INFLUENCE OF VEGETATION COMMUNITIES ON SMALL MAMMAL ABUNDANCE AND DIVERSITY IN AN AGRO-ECOSYSTEM IN ISIMANI DIVISION, IRINGA REGION, TANZANIA.

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN LAND USE PLANNING AND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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ABSTRACT

Vegetation communities are home for a number of animals including small mammals, hence any change in vegetation communities will influence their abundance and spatial distribution. This study aimed at investigating the influence of vegetation communities on small mammal abundance and diversity in Isimani agroecosystem landscape, southern Tanzania. Three study sites selected based on landscape characteristics and vegetation communities were investigated, classified and mapped. Fourteen vegetation communities were mapped and more than 80 trees species and 20 species of herbs were identified during the field survey. A total of 63 Small mammals trapping sites were randomly located in the three sites covering 188 km^2 where 507 small mammals of eight different species were trapped. The data obtained were later analysed to get an insight into their relationship. Boosted Regression Trees (BRT) modelling technique was used to establish the relationship between vegetation communities and small mammal abundance and diversity. Small mammals were found in large numbers in cultivated fields and fallowed areas. Trap success was high at high altitudes i.e. on the plateau, shamba rat i.e. *Mastomys natalensis* contributed for more than 80% of the total number of small mammals recorded. BRT model results showed that altitude was the most important vegetation communities' predictor variable contributing 45.6% on small mammals' abundance and (80.2%) on their diversity. Identification and mapping of different vegetation communities across agroecosystem landscape has proven to be very crucial for understanding vegetation - small mammals interactions in agroecological landscapes. This study recommend measures that reduce herbaceous vegetation from fallowed areas and encourage woody vegetation to be taken in order to supress grasses in vegetation bordering farms so as to achieve Ecological Based Rodent Management (EBRM). Also future studies that will investigate how small mammal abundance and diversity can be influenced by different vegetation communities seasonally in agroecological landscapes.

DECLARATION

I, James Victor Lyamuya, do hereby 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.

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DEDICATION

I would like to dedicate this work to my beloved parents, my dad Mr. Victor Elias Lyamuya and my mother Mrs. Anna Masaka Lyamuya.

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LIST OF ABBREVIATIONS AND SYMBOLS

a.m.s.l	above mean sea level
ANOVA	Analysis of Variance
BRT	Boosted Regression Tree
DBH	Diameter at Breast Height
EBRM	Ecologically Based Rodent Management
GIS	Geographic Information System
LIDAR	Light Detection And Ranging
LSD	Least Significant Difference
NDVI	Normalized Difference Vegetation Index
NIR	Near Infra-Red
ROI	Region of interest
Spp.	Species
SUA	Sokoine University of Agriculture

CHAPTER ONE

1.0 INTRODUCTION

1.1 Vegetation Community as an Indicator of Small Mammal Composition and Abundance

Vegetation communities and their associated characteristics are important indicators of the composition and abundance of small mammals (Mulungu *et al*., 2008). Any change in vegetation through human activities such as farming and bush clearing could induce changes in the abundance of small mammal communities (Ralaizafisoloarivony *et al*., 2014). Vegetation communities vary across a landscape and are crucial for understanding the distribution of small mammals (Thompson and Gese, 2013). The study conducted by Makundi *et al*. (2007) in Western Usambara Mountains, Tanzania shows that different vegetation communities varied across the landscape. In that study it was observed that shrubs were dominant both in the plateau and escarpment. The authors observed that these upland shrubs seem to have developed after natural forests were cleared for cultivation and later regenerated to secondary vegetation. Other studies have reported that conversion of vegetation communities is likely to induce stress conditions in animals particularly small mammals (Krebs, 1989) and pest re-emergence (Makundi *et al*., 2007). Studies conducted by Mulungu *et al*. (2008) in Mount Kilimanjaro reported that some small mammals including *Mastomys natalensis* gained pest status by forest disturbance and cultivation while others preferred complex and heterogeneous vegetation in different landscapes. Other studies conducted worldwide have demonstrated that vegetation features such as vegetation structure, cover and height, litter depth, and foliage height diversity, are important vegetation community variables that could affect small mammal abundance (Hoffmann and Zeller, 2005; Thompson and Gese, 2013). These features are directly related to the life form and growth pattern of specific vegetation species within a plant community (MacCracken *et al*., 1984). However, in the tropics and especially across small farming agroecosystems, there is a paucity of information on the influence of vegetation structural characteristics such as cover, density, height, litter and bare ground on the abundance of small mammals particularly those regarded as an important pest in agriculture (Mulungu *et al*., 2008). Therefore, there is a need to investigate the vegetation communities and their associated characteristics across cropping systems in order to provide information for explanation of small mammal population dynamics needed for ecologically based rodent management.

1.2 Vegetation and Small mammal Interaction

Each animal species selects specific vegetation communities for protection, foraging, or micro-climate (Melo *et al*., 2013). For example, Mulungu *et al*. (2008) in the study conducted in several sites on Mount Kilimanjaro reported that diversity of small mammal species varies with vegetation type. The authors observed that small mammal species were highest in the forested highland areas and lowest in the lowland areas covered by fallow and bush lands. In the Usambara Mountains, it was also observed that variability of small mammal's abundance was associated with the degree of fragmentation of the vegetation and the height of the vegetation (Ralaizafisoloarivony *et al*., 2014). The variability in the abundance of small mammals reported in many studies was mainly attributed to vegetation alteration likely due to the loss of food resources, available dew, disruption of vegetation structures, cover, shelter and increased predation risk (Hoffmann and Zeller, 2005). Therefore, the studies suggested that it is important to carry out quantitative studies on vegetation communities at both coarse and fine scales for explanation of small mammal population dynamics so as to contribute knowledge on the ecologically based rodent management (EBRM) strategies (Fitzherbert *et al.*, 2006).

1.3 Potentials of Vegetation Communities and Their Associated Structural Characteristics for Understanding Small Mammal Population Dynamics

Vegetation community is an area of vegetation which is relatively uniform with respect to structure and floristics and occur on the same land zone (Neldner *et al*., 2012). Vegetation communities harbour several species of small mammals. The structure of vegetation and how this structure varies across a landscape, is crucial to understanding the distribution of small mammals (Thompson and Gese, 2013). Diversity and abundance of small mammals in such vegetation communities reflect the quality and diversity of vegetation communities (De Klerk, 2014; Adam *et al.*, 2015).

However, the relationship between vegetation communities and small mammals is complex and has been studied from different perspectives. A study conducted by De Klerk (2014) at Kariega Game Reserve in South Africa investigated the extent to which small mammal community (including the specific species present and the species richness) interact in different habitats including areas cleared of alien vegetation. This study indicate that small mammal species richness and abundance are different in different habitats.

Vegetation community composition and structure (i.e. horizontal and vertical distribution of cover and height of dominant plants) may vary in both time and space (Brocklehurst *et al*., 2007). Vegetation structure is important in explaining species diversity patterns for many animal groups (Simonson *et al*., 2014). A study conducted by Westerman and Petersen (2010) in northern Michigan to evaluate the relationship between bird species diversity and vegetation observed significant correlation between foliage height, diversity, percent canopy cover and bird migratory species. A good correlation was reported between vegetation structural characteristics including height and small mammal pest outbreaks in a review study conducted by Jacob (2008) in agro ecosystems. Such vegetation community data contains useful information about the relationships between plant communities and small mammals (Zhang *et al*., 2008).

Recently the use of remote sensing tools has proved to be useful in studying the relationships and monitoring of animal species diversity in terrestrial environments (Vierling *et al*., 2008). For example, a study conducted by Simonson *et al*. (2014) explored the applicability of airborne LIDAR in vegetation structural characteristics assessment for monitoring animal species diversity in terrestrial environments. However, analysis of vegetation floristic and structural characteristics using geo-dataset derived from satellite data in conjunction with expert GIS engine for monitoring small mammal abundance have not been evaluated sufficiently in the tropical small farming agro-ecosystems. Such studies are of paramount importance especially in Tanzania where frequent small mammal outbreaks have been reported for guiding ecologically based small mammal management strategies (Vanden Borre *et al*., 2011).

1.4 Justification

Small mammal population fluctuations and breeding patterns investigated at localities in South-west, Central and North-east Tanzania show that these localities are ecologically heterogeneous in terms of vegetation types and small mammal species diversity (Makundi *et al*., 2005). Although much emphasis has been directed towards understanding the effect of weather on small mammal population dynamics in Tanzania (Makundi *et al.*, 2006), the intrinsic characteristics of the small mammal species and nature of vegetation have received much less attention. For example, it is reported that certain species populations can exhibit fluctuations more widely in certain types of vegetation than in others, but the mechanisms underlying such fluctuations are not very well understood (Fitzherbert *et al.*, 2006).

Studies that have been carried out in Tanzania to investigate small mammal population dynamics for ecologically based management of small mammal pests have focused on broad classes of vegetation such as natural forest, areas cleared for agriculture and lowland savannah vegetation which are mostly preferred by rats (Makundi *et al*., 2006). Understanding the relationship between interaction of vegetation communities in agro-ecosystems and the associated vegetation interfaces for explanation of small mammal's population dynamics is vital. Such information is of paramount importance in refining the prediction models needed for ecologically based small mammal management strategies. Efforts geared in this direction are likely to contribute towards reduction of yield losses of crops like maize and rice which are estimated to be around 5 to 15% in Tanzania. Therefore, this study intended to investigate the influence of vegetation communities and their associated characteristics on the abundance of small mammals across cropping systems in order to contribute knowledge for designing ecologically based small mammal management strategies.

1.5 Objectives

1.5.1 Overall objective

The overall objective of this study was to establish relationship between vegetation communities and small mammals' abundance in order to contribute knowledge for modelling small mammal population dynamics and outbreaks under smallholder farming agro-ecosystem.

1.5.2 Specific objectives

i. To map different vegetation communities across smallholder agro ecosystem landscape in the study area.

ii. To determine the abundance and diversity of small mammals in different vegetation communities across the landscape units in the study area.

iii. To establish spatial relationships between vegetation communities and their associated characteristics with small mammal abundance.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Mapping of Vegetation Communities

Vegetation community mapping is the process of delineating the geographic distribution, extent, and landscape patterns of vegetation types and/or structural characteristics (Brohman and Bryant, 2005). Mapping of vegetation types in the form of vegetation communities or ecosystems generally consider differences in dominant species composition, structure (Benson, 2006), cover, density, height and litter, which are important parameters for modelling small mammal population dynamics especially small mammal outbreaks (Thompson and Gese, 2013).

In Santa Catalina Island, California a vegetation map was produced where 15 different vegetation communities were identified as well as three non-vegetated types (bare, bare streambed, and developed) (Knapp, 2005). The map was used to determine habitat preferences by feral cats (*Felis catus*) and to determine preferred denning habitats for the endemic island fox (*Urocyon littoralis* ssp). In Ozark National Scenic River ways, USA 49 classes of vegetation communities were mapped using a hybrid combination of statistical methods and photointerpretation (Chastain *et al*., 2008). The mapped vegetation communities were used to facilitate resource management planning including ecological systems groupings, woodland/forest management and wildland fuel production. In the Usambara Mountains Tanzania, Ralaizafisoloarivony *et al*. (2014) produced a general vegetation habitat map at a scale of 1:20 000 for monitoring small mammals related to plague outbreaks. In this study several vegetation habitats were explored including cultivation (annual crops: maize, beans and Irish potatoes) which occupied 24% of the total study area followed by plantation forest (19%), shrub (18%), natural forest (17%), settlements (12%) and the rest were comprised of herbaceous vegetation, rocky surfaces, and horticulture (10%). Observations from this study demonstrated that natural forest, cultivated and shrub habitats were the most favoured by small mammals. As reported earlier vegetation habitats and their associated characteristics are important indicators of the composition and abundance of small mammals (Mulungu *et al.*, 2008). Therefore, mapping vegetation communities at farm scale could significantly contribute to the development of ecologically based small mammal management strategies (Simonson *et al.*, 2014).

