data Analysis

Data analysis were performed in the Paleontological Statistics software (PAST v 4.03) and R statistical software.

First, abundance of rodents was estimated using Minimum Number Known Alive technique (Krebs, 1966) and compared the abundance of dominant genera (*Praomys* sp.) between secondary and primary forest types. Prior to this, *Praomys* sp. abundance data were tested for normality using Shapiro Wilk-test, *t*-test was then used to test significance difference in abundance between the two sites. Then the composition of each genera was confirmed based on relative abundance of each genera based on the proportion composition of each individual genera to the total number trappable at each study site. Further, rodent genera diversity was calculated based on Shannon Wiener index, in PAST program.

Second, to examine the association between rodents and vegetation characteristics, Canonical Correspondence Analysis (CCA) in the program PAST was used (Thompson and Gese, 2013). At this stage, both rodent and vegetation characteristic data were pooled to the grid level then performed the CCA as an ordination to plot rodent abundance against vegetation characteristics. Thus, an ordination diagram based on the first two canonical axes was constructed.

Third, to determine detection and occupancy probability in the two forest stands, a single-season occupancy modeling by MacKenzie *et al.* (2002, 2006) used. Models were fitted by using the *occu* function of the *unmarked* package in R program (Fiske and Chandler 2011). Before modeling examination of vegetation data distribution using correlation matrix for the 11 variables was done. For variable showing high correlation ($r > 0.4$), only one was included in the analysis model. In selection of variables to include in the model, biological or ecological meaning to the rodent population was considered. Thus, the study ended using eight measured vegetation characteristics variables including, herbs cover (HE), litter depth (LD), canopy height (CH), number of deadwoods (DW), number of

climbers (CL), number of saplings (SP), shrub cover (SH) and number of trees (TR). I then added secondary forest and primary forest habitats (HB) and survey time (T) to make 10 variables and assumed that all trap sites have the same probability of being occupied. Models for the most common individual taxa (*Praomys sp.*) recorded in both forest types were first built. Further, a global model containing all the recorded rodents in the study area was then built. The first model assumed constant detection (p) and occupancy (Ψ) probabilities across sites represented as $[p(\cdot)\Psi(\cdot)]$. The second model assumed constant occupancy among trap sites while detection probabilities were allowed to vary among 5 survey occasions represented as $[p(T)\Psi(\cdot)]$. However, for unbiased occupancy modelling it is recommended that the detection probability should be ≥ 0.15 in the $[p(\cdot)\Psi(\cdot)]$ (Ngo *et al.*, 2020). To reduce insignificant variables, the decisions on which variable were important predictors of rodent detection and occupancy probability, was based on the relative Akaike Information Criterion (AIC) weights of the top ranked models (Burnham and Anderson, 2002). Thus, the study retained models with lower delta AIC value than the null model. Finally, using goodness of fit (GoF) the study tested for the significant difference among the top ranked plausible models.

Fourth, to assess the effect of vegetation characteristics on the rodent abundance, a negative binomial GLM model was fitted to the abundance data using the MASS package built in the R-program. Before, a global model was built using all the abundance data from all recorded rodent genera in the area, and then, built an individual genera model using only the *Priomys* sp. because other genera had few data points to analyze individually. For each global and individual genera model, eight variables were included as predictors and rodent abundance as response variable. At this stage, the significance of each model variable was examined using the *drop1* function in a series of steps where non-significant term was removed in the model until a final plausible model was

obtained. At each step of removing single model term, a Chi-square test was used to examine model significance (Kamil *et al.*, 2018).

The final global model showed only number of saplings and percent shrub cover were two significant predictors or rodent abundance. Further, prediction models were built using predict function under the “ggplot2” package to understand how these variables were able to predict the rodent abundance in the study area. A similar procedure was used to build an individual *Praomys* sp. model. For each global and genera model, Akaike Information Criterion was used to examine and select the model that best fitted the data (Rija *et al.*, 2020).