2.2 Classification of Vegetation Communities

The vegetation classification has been an active field of scientific research since well before the origin of the word ecology and has remained so to the present day (Peet and Roberts, 2013). Normally classification is based on a set of vegetation criteria, including physiognomy (growth forms, structure) and floristics (compositional similarity and characteristic species combinations), in conjunction with ecological characteristics such as disturbance, bioclimate, and biogeography (Faber-Langendoen *et al.*, 2014). The role which vegetation analysis can play in classifying sites depends on the purpose of the classification and the size of the area to be studied (Di Gregorio, 2005). Vegetation description and classification provides units critical for inventory and monitoring of natural communities, planning and managing conservation programmes, documenting the requirements of individual species, monitoring the use of natural resources such as forest and range lands, and providing targets for restoration (Peet and Roberts, 2013). Both floristics and stand structure are important criteria for the meaningful delineation of tropical vegetation formations, especially in the forest/savanna transition zone (Torello-Raventosa *et al.*, 2013). If vegetation communities could be mapped using structural characteristics over large spatial scales, habitat structure–species diversity (HS–SD) relationships could be used to model species diversity and inform conservation planning and management (Simonson *et al*., 2014). Remote sensing tools that directly provide data relevant to organism–vegetation interactions across a hierarchy of scales promise to improve our understanding of animal–habitat relationships (Vierling *et al*., 2008).

2.3 Drivers Influencing the Pattern of Vegetation Communities

The term "vegetation" encompasses plants at multiple scales, from the most refined floristic levels (referred to as "plant communities" in this dissertation) to the broadest physiognomic or lifeform levels (Drake *et al*., 2009). The structure and the assembly of plant communities are a result of historical anthropogenic activities and natural phenomena such as distance to seed source, soil fertility (Rojas, 2014) and altitude (Mulungu *et al*., 2008). These phenomena are important in controlling the vegetation pattern change in nature. Failure to recognize the importance of these phenomena has been a major stumbling block in detecting and mapping vegetation patterns at various scales (Damman, 1979; Di Gregorio, 2005).

According to a study by Reed *et al*. (2009) on spatial distribution of vegetation types in the Serengeti ecosystem: the influence of rainfall and topography on vegetation patch characteristics showed that both variables were important contributors to the distribution of woodlands and grasslands in the Serengeti ecosystem. It was indicated that changes in patch characteristics had a complex interaction with rainfall and topography (Reed *et al*., 2009). Again a study by Jin *et al*. (2006) on impact of elevation and aspect on the spatial distribution of vegetation in the Qilian Mountain area in North West China clearly indicated that elevation is the dominating factor determining the vertical distribution of vegetation and growth in the area. Wana and Beierkuhnlein (2011) investigated the response in the relative abundance of plant functional types along altitudinal gradients and the relationship of plant functional types to environmental variables at Gughe-Amaro Mountains in Ethiopia. Results indicated that topographic attributes (altitude and slope) as well as soil organic carbon had played an important role in differentiating the relative abundance of plant functional types in the investigated gradient. Thus, considering specific plant functional types would provide a better understanding of the ecological patterns of vegetation and their response to environmental characteristics in tropical regions of Africa (Wana and Beierkuhnlein, 2011).

Anthropogenic activities be it deliberate or inadvertent are important determinants of vegetation dynamics and community assembly (Rojas, 2014) such as semi natural vegetation (Di Gregorio, 2005). The process of transformation of natural communities into semi-natural communities have a significant influence on biological diversity at the local and regional scales e.g. changes from forested to non-forested, often in grass-dominated ecosystems (Olsson, 2004). A study by Rojas (2014) on vegetation dynamics and community assembly in post-agricultural heathland Nørholm southwestern part of the Jutland peninsula in Denmark found that even after a century of abandonment of agricultural practices, land-use legacies were still present in the soil and were important determinants of vegetation dynamics and community assembly. However, the effects of land-use legacies were mostly mediated by the understory vegetation and differed according to the functional groups (Rojas, 2014). Other drivers that have been considered and also widely used in vegetation community studies include fire which has often been used as a management tool to achieve conservation goals (Kelly *et al.*, 2012). Livestock grazing (Hall *et al.*, 1995; Bond *et al.*, 2001); excessive harvesting of wood for fuelwood, charcoal and timber (Frost, 1996); and agriculture fragmentation (Stefania *et al.*, 2014) have been reported as the major anthropogenic factors influencing vegetation dynamics in the tropical ecosystems.

Species (both flora and fauna) also show many kinds of responses to changes in vegetation communities attributed mainly to anthropogenic activities in the landscape. The effects of changes on the biota can take many years to be expressed as there is a time lag in experiencing the full consequences of such changes. Long lived organisms such as trees may persist for many decades before disappearing without replacement while small local populations of animals may gradually decline before being lost (Bennett and Saunders, 2010).

2.4 Small Mammals in Agro Ecological Landscapes

From the perspective of an entire landscape, agroecosystem has been defined as patches of a particular vegetation community created or modified by humans, embedded within a spatially complex patch of many distinct vegetation patches of which some are anthropogenic and/ or natural (Holt *et al.*, 1995). In the tropical ecosystems, these vegetation communities harbour several species of small mammals. It has been suggested that diversity and abundance of small mammals in vegetation communities in the tropics reflect the quality and diversity of the tropical ecosystems (Adam *et al.*, 2015). This was attributed to the fact that each animal species selects specific microhabitats for protection, foraging, or micro-climate (Melo *et al.*, 2013).

Furthermore, spatial distribution, population density, and reproductive success of small mammals in the tropics may be altered by changes in vegetation composition and structure (Moseley *et al.*, 2011). Rainfall and seasonality (Moseley *et al.*, 2011; Fischer *et al.*, 2012; Mulungu *et al.*, 2014) as well as topography (Hieronimo *et al.*, 2014) are also the major abiotic factors reported to control the abundance and diversity of small mammals. It has also been reported that vegetation community dynamics often brought about by human activities such as; livestock grazing, fire (Yarnell *et al.*, 2007; Bock *et al.*, 2011) and crop farming (Bianchi *et al*., 2006; Stefania *et al*., 2014) are biotic accelerators which control the abundancy and diversity of small mammals in an agro-ecosystem landscape.

2.5 Ecological Small Mammal Management and Vegetation Communities in Agricultural Landscapes

Agriculture intensification has led to expansion of agricultural land, enlargement of field size and removal of non-crop habitat resulting in a simplification of agricultural landscapes and rapid decline in farmland biodiversity (Bianchi *et al*., 2006). These changes are likely to affect both the composition and diversity of small mammal communities living in such landscapes (Stefania *et al*., 2014). For example, a study by Bianchi *et al*. (2006) on sustainable pest regulation in agricultural landscapes reported that diversified landscapes provide vegetation communities that are most potential for conservation of biodiversity and sustained pest control functions. A study by Stefania *et al*. (2014) on abundancy of small mammals' species and diversity along a gradient of agricultural intensification in North-East Italy demonstrated that population abundance, type of species present and species diversity were affected by agricultural intensification and landscape naturalness. The insights provided by these studies highlight the importance of Ecological Based Rodent Management (EBRM) as a way to control rodent pests in an agro-ecosystem. This is attributed to the fact that EBRM decreases impacts on natural resources, promotes more diverse natural enemy communities, and strengthens biological control of especially rodent pests in crop fields (Crowder and Jabbour, 2014).

Ecological Based Rodent Management approach has been demonstrated with success in Asia and hence it provides a strong justification to spearhead research in Africa in order to develop similar management strategies for rodent pests control in agricultural landscapes (Makundi and Massawe, 2011). Therefore, this study aims to provide insights into the influence of vegetation communities and their associated characteristics on the abundance of small mammals across cropping systems as an intervention to advance knowledge for designing ecologically based rodent management strategies in semi-arid cropping systems. Findings of this study will help experts from different fields especially agriculture in policy formulation in order to reduce food loss by controlling rodent outbreaks in different agro-ecosystems.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The study was conducted in Isimani division, Iringa Region, Tanzania. The approximate geographical location is between Universal Transverse Mercator (UTM) coordinates 775 000 m and 825 000 m Eastings and between 9 210 000 m and 9 140 000 m Northings, Zone 36N (Fig. 1).

3.1.2 Climate

Isimani is mostly low land characterized by semi-arid climate with unimodal rainfall pattern. The rainfall season in Isimani is from November to April of the following year with a maximum mean monthly rainfall of 138 mm occurring during the month of January. Mean annual rainfall for Isimani is 598 mm. Mean monthly minimum temperature ranges from 12°C in July to 16.5°C in December, while mean monthly maximum temperature ranges from 24.3°C in July to 28.8°C in November (Kijazi *et al.*, 2013).

3.1.3 Landform and soils

Isimani lies along the Iringa - Dodoma road generally traversing flat/rolling and rolling/hilly terrain. The area includes part of Nyang'oro escarpment discending all the way to Mtera dam (Iringa/Dodoma border) with slope gradient reaching up to more than 10%. The geology of Isimani area can generally be classified as sedimentary with metamorphic rocks such as limestone including travertine. These occur as either marble, quartzite, graphitic schist, chlorite, amphibole, mica and kyalite schist, hornblende, biotite and garnet, gneiss, acid gneiss, granulate or charnokite (Gaye *et al*., 2009).

The soils in the study area varies from sandy loam to clay loam with black cotton clay soils in some areas (Fig. 2). Most of the farmlands are located on sandy loam soils and some in the black cotton clay soils in the low lands depressions. Black cotton clay soils characteristically show wide cracks during dry season and are dominated with Acacia woodland mostly in the plateau landscape. The soils of the escarpment are dominantly gravelly and stony sandy loams.

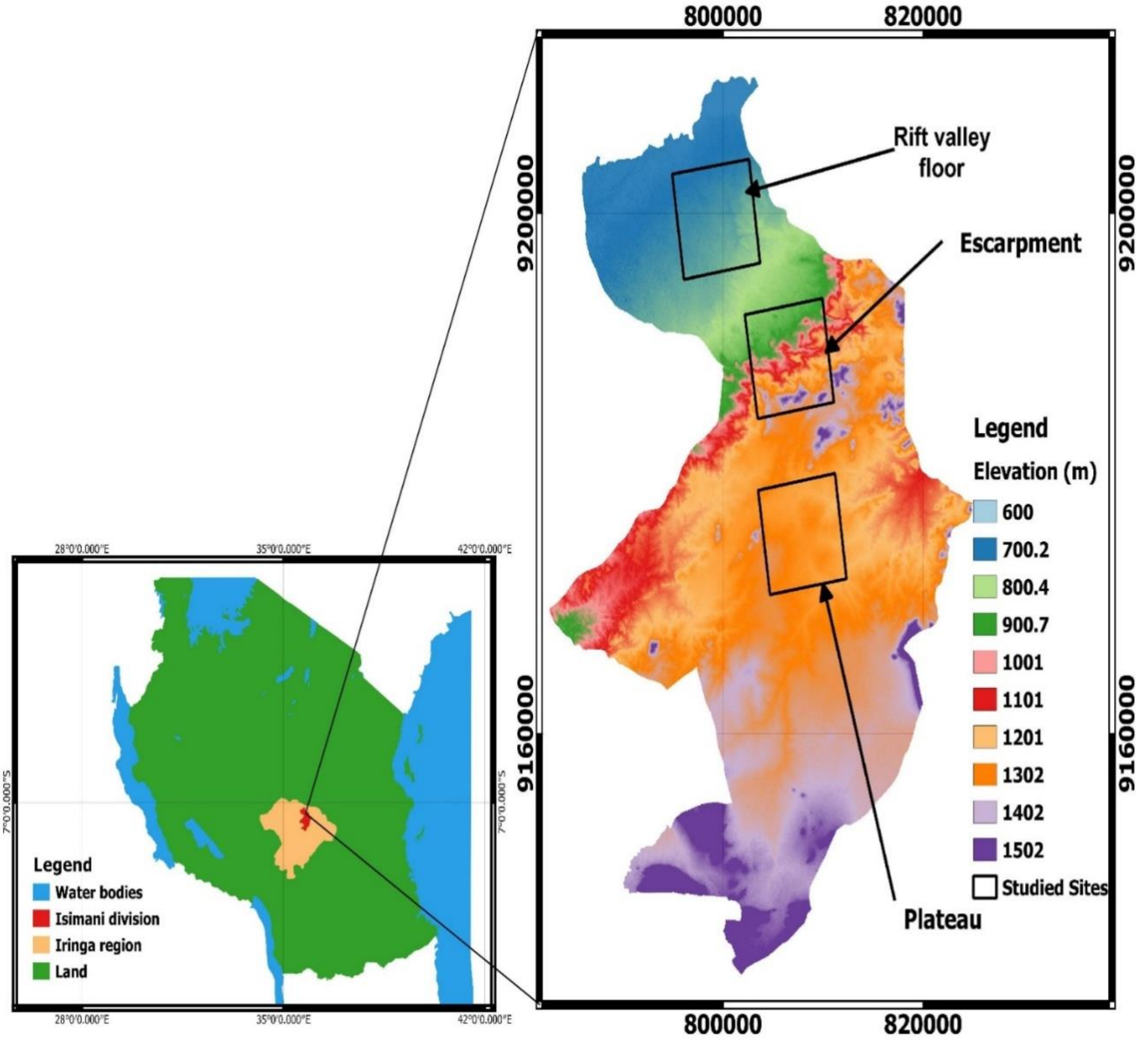


Figure 1: Location map of the study area

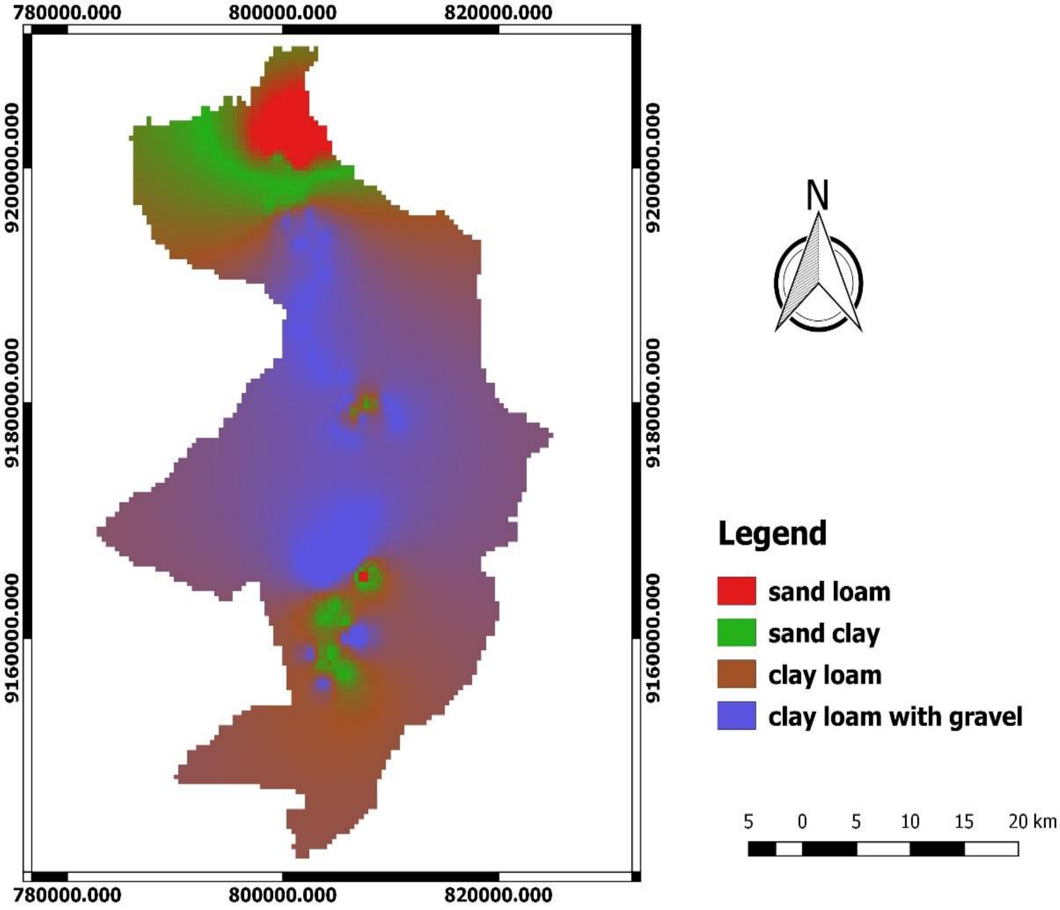


Figure 2: Soil map of Isimani division interpolated from point soil survey data

3.1.4 Vegetation and land use

Rain fed agriculture is the dominant land use system in the study area. The majority of farmers are subsistent growing maize as major staple crop as well as cash crop. Other crops grown in the area include tobacco, cotton, legumes (cowpeas and beans), millet, sorghum, groundnut and sunflower. Open grassland with scattered shrubs and patches of thick thorny bushes are predominant vegetation in the area. The tree species are dominantly scattered from place to place across the landscape. Only a small area is still covered by natural woodlands in the study area. Most of the remaining natural woodlands; miombo woodlands in particular can be found in Nyag’oro escarpment and on other hilly areas (Mbilinyi, 2000).

3.2 Methods

3.2.1 Mapping vegetation communities

Mapping of vegetation community was done at two levels: (i) general mapping with Multispectral satellite image (ii) detailed characterisation of vegetation communities in the field.

3.2.1.1 Mapping with remote sensing

Mapping with remote sensing involved multispectral satellite image SENTINEL-2 from European Space Agency (ESA) captured on 23 June 2016 with a cloud cover of 5.24% and spatial resolution of 10m, 20m and 60m depending on the band combination (Congedo, 2017)). The image had a processing level 1C which included radiometric and geometric corrections with ortho-rectification and spatial registration on a global reference system with sub-pixel accuracy.

The Semi-Automatic Classification Plugin in QGIS was used to classify the image to obtain general vegetation community classes. The plugin allows for the semi-automatic supervised classification of the images, providing tools to expedite the classification process (Congedo, 2013). Training was conducted by clicking on an image pixel, and a polygon i.e. Region of Interest (ROI); which contains spectrally homogeneous pixels considered to represent a vegetation community class of interest. To increase accuracy during creation of homogeneous ROIs and determination of vegetation communities, Normalized Difference Vegetation Index (NDVI) was used throughout the ROI creation process. After obtaining training areas the classification was performed using Maximum Likelihood algorithm. In this process three vegetation community classes (acacia wooded grassland, undifferentiated woodland and acacia woodland) and three non-vegetative classes were successfully classified on the rift valley floor. Three classes of vegetation community namely Miombo woodland, undifferentiated woodland and acacia woodland on the escarpment and two (Miombo woodland and acacia woodland) out of eight vegetation community classes on the plateau. The six classes which could not be independently classified on the plateau was due to similarity in spectral signatures mostly caused by the fragmentation of the agriculture fields and the fact that some vegetation communities have almost similar characteristics but differ in different landscape units where they occur. Due to these circumstances the obtained vegetation community map was intensively validated in the field. The Classes that were not correctly classified in the field were identified and corrected. GPS supported field survey conducted in June 2016 together with Google earth image provided an independent reference data that helped improve the vegetation community classes obtained from SENTINEL-2 satellite image.

3.2.1.2 Detailed characterisation of vegetation communities in the field

The general vegetation community base map obtained from classification of SENTINEL-2 satellite image was used to guide detailed characterisation of vegetation community in the field. Both purposeful and stratified random sampling were used, whereby representative study sites were selected based on landscape characteristics (landform, slope and relief dissection), vegetation and land use and severity of rodent outbreaks as reported by farmers in Isimani division, Iringa, Tanzania.

From the definition of vegetation community (Neldner *et al.*, 2012), the study area was divided into three major landscape zones: the Plateau (1590 – 1073 m a.m.s.l), Escarpment (1072 – 851m a.m.s.l) and rift valley floor (850 -704 m a.m.s.l) (Fig. 1). Based on the three landscape zones, three study sites with an area of 62.55 km^2 each were located and demarcated for detailed studies and mapping of vegetation communities (Fig. 1). A buffer of 1 km on either side of the transect along Iringa-Dodoma highway was created to mark the boundary for the extent of the study area and was used to guide sampling and data collection on vegetation communities and trapping of small mammals.

Based on landscape characteristics, 24 quadrats (1 ha or 100 x 100 m) for each study site were geographically located for detailed studies. The 24 quadrats were identified by a number; randomly located within the study sites. From each quadrat 12 subplots were located where by six subplots were located from each diagonal of the quadrats for identification and mapping of vegetation communities. The circular subplots of 5 m radius were used, each being situated 20 m from the conner points and from each other (Fig. 3). Then all vegetation community variables such as vegetation structural characteristics and floristic composition measured as percent bare ground, basal cover, litter, shrub density, and mean grass cover, and shrub height were recorded within this radius of 5 meters. Finally data from the 12 subplots were used to estimate on average the overall vegetation community characteristics of the respective quadrat.

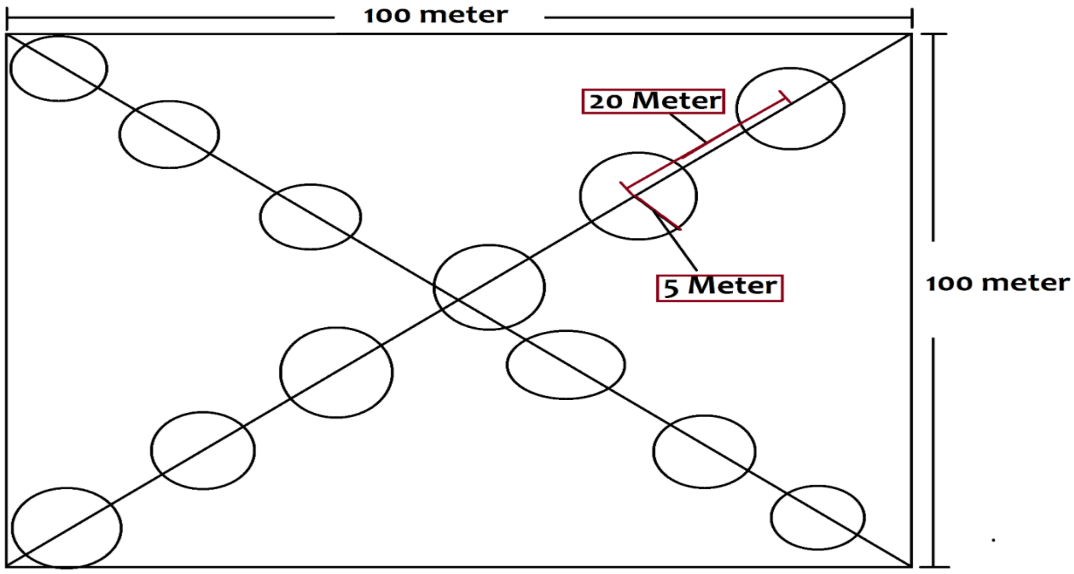


Figure 3: **Illustration of procedure for identification and mapping of vegetation community characteristics within a quadrat in the identified sampling sites**

In the field both vertical and horizontal pattern of the vegetation community variables were recorded from each spatially located quadrat. Data on percentage cover for each identified vegetation species/types, life forms, height, land use/cover, management practices and soil properties were studied and recorded. Identification of vegetation based on physiognomic, structural and floristic aspects was done and vegetation described using taxa i.e. floristic composition of the plant community according to FAO guidelines (Di Gregorio, 2005). The vegetation community regional ecosystem hierarchy by Neldner *et al*. (2012) was done in the grid of 100 x 100 m. For example, agriculture fields were classified based on the crop type in situ e.g. maize field, while natural and semi natural vegetation were classified based on physiognomy (Fig. 4) and floristic composition just as found in the field. From this procedure 14 different vegetation communities and three non-vegetative classes were identified. Data collected were entered in the computer Microsoft Excel sheet for calculation of vegetation diversity index. Data were also later summarized to obtain dominant life form in percentage, Shannon index and species within each quadrat.