CHAPTER FOUR

4.0 RESULTS

4.1 Rodent Genera Composition, Abundance and Diversity

4.1.1 Rodent genera composition

One hundred ninety-one individual rodents (101 males and 90 females), in six genera were captured in 2940 trap nights between March 2020 and July 2020. Of the six genera, *Praomys* sp. was the highest in number in the collection and across the natural forest. On the other hand, *Beamys* sp. was the least captured genera in the study area while *Grammomys* sp. was the highest in number in the restored forest (Table 2).

Table 2: Rodent genera composition between primary and secondary forests and its relative abundance (percent contribution) in Lulanda Forest Reserve, Southern Tanzania

Genus name	Primary		Secondary Forest	Total	Per cent Contribution
	Forest	Per cent Contribution			
<i>Praomys</i> sp.	83	43.5	29	111	15.2
<i>Lophuromys</i> sp.	3	1.6	8	11	4.2
<i>Grammomys</i> sp.	0	0	42	42	21.9
<i>Mus</i> sp.	0	0	17	17	8.9
<i>Beamys</i> sp.	1	0.5	0	1	0.0
<i>Dendromus</i> sp.	0	0	9	9	4.7

4.2.2 Rodent genus abundance

The abundance of rodents varied significantly between the two forest types (Table 3). The *Praomys* sp. abundance was significantly higher (Student's *t*-test = 7.11 p=0.0001) in primary forest than in a secondary forest.

Table 3: Summary of rodent abundance based on minimum number known alive (MNKA) in primary and secondary forest types in Lulanda forest reserve

Time	Secondary forest				Primary forest			
	Mus sp.	Praomys sp.	Grammomys sp.	Lophuromys sp.	Dendromus sp.	Beamys sp.	Lophuromys sp.	Praomys sp.
March	10	2	2	0	5	1	0	13
April	3	4	6	0	2	0	0	22
May	2	3	7	3	1	0	1	14
June	1	6	9	2	0	0	1	16
July	0	5	8	2	0	0	1	16

4.3.3 Rodent genera diversity

Genera diversity of rodents was significantly higher in restored forest than in the natural forest (Student's *t*-test = 13.1, df=159, p = 0.0001).

4.4 Association of Rodent Genera with Vegetation Characteristics

The rodent genera showed association with the measured vegetation characteristics in the study area (Fig. 3). *Dendromus* sp. and *Mus* sp. occurred more often in areas with dense shrubs and trees. *Grammomys* sp. and *Lophuromys* sp. were more often found in areas rich in herbaceous vegetation. *Praomys* sp. and *Beamys* sp. were confined in areas covered with more saplings and leaf litter, dense crown cover, and high trees.