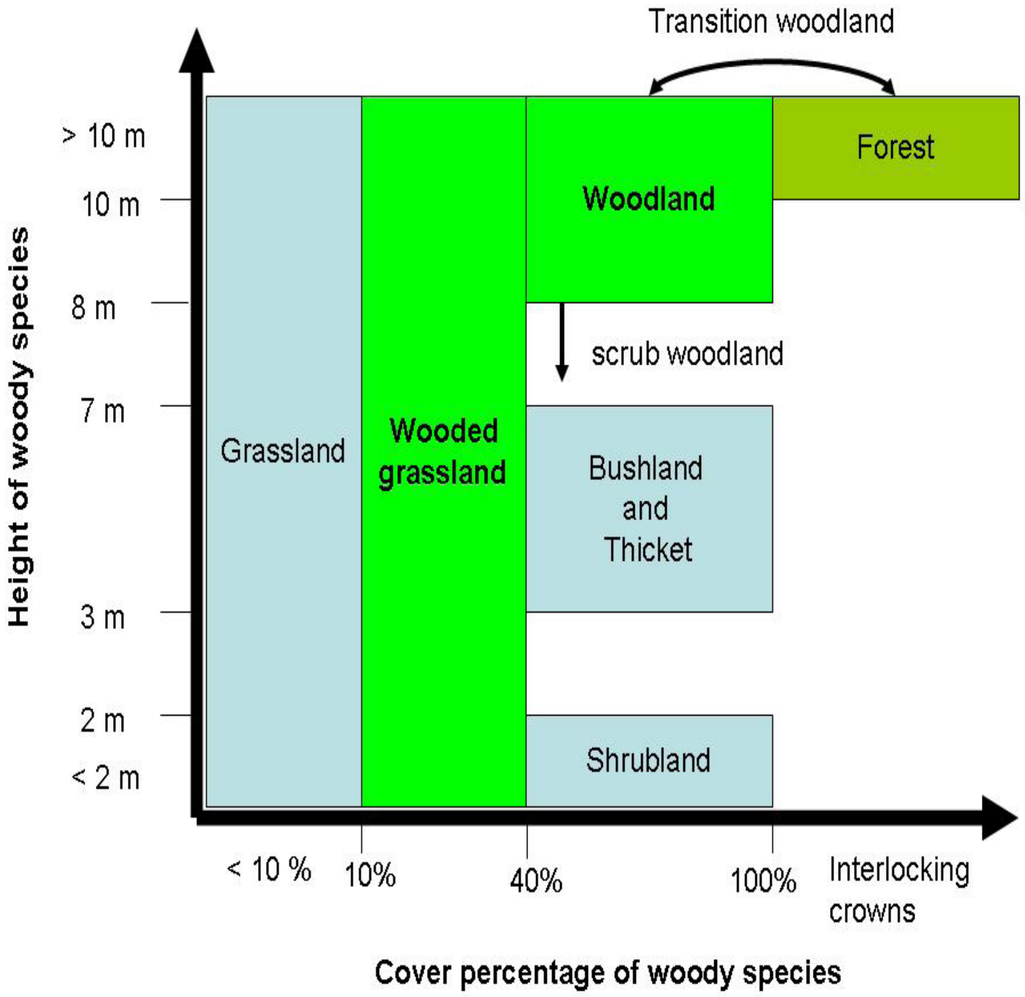


Figure 4: Height and cover percentage limits for major physiognomic types (Source: Kindt *et al.*, 2011)

3.2.1.3 Mapping terrain characteristics

Terrain attributes were also obtained from Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) with 30 m resolution. The Digital Elevation Model was used to obtain various landform derivatives for characterising the vegetation communities. Terrain analysis modules in QGIS and IDRIS salve were used to obtain the DEM derivatives such as slope gradient, slope aspect, slope shape and relief across the studied landscapes. The DEM derivatives were refined to match the terminology of the FAO Guidelines for soil profile Description (FAO, 2006).

3.2.2 Determining the abundance and diversity of small mammals in different vegetation communities across the landscape units in the study area

In this study small mammals were trapped randomly in different vegetation communities across the studied landscape units. The trapping sites were guided by vegetation community map obtained under section 3.2.1. A total of 144 trap sites (quadrats) were located within the three major landscape units identified for this study i.e. the plateau, the escarpment and rift valley floor. In this exercise a total of 49 Sherman LFA live traps (7.5 x 9.0 x 23 cm; HB Sherman Traps, Tallahassee, USA) baited with peanut butter and maize flour were used (Mulungu *et al*., 2008; Hieronimo *et al*., 2014). For each spatially and randomly located quadrat measuring 100 x 100 m, Traps were arranged in 7 line placed 10 m from each other; and trapping was carried out for three consecutive nights. (Hieronimo *et al*., 2014). Every morning the traps were inspected and rebaited when necessary. The number of small mammals captured for each quadrat were counted and identified to specie level. The trap success was also calculated based on the number of small mammals trapped divided by the product of the number of traps used and number of trapping nights (Equation 1) (Ralaizafisoloarivony *et al*., 2014) without considering their species within one or different vegetation community over a certain period of time.

$$Trap\ success = \frac{N}{Nt \times Nn} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where:

N= number of small mammals trapped,

Nt= number of traps used,

Nn= duration in terms of nights during which the trap was set

3.3 Data Analysis

Microsoft excel was used to summarise the data for further analysis. Descriptive statistical analysis was employed to explore the influence of vegetation communities and their associated characteristics on small mammal abundance. This included the estimation of average and percentage cover of different vegetation communities and their associated characteristics. Species richness and diversity were computed by using Shannon-Weiner Diversity Index calculated by using equation 2 (Admas and Yihune, 2016).

$$H' = -\Sigma \text{ (pi) } \ln \text{ (pi)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where: H′ = index of species diversity

pi = proportion of total sample belonging to i^{th} species

Wherever it was applicable the degree of association between variables was measured by linear regression, scatter plot analysis and the Pearson correlation coefficient (R) at $P \leq 0.05$. Analysis of variance (ANOVA) and Boosted Regression Trees (BRT) modelling technique in SPSS version 20 and R software respectively were used to establish the important vegetation communities (predictor variables) for predicting small mammal abundance and distribution in different vegetation communities.

Boosted regression tree model in R-software was used to establish relationships between small mammal abundance, Small mammal diversity and the parameters of the vegetation communities. Models were fitted using the gbm package in R-software. Step function and a Gaussian response type, with most effective settings for learning rate (0.001– 0.00001) and bag fraction (0.5–0.75) as found by repeated trial and error (Elith *et al*., 2008). In this study, tree complexity was set to 3 due to the fact that the data set used is small for this type of model. For model development and validation the 10-fold cross-validation (CV) was used, with the benefit of using the full data set to fit the final model as recommended by Elith *et al*. (2008). During data exploration all predictor variables were tested for ecologically acceptable level of collinearity (i.e. individual variance inflation factor (VIF) of <5) between predictor variables (Zuur *et al*., 2010).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Spatial Distribution of Vegetation Communities across Smallholder Agro-ecosystem Landscapes

4.1.1 Mapping of different vegetation communities

Plant physiognomy, floristic composition and landform are among the major factors used to characterise and map the vegetation communities in the study area. Categorization of the studied vegetation communities with respect to landform patterns (plateau, escarpment and rift valley floor) are presented in Table 1. The Vegetation diversity indices for different vegetation communities are also displayed in Table 1.

4.1.1.1 Vegetation communities of the plateau

On the plateau eight vegetation communities namely: acacia woodland, miombo woodland, acacia wooded grassland, miombo wooded grassland, grassland and agriculture comprising maize, sunflower and mixed cropping fields were identified and mapped (Fig. 5). Acacia woodland on the plateau are scattered on the convex-linear slopes and dominantly in the valley bottoms of the landscape. The vegetation is dominated by *Acacia tortilis*. Cultivated fields and fallow with mixed cropping account for more than 60% of all the studied vegetation communities.

Table 1: Categories of different vegetation communities across major landscapes in the study area

Landform	Vegetation community map units	Vegetation community associated characteristics				
		Vegetation Community description	**Area (km^2)**	**% Cover**	**Vegetation diversity index**	**Distinctive Species**
Plateau	Miombo Woodland	Miombo woodland;	4	5.7	1.6	*Brachystegia spp.*
	Acacia woodland	Acacia woodland	10	15.8	1.5	*Acacia tortilis spp.*
	Wooded grassland	Miombo wooded grassland, Acacia wooded grassland	84	13.4	1.8	Variety of grass spp. and *Brachystegia spp., Acacia tortilis* and variety of grass spp.
	Cultivated fields	Maize fields, Sunflower fields	19	31.0	1.2	*Zea maize, Helianthus spp.*
	Fallow/Mixed cropping	Maize and sunflower fields, grassland patches	18	29.6	1.6	*Zea maize* and *Helianthus spp.*; Variety of grass spp.
	Bare soil	Patches of bare land	0.3	0.4	0	-
	Water bodies	Dam, rivers and streams	0.01	0.02	0	-
	Built up areas	Road and buildings	3	4.2	0	-
Escarpment	Acacia Woodland	Acacia woodland	14	22.3	1.9	*Acacia tortilis spp.*
	Undifferentiated woodland	North Zambezian undifferentiated woodland,	22	34.7	2.1	*Combretum spp.* and *Commiphora spp.*
	Miombo woodland	Miombo woodland	15	23.5	1.4	*Brachystegia spp.*
	Road/rock outcrop	Rock cliffs, Rock outcrops, and boulder swith gravelly and stony sandy loams	1	1.2	0	-
	Bare soil	Patches of bare land	2	3.4	0	-
Rift valley floor	Acacia woodland	Acacia woodland	25	39.5	1.6	*Acacia tortilis*
	Undifferentiated woodland	North Zambezian undifferentiated woodland	3	5.3	1.6	*Combretum spp, commiphora spp.* and *Brachystegia spp*
	Acacia wooded grassland	Acacia wooded grassland	20	31.8	1.3	*Acacia tortilis* and variety of grass spp.
	Bare soil	Patches of bare l	9	13.8	0	-
	Built up areas	Road and buildings	1	0.9	0	-

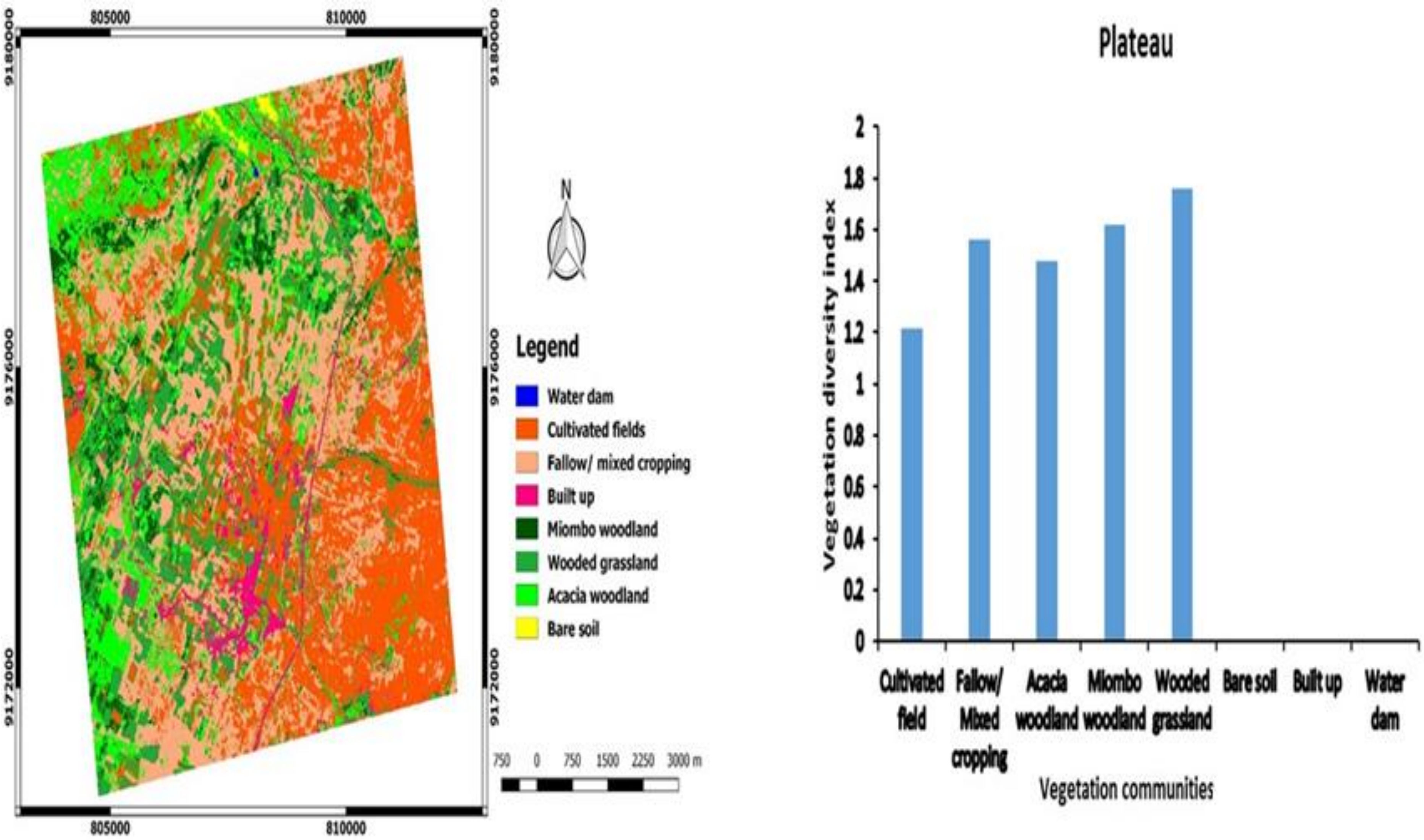


Figure 5: Vegetation communities and vegetation diversity index in the Plateau landscape