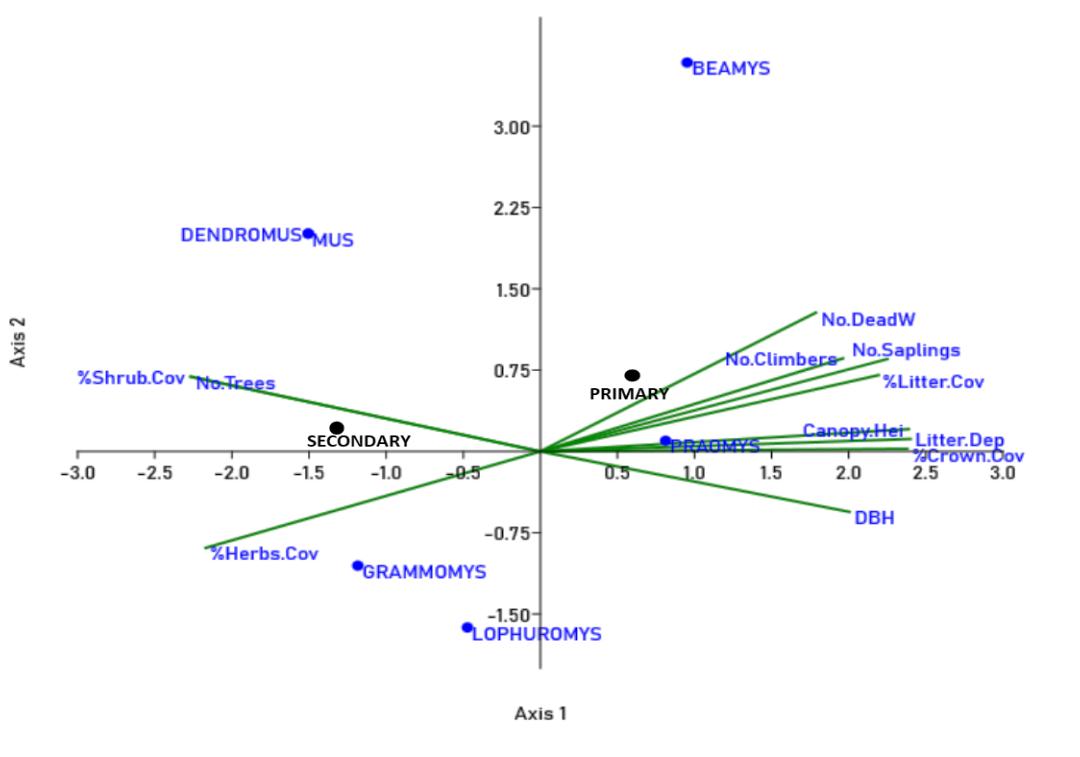


Figure 2: Ordination of rodent genera (capitalized) composition in Lulanda Forest Reserve based on vegetation characteristics indicated by green lines. Where shrub percent cover (%Shrub.Cov), number of trees (No.Trees), number of dead woods (No.DeadW) percent crown cover (%Crown.Cov) Canopy height (Canopy.hei), percent herbaceous cover (%Herb.Cov), Diameter at Breast Height (DBH), number of climbers (No.Climbers), percent leaf litter cover (%Litter.Cov) and leaf litter depth (Litter.Dep). The axis corresponds to the genera scores scaled by Eigenvalues. The Eigenvalues of axis 1 and axis 2 are 0.78 and 0.03, respectively and the Eigenvalue of the axis 3 is 0.02 (not displayed).

4.5 Rodent Detection and Occupancy Probability

The proportion of sites occupied by rodents from the constant model $[p(\cdot)\psi(\cdot)]$ was 0.561 ± 0.0745 (CI= -0.346+0.839). The proportion of occupied sites based on the second model $[p(\text{Survey})\psi(\cdot)]$ which assumed a constant occupancy probability (ψ), with a varied detection probability across sites (p) was 0.237 ± 0.3 (CI = -0.351–0.825).

The set of rodent occupancy models contained the 16 models that were ranked based on AIC values with or without interactions between factors (Table 4). The four best models are with <2.0 AIC units, i.e. they are demonstrably the best models for making inference. The goodness of fit revealed that there was no significant difference among the top ranked models $p=0.11$. Variables describing vegetation characteristics were the best overall descriptors of rodent occupancy. These includes percent herbs cover (HE), percent shrubs cover (SH) and number of trees (TR). In terms of model weights the four models $[p(.)\Psi(HE+SH)]$, $[p(.)\Psi(HB)]$, $p(.)\Psi(HE+SH+TR)]$ and $[p(.)\Psi(HE)]$ models had 39%, 20%, and 20% and 19% respectively, explaining a total of 98% accumulative weight.

I found that out of the nine used detection models, habitat type was ranked the best model with smaller delta AIC, thus best predictor of rodent detectability in the studied area. I found a significant difference in rodent detection between secondary and primary forest habitats (coefficient estimates = 1.44 ± 0.269 and -2.66 ± 0.261 respectively), therefore realized that secondary forest positively influenced the occupancy of rodents in Lulanda.

Table 4: Summary of model selection based on AIC for occupancy and detection analysis of the rodents surveyed in Lulanda Forest Reserve, Sothern Tanzania. K=number of parameters, W=AIC weight and cW= cumulative weight

Model	K	AIC	ΔAIC	W	cW
Occupancy models					
[p(.) Ψ (HE+SH)]	4	626.99	0.00	3.90e-01	0.39
[p(.) Ψ (HB)]	3	628.29	1.30	2.00e-01	0.59
[p(.) Ψ (HE+SH+TR)]	5	628.31	1.31	2.00e-01	0.79
[p(.) Ψ (HE)]	3	628.40	1.40	1.90e-01	0.98
[p(t) Ψ (HB)]	7	633.35	6.36	1.60e-02	1.00
[p(.) Ψ (LC)]	3	637.30	10.31	2.20e-03	1.00
[p(.) Ψ (SP)]	3	638.09	11.10	1.50e-03	1.00
[p(.) Ψ (CL)]	3	640.38	13.38	4.80e-04	1.00
[p(.) Ψ (.)]	2	648.06	21.07	1.00e-05	1.00
[p(.) Ψ (LD)]	3	648.10	21.10	1.00e-05	1.00
[p(.) Ψ (WD)]	3	648.23	21.24	9.50e-06	1.00
[p(.) Ψ (SH)]	3	649.37	22.38	5.30e-06	1.00
[p(.) Ψ (TR)]	3	649.78	22.79	4.40e-06	1.00
[p(.) Ψ (CH)]	3	649.91	22.91	4.10e-06	1.00
[p(T) Ψ (.)]	6	653.12	26.13	8.20e-07	1.00
Detection models					
[p(HB) Ψ (.)]	3	621.23	0.00	1.0e+00	1.00
[p(HE) Ψ (.)]	3	637.44	16.21	3.0e-04	1.00
[p(SP) Ψ (.)]	3	637.62	16.39	2.8e-04	1.00
[p(CL) Ψ (.)]	3	641.99	20.76	3.1e-05	1.00
[p(WD) Ψ (.)]	3	646.07	24.84	4.0e-06	1.00
[p(LD) Ψ (.)]	3	649.84	28.61	6.1e-07	1.00
[p(TR) Ψ (.)]	3	650.00	28.77	5.7e-07	1.00
[p(SH) Ψ (.)]	3	650.00	28.77	5.6e-07	1.00
[p(CP) Ψ (.)]	3	650.04	28.81	5.5e-07	1.00

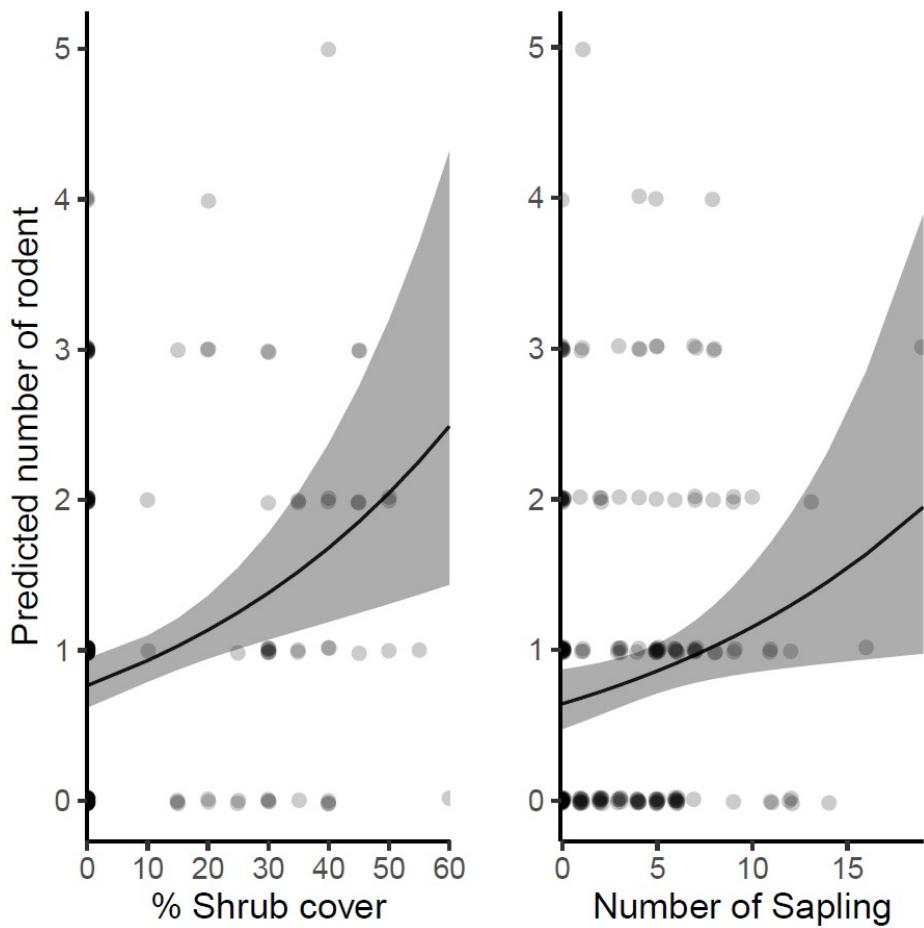
4.6 Effect of Vegetation Characteristics on Rodent Abundance