Miombo woodlands are mainly remnants of the former vegetation before clearing and occupy the edges of the plateau. Observation in the field show that this type of vegetation is characterised by trees belonging mainly to the genera Brachystegia including *Brachystegia microphylla* and *Brachystegia longifolia*. There are some other minor vegetation community species occurring in association with the Miombo woodland such as *Pterocarpus holtzii/ Pterocarpus tinctorius, Dichrostachys cinerea* and *Dalbergia melanoxylon*. Miombo woodlands are highly dynamic semi-arid ecosystems found on a number of nutrient-poor soil groups (Strömquist and Backéus, 2009). However, anthropogenic activities such as bush fires; excessive harvesting of wood for fuelwood, charcoal and timber; and agriculture have been reported as the major drivers of these dynamics (Frost, 1996). Semi natural vegetation communities such as miombo wooded grassland and acacia wooded grassland which have been collectively represented as wooded grassland on the map (Fig. 5) are also common in the area. Literature suggest that the dynamics observed on the vegetation communities in this study are a result of anthropogenic activities and fragmented agriculture (Timberlake *et al*., 2010). Wooded grassland is only 13% of all the studied vegetation communities (Table 1). This vegetation is dominated by grasses accounting for more than 60% with tree cover ranging between 10 and 40%. *Dichrostachy scinerea* and *Albizia petersiana* which also characterise miombo woodland (Kindt *et al*., 2011) were also common in the study area (Frost, 1996).

4.1.1.2 Vegetation communities of the escarpment

The major part of the escarpment is dominated by miombo woodlands in nature with grasses and shrubs underneath. The escarpment is vegetated by three types of vegetation communities: miombo woodland, North Zambezian undifferentiated woodland and acacia woodland; and two non-vegetated classes of bare soil, road and rock outcrops and is used as forest reserve (Fig. 6). The soils are very shallow rocky and stony (Frost, 1996). The vegetation communities on the escarpment form an ecological transition zone from Zambezian phytochoria to Somali masai centre of endemism in the central plateau of Tanzania and it has high specie richness. Miombo woodlands on the escarpment which are part of forest reserve form an edge ecosystem adjacent to village communities and is managed under Community Based Forest Management (CBFM) strategy (Topp-jørgensen *et al*., 2005; Nyamoga and Ngaga, 2016).

The miombo vegetation community on the escarpment is mainly dominated by the genera Brachystegia, including *Brachystegia microphylla* and *Brachystegia longifolia*. The North Zambezian undifferentiated woodland or sometimes referred to as undifferentiated woodland is the dominant vegetation community covering about 37.2% of the escarpment. Generally *Combretum spp* are dominant on the upper part of the escarpment while *Commiphora spp* dominate the lower part both occurring in association with a number of other species (Timberlake *et al*., 2010). The most frequent observed tree species in this community include *Combretum molle, Combretum zeyheri, Commiphora ugogensis, Commiphora africana, Pseudolachnostylis maprouneifolia, Burkea africana* and *Pseudolachnostylis maprouneifolia*. This vegetation community has highest species diversity (Fig. 6) (White, 1983; Kindt *et al*., 2011).

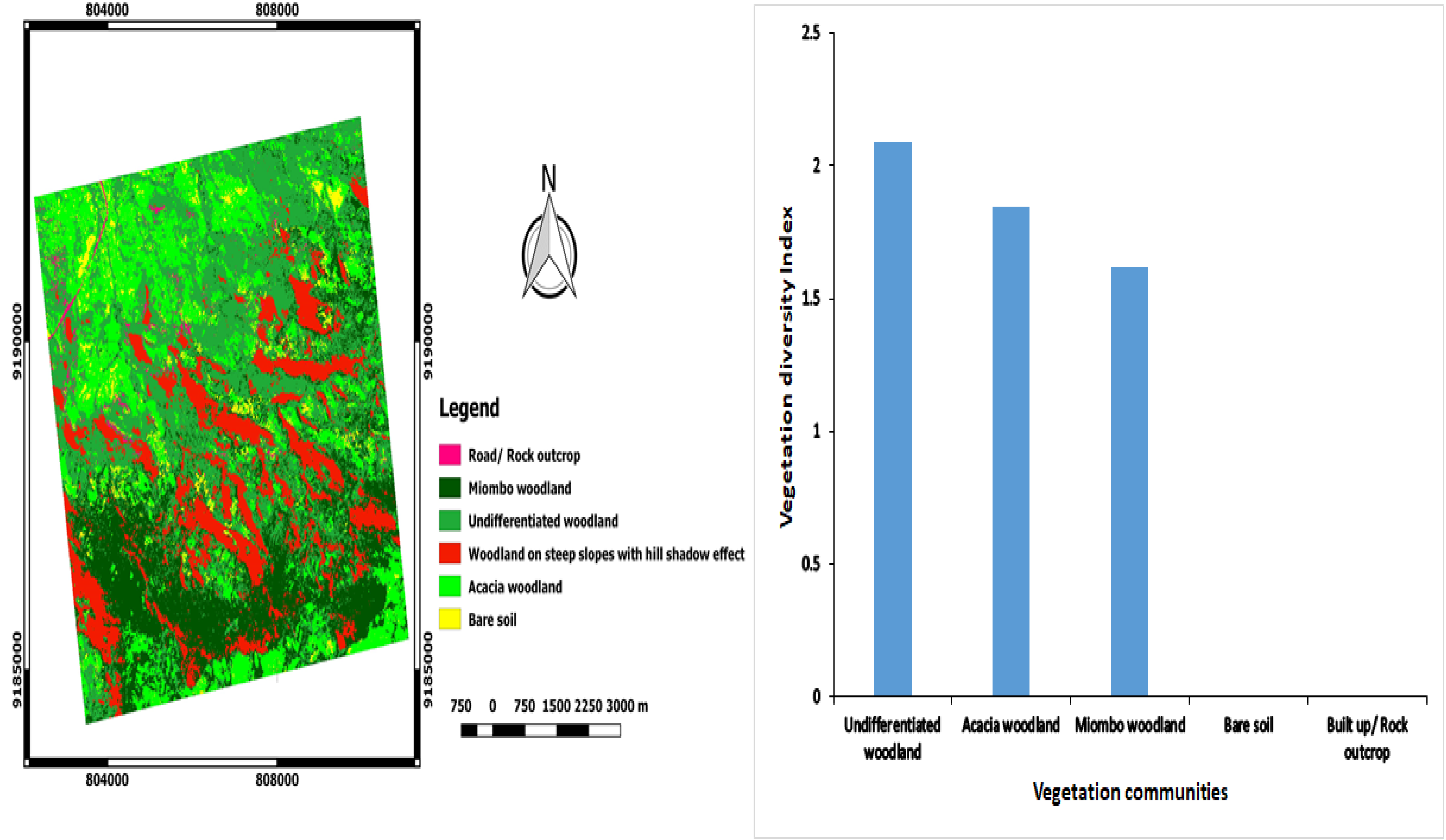


Figure 6: Vegetation communities and vegetation diversity index in the escarpment

4.1.1.3 Vegetation of the rift valley floor

The map of vegetation community on the rift valley floor is given in Fig. 7. Rift valley floor is part of the central rift valley system bounded by central plateau (Dodoma-Singida system) and the southern highlands. Dominantly grazing lands with scattered sorghum cultivation and settlements are common land cover types. Crop cultivation and livestock keeping - practices assume a semi nomadic type. Cultivation which includes rainfed and irrigated agriculture is dominantly practiced along Ruaha Mkuu River which is feeding to Mtera dam. The dominant vegetation types include acacia woodland with baobab (*Adansonia digitata*).

Three types of vegetation communities and one non vegetative class were identified on the rift valley floor (Fig. 7). The identified vegetation communities include Acacia woodland, North Zambezian undifferentiated woodland, Acacia wooded grassland and bare land. *Sigi* and *Hungo* are the common grass species found on these vegetation communities. Acacia woodland is the dominant vegetation community representing about 37% of the total area studied (Fig. 7). The rift valley floor is more or less similar to the escarpment landscape in terms of vegetation species diversity. Other species observed on this landscape include *Adansonia digitata* and *Cactus sp*. which appear more frequently than the other two landscapes. Small patches of undifferentiated woodland are common, dominated by *Commiphora* species over that of the *Combretum* species.

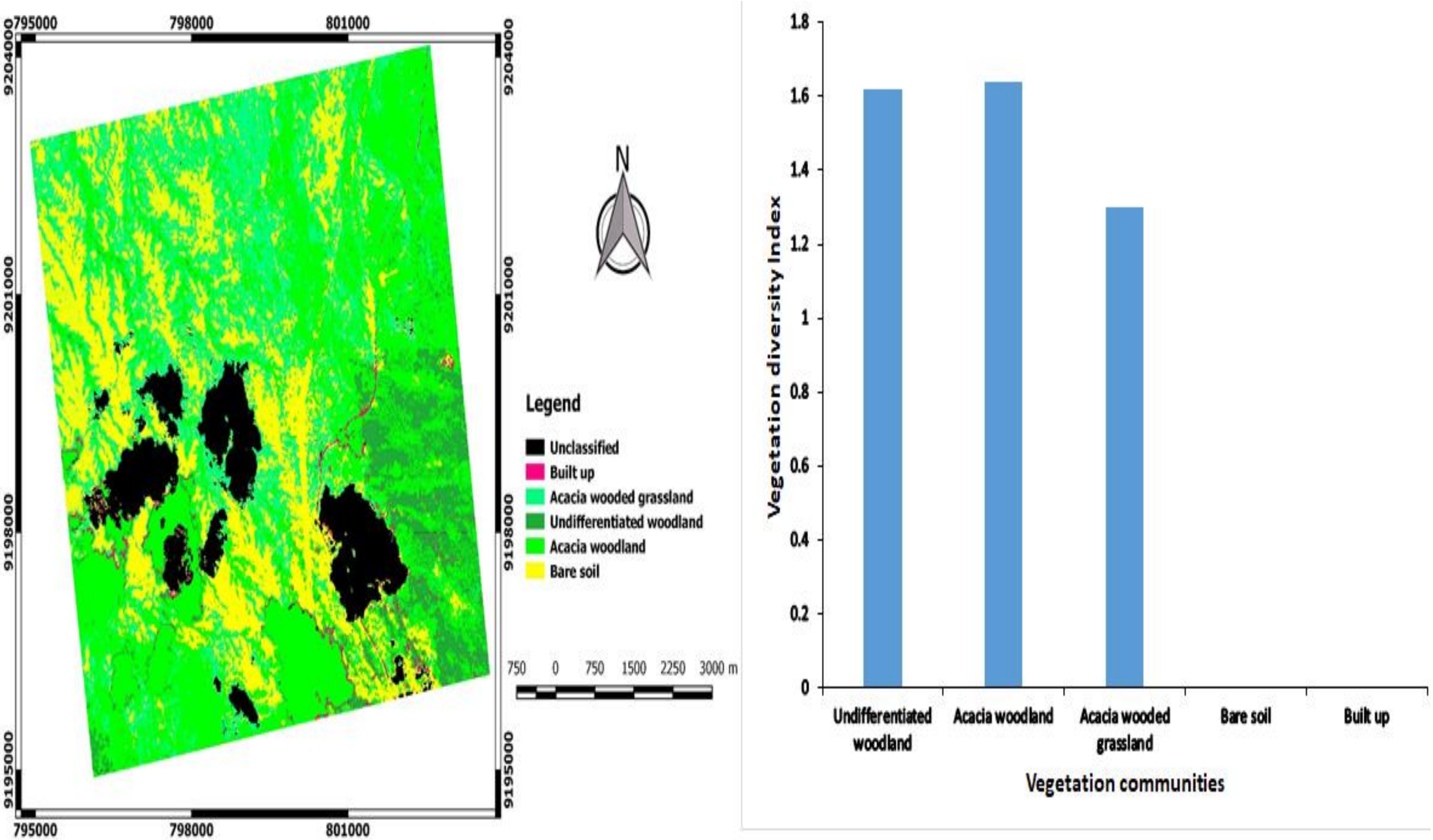


Figure 7: Vegetation communities and vegetation diversity index in the rift valley floor