The global GLM model revealed number of saplings and percent cover of shrubs were the only strongest predictors of rodent abundance across the natural and restored sites (Fig 4; Table 5). The rodent abundance was mostly likely to increase in high number of saplings and high percent cover of shrubs across the study area. In contrast, an individual

genera analysis based on the *Praomys sp.* abundance data showed habitat type, shrub cover and number of sapling were the strongest predictors of this rodent genera abundance in the reserve (Fig 5; Table 4). The *Praomys sp.* abundance was mostly likely to decrease in high percent cover sites and in restored forest but increased in natural forest and in areas where there were more tree saplings.

Table 5: Estimated GLM regression coefficients (β), Standard errors ($\pm SE$), Z-values and P values for the global (A) and *Praomys sp.* (B) models from AIC selected generalized linear models explaining effect of saplings, shrubs and restored habitat on rodent abundance

Variable	Estimate (β) and Std. Error ($\pm SE$)	Z-value	Probability ($> z$)
(A) GLOBAL			
(Intercept)	-0.442 \pm 0.155	-2.854	0.004**
Number of Saplings	0.058 \pm 0.024	2.407	0.016*
% Shrub cover	0.019 \pm 0.006	3.495	0.001***
(B) PRAOMYS SP.			
(Intercept)	-0.419 \pm 0.231	-1.816	0.069
Number of Saplings	0.055 \pm 0.031	1.785	0.074
Secondary Habitat	-0.809 \pm 0.309	-2.615	0.009**
% Shrub cover	-0.050 \pm 0.023	-2.335	0.019*