Acacia wooded grassland is dominated by s*igi* grasses but with woody canopy cover ranging from 10 to 40%. In the dry season the lands remain bare (22.7%) due to intensive pastoralism (Su *et al*., 2015). Livestock grazing tend to have very selective influence on plant communities. Intensive grazing results in physiological damage to palatable species, causing them to lose competitive status and decline, a condition called retrogressive succession (Hall *et al*., 1995). Bond *et al*. (2001) went further and suggested that lower fire frequency and higher herbivore density could be responsible for the shift in community structure along the gradient space of the landscape.

4.1.2 Proportions of different vegetation communities across different landscapes

Vegetation communities in Isimani division has showed a remarkable variation in their vegetation structure, species composition and diversity along the landscape. The proportions of different vegetation communities across different landscapes in the study area are given in Fig. 8. The three studied landscape zones (plateau, escarpment and rift valley) occupy a total area of about 188 km^2 with each landscape zone occupying about 63 km^2. Cultivation is the major anthropogenic activity influencing the vegetation community dynamics in the plateau landscape. Cultivated fields, fallow and mixed cropping are important vegetation communities in the plateau area where rodent pest outbreaks have been reported.

In terms of coverage, these vegetation communities cover about 60 % of the plateau area, while in the escarpment and the rift valley floor they are not significant and could not be mapped (Fig. 8). Maize and sunflower fields were represented as cultivated fields and constitute about 31% of the area studied i.e. 20 km^2; grassland and mixed cropping were represented as fallow covering about 30% of the plateau area which is equivalent to about 19 km^2. Undifferentiated woodland is the dominant vegetation community in the escarpment area covering 35% of the landscape while Acacia woodland dominate the rift valley floor by 40% of this landscape.

Vegetation cover and landform patterns can have significant influence on the abundance of small mammals in the landscape (Hieronimo *et al*., 2014). For example, in the Usambara Mountains Tanzania, Hieronimo *et al*. (2014) and Ralaizafisoloarivony *et al*. (2014) observed that there was a significant variation ($P<0.05$) in small mammal abundance among different vegetation cover types across different landscapes. Vegetation types and their associated characteristics are important indicators of the composition and abundance of small mammals (Mulungu *et al*., 2008). Any change in vegetation communities by for example anthropogenic activities including clearing, bush fires, cultivation and cropping could induce changes in the abundance of small mammals across the landscape.

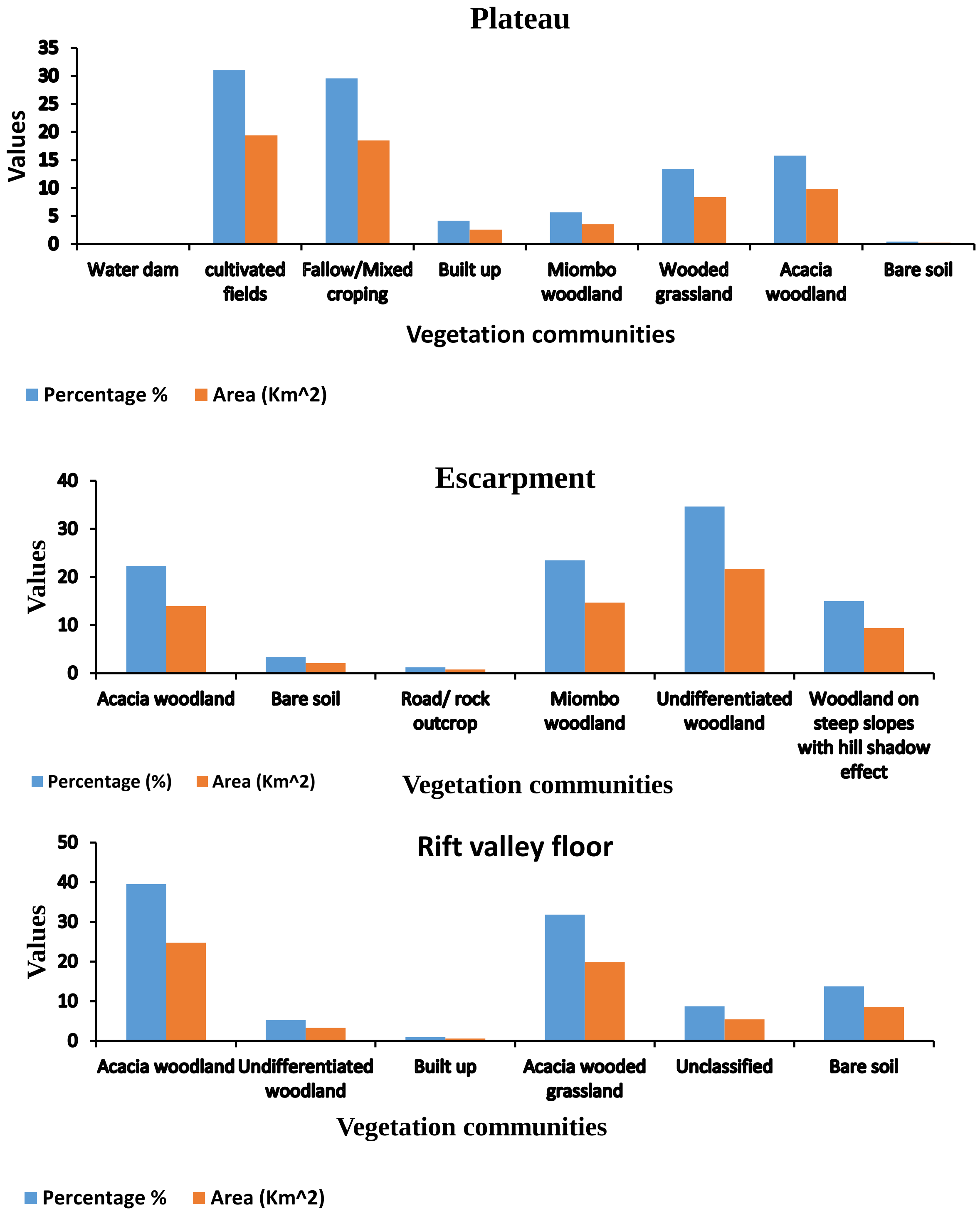


Figure 8: **Proportions of different vegetation communities across different landscapes in the study area**

4.2 Abundance and Diversity of Small Mammals in Different Vegetation Community across Landscape Units

4.2.1 Influence of vegetation communities and their associated characteristics on small mammal abundance

Results of this study show that vegetation communities have varying influence on small mammal abundance across the studied agroecosystem landscapes. The abundance and dominant species of small mammals trapped in different vegetation communities are presented in Tables 2 and 3. A total number of 493 animals were trapped in the plateau and seven in the escarpment and rift valley floor respectively (Table 2). A total of 393 animals which account for about 80 % of all animals trapped in the plateau landscape were captured in the cultivated fields and mixed cropping systems including fallow areas. The results reveal further that acacia woodland and undifferentiated woodland in the escarpment and acacia wooded grassland of the rift valley floor had the lowest abundance of small mammals. Low abundance of small mammals in the vegetation community of the rift valley floor could be due to frequent grazing associated with small mammal habitat disturbance (MacCracken *et al.*, 1984; Masters *et al.*, 2003).

Some vegetation communities have higher influence than others within and across the studied landscapes (Fig. 9). Maize fields, fallow with mixed maize and sunflower cropping fields and wooded grassland have registered higher number of small mammal abundance in the plateau landscape (Fig. 9).

As for the escarpment, acacia woodlands were dominated by relatively higher number of small mammals when compared with undifferentiated woodlands. Undifferentiated woodlands had relatively higher number of small mammals in the rift valley floor landscape than acacia woodland and acacia wooded grassland.

The results of this study have demonstrated that within the studied vegetation communities, the highest small mammal abundance was recorded in the high altitudes >1300 m in the plateau landscape. This landscape had also higher trap success (6 – 11) as shown in Table 3. For this landscape, the highest trap success was also within the same high altitude range. In the other vegetation communities in the escarpment and rift valley floor with lower altitude (<1000 m), there were no mammals trapped. Findings from this study also indicate that *Mastomys natalensis* and *Tatera girbillus* formed the majority of the small mammals in the cultivated fields and fallow/mixed cropping fields in the plateau landscape i.e forming 74.9% of all small mammals traped.

Table 2: Number of dominant small mammal species in different vegetation communities

Landscape	Vegetation Community	MN (%)	AC (%)	EL (%)	AN (%)	LZ (%)	T-GB (%)	GR (%)	CH (%)
Plateau	Acacia woodland	-	-	-	-	-	-	-	-
	Bare soil/land	-	-	-	-	-	-	-	-
	Built up areas	-	-	-	-	-	-	-	-
	Cultivated fields	119(23.46%)	1(0.2%)	-	-	-	7(1.38%)	-	4(0.79%)
	Fallow/mixed cropping fields	239(47.14%)	7(1.38%)	-	-	1(0.2%)	15(2.96%)	-	5(0.99%)
	Miombo woodland	-	-	-	-	-	-	-	-
	Wooded grassland	81(15.97%)	5(0.99%)	-	1(0.2%)	1(0.2%)	3(0.59%)	-	4(0.79%)
	Water bodies	-	-	-	-	-	-	-	-
Escarpment	Acacia woodland	-	-	-	-	-	2(0.4%)	-	-
	Bare soil/land	-	-	-	-	-	-	-	-
	Road/ rock outcrops	-	-	-	-	-	-	-	-
	Miombo woodland	-	-	-	-	-	-	-	-
	Undifferentiated woodland	-	5(0.99%)	-	-	-	-	-	-
Rift valley floor	Acacia wooded grassland	-	1(0.2%)	-	-	-	-	-	-
	Acacia woodland	-	1(0.2%)		1(0.2%)	-	-	-	-
	Bare soil/land	-	-	-	-	-	-	-	-
	Built up areas	-	-	-	-	-	-	-	-
	Undifferentiated woodland	-	2(0.4%)	-	2(0.4%)	-	-	-	-

Key: MN= Mastomys natalensis, AC= Acomys, EL= Elephant shrew, AN= Arvicanthys, LZ= Lemniscomys zebra, T-GB= Tatera gerbillus, GR= Graphiurus and CH= Crocidura

Table 3: Abundance and dominant small mammal species in different vegetation communities