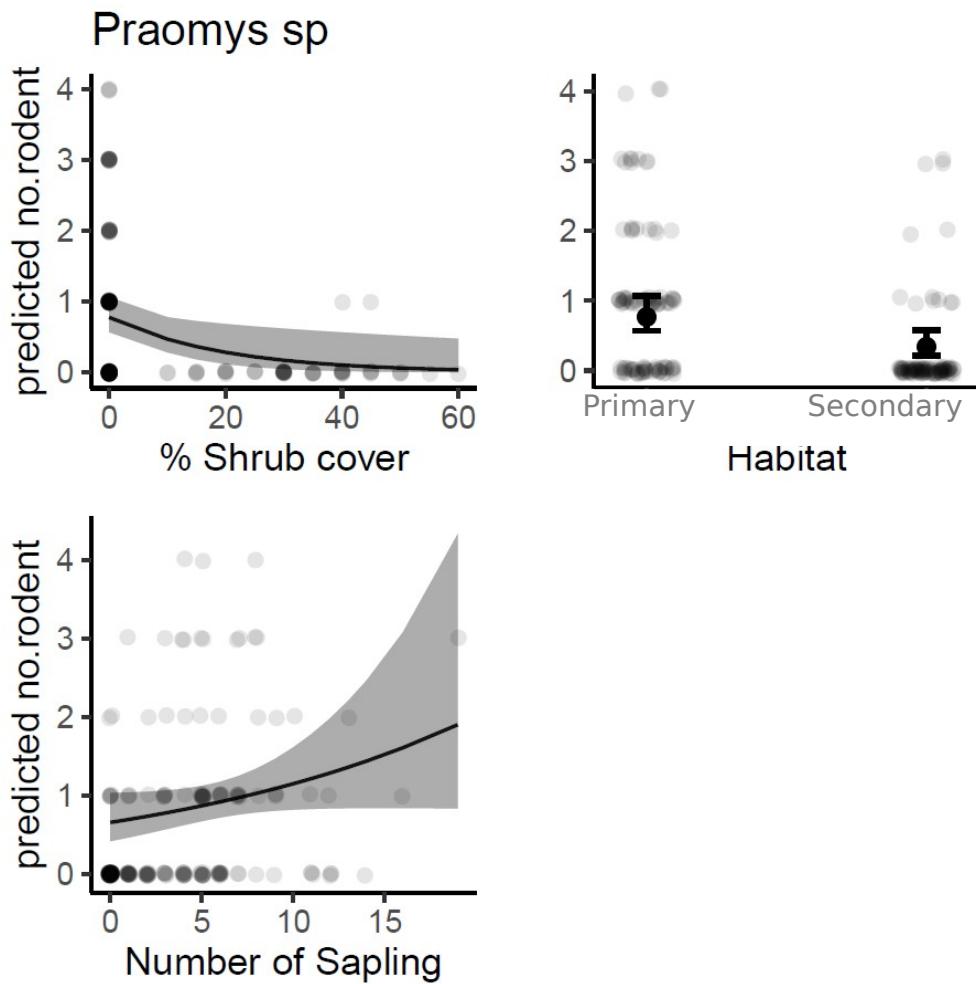


Figure 4: Effect of three predictors on *Praomys* sp. abundance in Lulanda Forest Reserve. Shrub cover and restored forest negatively affected the *Praomys* sp. abundance (top), while saplings positively predicted increase in *Praomys* sp. abundance in the study area (bottom).

CHAPTER FIVE

5.0 DISCUSSION

This study aimed to understand how local vegetation characteristics explain rodent abundance, diversity and occupancy in a secondary forest in Lulanda forest reserve, southern Tanzania. The study found (1), five and three rodent genera in the secondary and primary forest respectively, (2) Abundance of *Praomys* sp. was significantly higher in primary forest than in the secondary forest. (3) Higher genera diversity in secondary forest than primary forest. (4) Rodent genera associated with vegetation characteristics whereby three rodent communities were structured according to local vegetation characteristics, (5) Herbaceous cover, shrub cover and number of trees were the most important vegetation characteristics driving occupancy of rodent while detection probability was determined by habitat type and there was no significant variation in detectability among survey occasions (6) the overall abundance of rodents was predicted by the number of saplings and shrub cover while the abundance of *Praomys* sp. was best predicted by natural forest habitat. These results are discussed in detail below.

Rodents genera composition, abundance and diversity

The observed composition of rodent genera in the study area are broadly similar to the genera reported in a previous study by Kisingo *et al.* (2005) in this reserve and are common in the Eastern Arc Mountains (EAM) for which Lulanda Forest Reserve is part of (Stanley *et al.*, 2007). In this study, *Praomys* sp. and *Grammomys* sp. were more abundant than other genera (Table 2). The availability of *Praomys* sp. and *Lophuromys* sp. which are forest specialist genera (Cassola, 2016) in both the restored corridor and natural forest patches could be indicative of greater similarity in habitat

resources available between the two forest types and also suggests that the secondary forest is progressing toward the primary forest. The study presumed that the primary forest patches might have served as refuge and source for genera recolonization of the restored corridor after farming disturbances that fragmented the area. Further, the dominance of *Praomys* sp. in the primary forest could be because this genus is common throughout the EAM habitats as reported previously by Stanley and Goodman (2011), Magige and Lema (2018). On the other hand, the dominance of *Grammomys* sp. in the restored forest could be attributed to the high herb and shrub covers recorded in the restored sites than the natural forests. This genus prefers thicket-like habitat, so its common name “woodland thicket rat” (Kingdon, 2014). A single individual capture of *Beamys* sp. was not surprising, as it could be due to its arboreality and trap shyness (Kingdon, 2014).

The high rodent abundance in the primary forest was amplified by *Praomys* sp., which was the most dominant across the studied habitat sites. Studies including Stanley *et al.* (2011) and Monadjem *et al.* (2015) regard *Praomys* sp. as endemic to montane forests in East Africa including the EAM. The genera forages on the ground in areas rich of leaf litter (Happold, 2013). This signals high likelihood for the now connected Fufu and Magwila forest patches via the restored corridor to hold suitable conditions for this genera distribution.

Higher genera diversity in the restored forest observed in this study may suggest that the corridor supports diverse resources such as nesting and escape cover, food etc., for the rodent genera. This is due to that corridors are effective in increasing diversity and abundance of rodents in fragmented habitat (Pardini *et al.*, 2005; Lidicker, 2007).