Landscape	Vegetation Community	Small mammal species trapped	TNR	RP (%)	MTs	MDI
Plateau	Acacia woodland	-	-	-	-	-
	Bare soil/land	-	-	-	-	-
	Built up areas	-	-	-	-	-
	Cultivated fields	MN, T-GB, CH, AC	131	26	6.15	0.52
	Fallow/mixed cropping fields	MN, T-GB, LZ, CH, AC,	267	54	10.11	0.51
	Wooded grassland	MN, T-GB, CH, LZ, GR, LZ, AC	95	19	11.06	1.11
	Miombo woodland	-	-	-	-	-
	Water bodies	-	-	-	-	-
Escarpment	Acacia woodland	T-GB	2	0.4	1	0
	Bare soil/land	-	-	-	-	-
	Road/ rock outcrops	-	-	-	-	-
	Miombo woodland	-	-	-	-	-
	Undifferentiated woodland	AC	5	1	0.42	0
Rift valley floor	Acacia wooded grassland	AC	1	0.2	-	0
	Acacia woodland	AC, AN	2	0.4	1	0.16
	Bare soil/land	-	-	-	-	-
	Built up areas	-	-	-	-	-
	Undifferentiated woodland	AN, AC	4	0.8	1.5	0.20

TNR = Total number of small mammals trapped, RP = Proportion of small mammals per vegetation community, and MTs = Mean trap success, MDI = Mean Small mammals diversity index, MN= Mastomys natalensis, AC= Acomys, EL= Elephant shrew, AN= Arvicanthys, LZ= Lemniscomys zebra, T-GB= Tatera gerbillus, GR= Graphiurus and CH= Crocidur

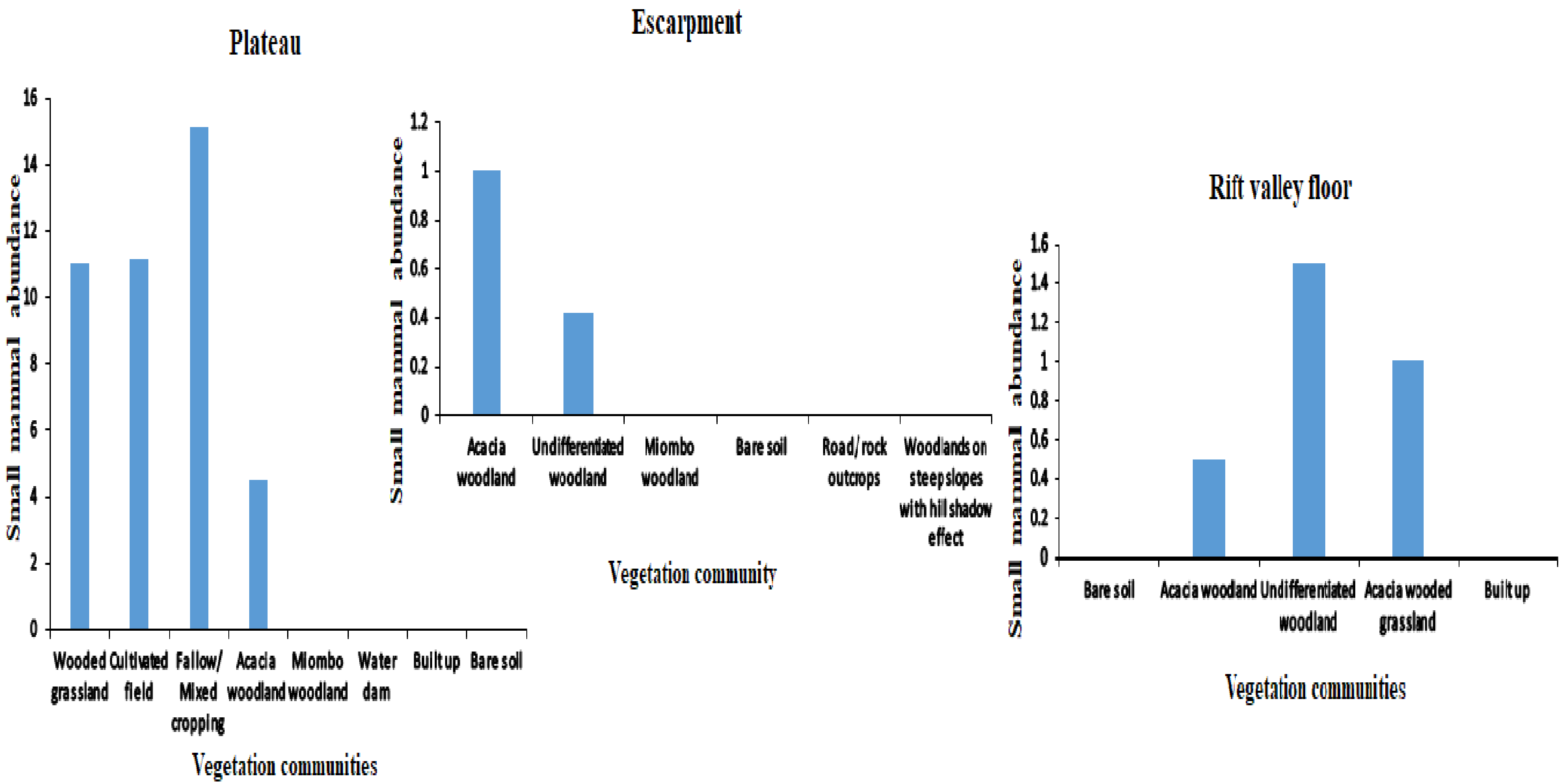


Figure 9: Small mammal abundance in different vegetation communities

Key: Plateau (Elevationn = 1295 – 1590 m asl, landform = Undulating hills - convex low ridge summits alternating with linear slopes grading to concave bottomlands); Escarpment (Elevation = 926 - 1295 m asl, landform = A long, steep slope at the edge of the plateau descending to the rift valley floor of the central rift valley system in Tanzania); Rift valley floor (Elevation = 700 – 925 m asl, landform = part of the central rift valley system bounded by central plateau (Dodoma-Singida system) and the southern highlands)

A previous study by Ralaizafisoloarivony *et al*. (2014) reported that in West Usambara Mountains, Tanzania annual cultivated crops habitat accounted for 80% of *Mastomys natalensis* and were localised in the high altitudes >1,900 m. Hieronimo *et al*. (2014) asserted that localisation of small mammals in specific ecological setting across the landscape is influenced by availability of food, water, rainfall and shelter and these are important factors for the variation on the abundance of small mammals observed in the study area. The findings of this study are also consistent with earlier studies by Mwanjabe (1993), Makundi *et al*. (2007) and Mulungu *et al*. (2011). It is therefore demonstrated that the cultivated fields dominantly cropped with maize and sunflower and also associated with grass fallow in the plateau landscape were the preferred localized habitats for the small mammals than the vegetation communities located in the escarpment and rift valley floor landscapes.

4.2.2 Influence of vegetation communities and their associated characteristics on small mammal diversity

Small mammal diversity has been influenced by vegetation communities differently across the landscape. The results of small mammal diversity index in different vegetation communities are presented in Figure 10 and also in Table 3. The findings show that cultivated and fallow/mixed cropping fields contained the highest species diversity (>0.50) and richness. Five species were found both in cultivated and fallow/mixed cropping fields including *Mastomys natalensis*, *Acomys*, *Lemniscomys zebra*, *Tatera gerbillus*, and *T. rocidura* in which *Mastomys natalensis* constituted about 60% of all the species trapped. Ralaizafisoloarivony *et al*. (2014) demonstrated that annual cultivated crops accounted for 80% of *Mastomys natalensis* while natural forest accounted for 60% of *Praomys delectorum*. Previous studies have shown that due to competition between species, some less competitive rodents are confined to meager habitats such as natural forest while other species such as *M. natalensis* present prolific and opportunistic behaviors which enable them to take advantage of changes in habitats, particularly in relation to food resources (Massawe *et al.,* 2005). Major rodent pest involved in many outbreak areasin Tanzania is *Mastomys spp.* or *shamba* rat due to its ability to reproduce big litter size (Suleiman and Rosentrater, 2015). *Mastomys natalensis* is the most dominant and destructive species in maize cropping systems. Therefore, these findings will significantly contribute knowledge towards the current intervention on ecologically based rodent management (EBRM) strategies.