This result is similar to the high diversity of rodents in the restored corridor previously published by Kisingo *et al.* (2005) in this area.

Association of rodents with vegetation characteristics

The association of rodent with vegetation characteristics shows the first rodent community composed of *Mus* sp. and *Dendromus* sp. in a secondary forest associated with shrubs and herbaceous vegetation. The two genera are known to be widely distributed across Tanzania and have a tolerance of a degree of habitat modification (Child, and Monadjem, 2016).

As predicted, the association of the second community comprising of *Grammomys* sp. and *Lophuromys* sp. with herbaceous vegetation particularly in the secondary forest, suggests that restoration has provided favorable conditions to the two populations similar to primary forest as one of these genera (*Lophuromys*) was recorded in both forests. The third community with *Beamys* sp. and *Praomys* sp. populations were more confined in natural forest though *Praomys* sp. was recorded in the restored habitat. Their correlation with canopy height, dead wood, dense forest, saplings and litter cover (Fig. 3) is an important attribute that suggests the secondary forest has a suitable habitat for these specialist genera to live in.

Rodent detection and occupancy

Detection of rodents was strongly predicted by secondary forest habitat type. This suggest that this habitat site currently provide conducive conditions for rodents to exist. Based on the ranked occupancy models, suggest that the probability of rodent occupying a site increases with increased combination of these habitat characteristics. The increased rate of rodent occupancy in response to increased shrub and herbaceous cover signifies that these vegetation characteristics are very important for rodents to thrive in the area. This is in line with most studied rodent-habitat relationships which explain that grasses/herbs and

shrubs are the best location where rodents obtain food resources, nesting sites as well as cover for escaping predation (Datiko and Bekele, 2014). The significant effect of these vegetation characteristics on rodent occupancy is consistent with previous results reported by Krebs *et al.* (2010). Number of trees influenced rodents in the area, revealed the role of trees in the habitat for rodents to obtain ecological requirements (Stephens and Anderson, 2014). Further, trees provide unique microhabitat for most small mammals including rodents (Mena and Medellín, 2010) they derive protection from large trees, obtain food such as seeds and fruits under trees (Chen *et al.*, 2019). Thus, I attribute the rodent occupancy in dense trees because Lulanda secondary forest has various medium to large size trees that are suitable for rodent to utilize.

Effect of vegetation characteristics on rodent abundance

The effect of vegetation characteristics on the abundance of rodent were strongly predicted by number of saplings and shrub cover. This is probably attributable to seeds and fruits that drop under trees which later grow as saplings. Rodents are important proxies for the dispersal of seed plants (Chen *et al.*, 2019) thus probably spend much time foraging in these areas. In the study area most of the recorded rodent genera are omnivorous, feeding seeds and insects under tree ground leaf layer. The high shrub cover on the other hand, are suitable sites for rodents to get food resources, shelter and security as these sites create unique microhabitat resources providing food and nesting materials for them (Kingdon, 2014). Contrary to saplings and shrub cover, the restored habitat showed a negative effect to *Praomys sp.* abundance. This suggests that, although *Praomys sp.* were recorded in the corridor, yet the site may have not yet attained enough habitat attributes for this specialist genera.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This study contributes to improving our understanding on the association of vegetation characteristics with rodents in a restored forest particularly the abundance, diversity and occupancy of rodents in a secondary forest by comparing with the primary forest. The study found higher genera diversity in secondary forest than primary forest. The results also highlighted three rodent communities associating with vegetation characteristics. The study confirmed that, the number of saplings and shrub cover predicts the abundance of rodents in Lulanda. Further, the result revealed that herbaceous cover, shrub cover and number of trees drive rodent occupancy in Lulanda.

6.2 Recommendations

- i. The survival of rodents in Lulanda Forest Reserve depends on the survival of the entire forest in the area, thus forest managers should continue maintaining this montane forest for the benefits of all life forms present in the area.

- ii. Further, based on study findings, the forest restoration improves rodent genera coming back in restored areas, continuing to restore degraded areas elsewhere is an increasing priority.

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