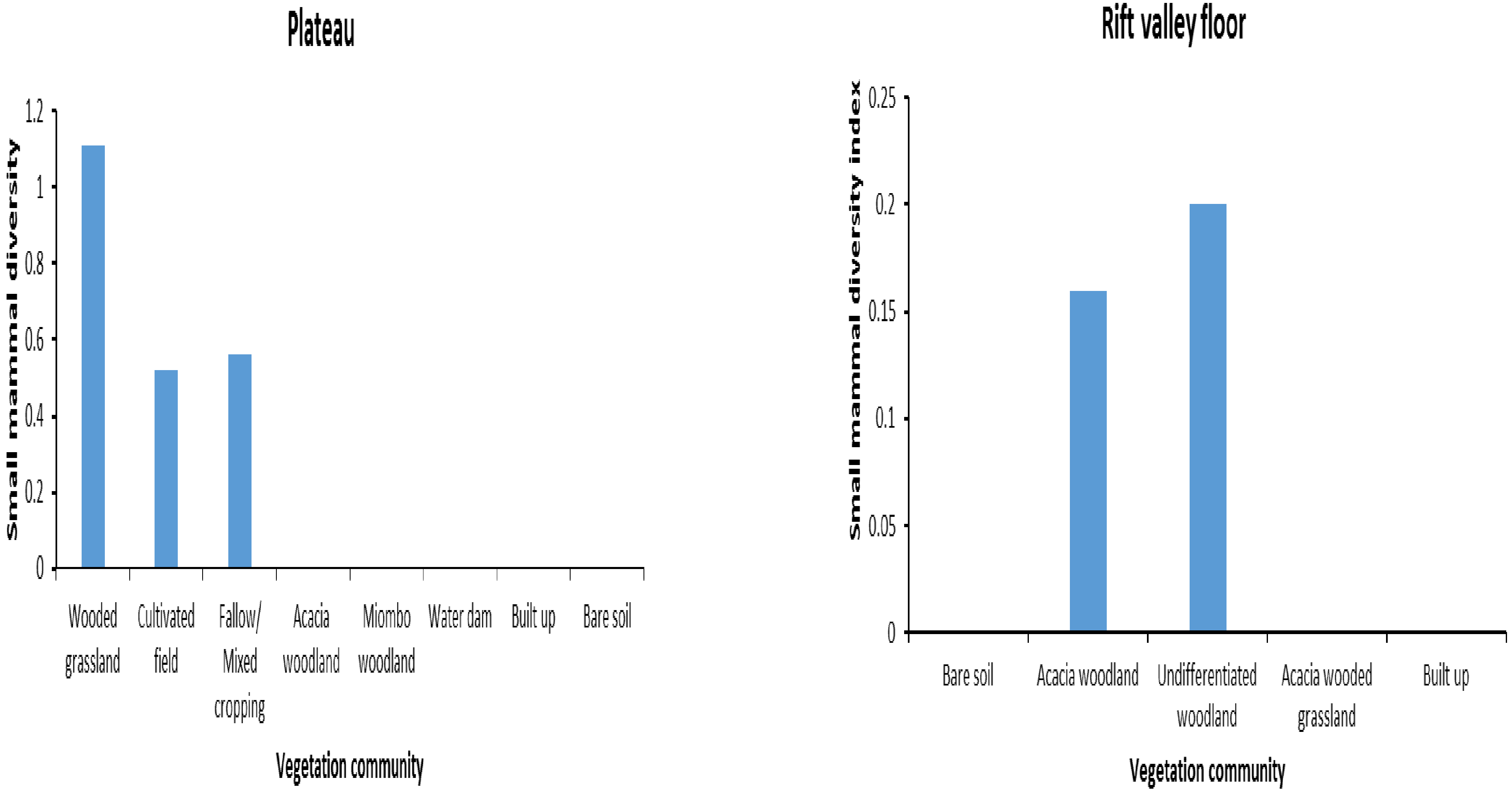


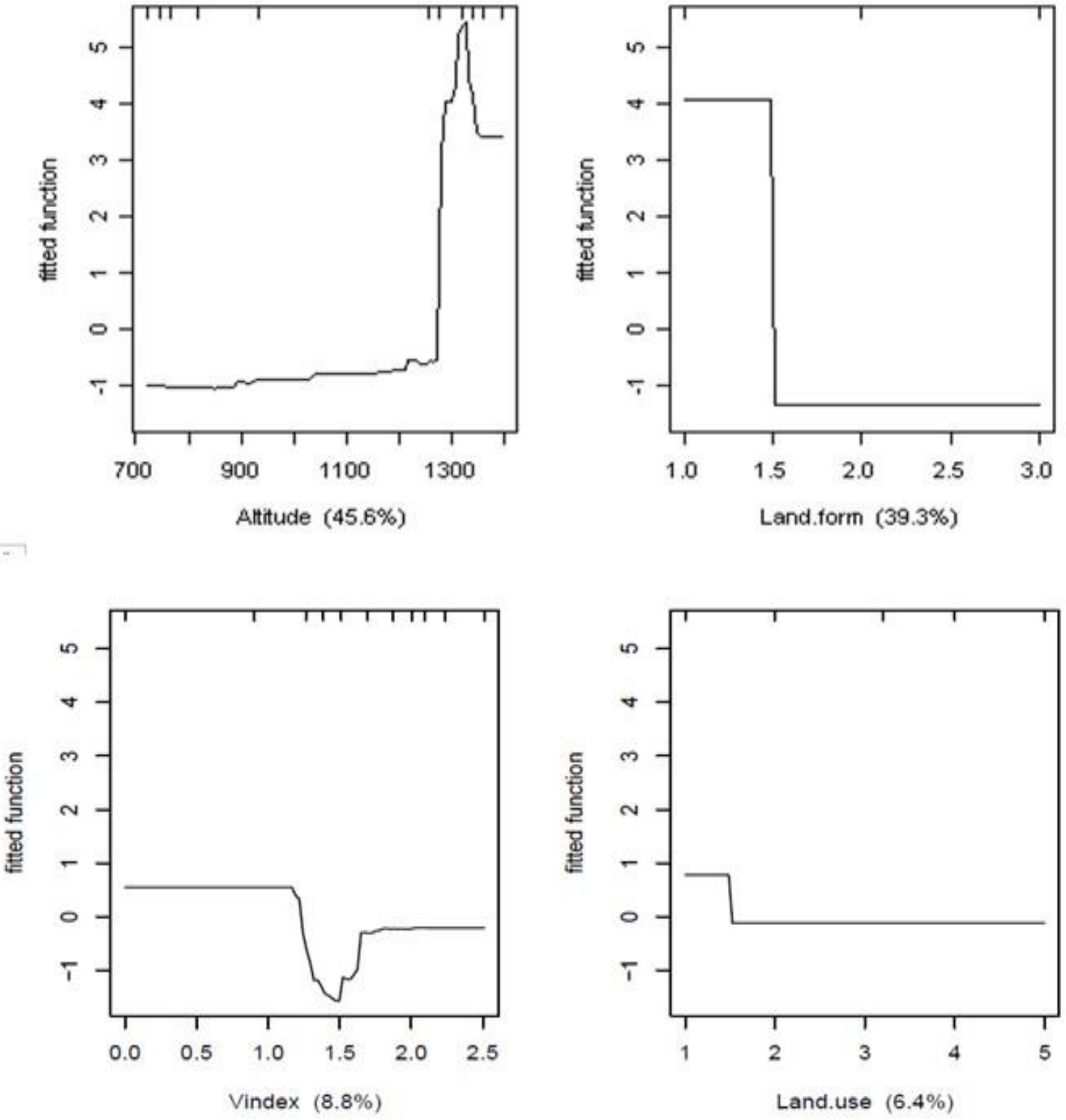
Figure 10: Small mammal diversity index in different vegetation communities across land scape units

4.3 Spatial Relationships between Vegetation Communities and Small Mammal Abundance

4.3.1 Influence of vegetation community variables on small mammal abundance (trap success) as demonstrated by BRT model

Four vegetation community predictor variables were identified by the BRT model as having influence on small mammal abundance (trap success) (Fig. 11). All four predictor variables had the ecologically acceptable level of individual variance inflation factor i.e. VIF<5. Altitude was the most important predictor with contribution of (45.6%) with a strong positive effect. Small mammal abundance was low at lower altitudes. Similar results were reported by Hieronimo *et al*. (2014) on in the Western Usambara Mountains, Tanzania that elevation positively influenced the abundance of small mammals. The authors further suggested that this could be attributed by favourable microclimate which has lead to the increased resource availability (water and food) as one moves from low to high altitude in the studied landscapes.

The second most important predictor was landform with contribution of about a third of the total influence (39.3%) and a strong negative effect (Fig 11). The plateau (coded 1) seem to have highest abundance of small mammals, however the abundance experiences a sharp decrease as it reaches the escarpment (coded 2) and rift valley floor (coded 3). This is in agreement with the study by Ralaizafisoloarivony *et al*. (2014) in the Usambara Mountains, Tanzania who observed that a large number of small mammals were captured in the plateau landscape with higher elevation compared with other landscapes at lower elevations. Hieronimo *et al*. (2014) suggested that, this could be attributed to the presence of food and water on the plateau landscape making it a conducive habitat for small mammals.



The relative contribution of each predictor is given in brackets. CV deviance = 42.638, standard error = 9.131, number of trees =2550. Key: Altitude = Altitude, Land.form = Landform, Vindex = Vegetation diversity index (Shannon index), Land.use = Land use, cv = cross validation

Figure 11: Partial dependence plots showing the four most influential vegetation community variables influencing small mammal abundance (trap success)

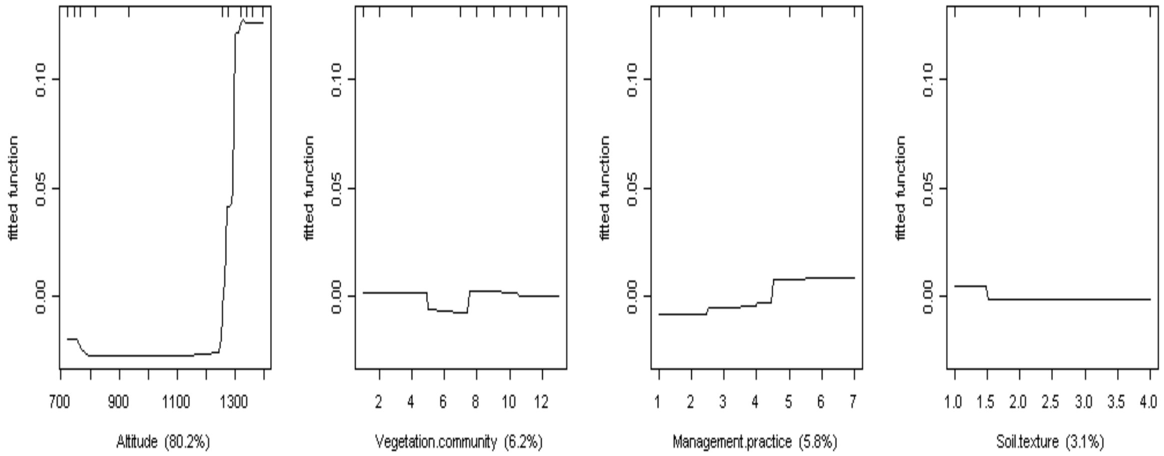
On the other hand, the low number of small mammals on the escarpment could be attributed to the vegetation structure which has woody species covering more than 60% and grasses less than 40% (Kindt *et al*., 2011) making it not favourable for harbouring small mammals. However on the rift valley floor the low number of small mammals could be explained by the nature of land use which include extensive livestock grazing leading to decrease in herbaceous vegetation particularly grasses making it an unfavourable habitat for small mammals (Hoffmann and Zeller, 2005; Bock *et al*., 2011).

Vegetation diversity and land use had weak negative effect with small contribution of 8.8% and 6.4% respectively (Fig 11). Small mammal abundance was observed to be a bit high at lower vegetation diversity indices before sharply falling at 1.5 and slightly increasing again. This phenomenon could be explained by the fact that vegetation communities like grassland, maize field, sunflower field and acacia wooded grassland of the plateau provide conducive habitat for small mammals (Adam *et al*., 2015). Land use (Coded 1) showed a slight negative effect as land use varied from that dominated by cultivation of annual crops (coded 1) to the rest of the land use types (coded from 2 to 5 (forest reserve, High Tension Power Transmission Line Reserve-HTPLR, range land and human settlements). These results are in agreement with previous studies which reported that land use patterns influence small mammal dynamics (Masters *et al*., 2003; Fischer *et al*., 2012).

4.3.2 Influence of vegetation communities and their associated characteristics on small mammal diversity as demonstrated by BRT model

Four vegetation community predictor variables having influence on small mammal diversity (Fig. 12) were selected by the BRT model. All four predictor variables had the ecologically acceptable level of individual variance inflation factor i.e. VIF<5. Altitude was the most important predictor with contribution of more than three quarters of the total influence (80.2%) and a strong positive effect. The altitude of 1300 m seems to be the threshold for sharp increase in small mammal diversity. Similar findings were reported by Mulungu *et al.* (2008) that small mammal species diversity varies with altitude. Variability in the spectrum of small mammals in the high altitudes could be attributed to the degree of fragmentation of the habitats and the vegetation structure associated with cultivation of annual crops and fallow periods which are favourable habitats for small mammals (Ralaizafisoloarivony *et al*., 2014).

The second most important predictor was vegetation community (coded 1, 2, 3, and 4) with contribution of (6.2%) and a weak negative effect on small mammal diversity. The vegetation communities coded 1, 2, 3 and 4 comprised the miombo wooded grassland, acacia woodland of the escarpment, acacia woodland of rift valley floor and acacia wooded grassland of the plateau.



The relative contribution of each predictor is given in brackets. CV deviance = 0.084, standard error = 0.015, number of trees = 1600. Key: Altitude = Altitude, Land. Form = Land form, Vegetation. Community = Vegetation community, Management. Practice = Management practice, Soil. Texture = Soil texture, cv = cross validation.

Figure 12: Partial dependence plots showing the four most influential vegetation community variables influencing small mammal diversity

Management practices showed a weak positive influence while soil texture indicated a weak negative influence with a contribution of 5.8% and 3.1% respectively. According to Mulungu *et al*. (2011), *Mastomys natalensi*s is the most abundant species in farms cultivated with annual crops. Other species which were found in fields cultivated with annual crops but in small numbers are *Tatera gerbillus* and *T. crocidura*. Diversity in semi natural vegetation communities resulting from fallow and agriculture fragmentation i.e. acacia wooded grassland of plateau, miombo wooded grassland and grassland had the highest mean small mammal diversity index of 0.72, 0.39 and 0.37 respectively with all seven small mammal species being found in the acacia wooded grassland of the plateau. Similarly, Panzacchi *et al*. (2010) reported highest abundance and diversity of small mammals was recorded in abandoned meadows in boreal forests of south-eastern Norway. Small mammal diversity was very low in the vegetation communities of the rift valley floor attributed to the nature of the land use system which is comprised of extensive grazing that do not favour conducive habitat for small mammals (Yarnell *et al*., 2007).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

Identification and mapping of different vegetation communities across agroecosystem is very crucial for understanding their influence on small mammals. Fourteen vegetation communities and three non-vegetative class were identified and classified based on their structural and floristic composition in the three landscape zones. On the other hand these vegetation communities are home for a number of small mammals, which together form a huge ecosystem.

Small mammals were found all over the landscapes but at a varying amounts. Small mammal abundance and diversity were high in agricultural fields and semi natural vegetation communities, mostly resulting from fallow practices than the natural vegetation communities. The high abundance in agricultural fields might be contributed by the generalist species *Mastomys natalensis* which has mastered this ecosystem, while the diversity was highly contributed by the heterogeneity (i.e. in both composition and structure) of the vegetation with high percentage cover of herbaceous plants.

Abundance and diversity of small mammals varied among vegetation communities in response to variation in floristic composition and level of human disturbance. Thus any change in plant community implies changes to these fauna spatial distribution. In this study, results show that both small mammal abundance and diversity are influenced by vegetation communities. Other important vegetation community variables such as altitude, land use, management practice, soil texture, landform and vegetation diversity index were found to have influence on either small mammal abundance, diversity or both.

It can therefore be concluded that, vegetation communities are potential in studying vegetation - small mammals interactions in agroecological landscape as they have shown remarkable influence on abundance and diversity of the latter. Small mammals have shown to prefer vegetation communities found in high altitudes with semi natural vegetation communities such as grassland and wooded grassland found to harbour large numbers and diverse species especially during the dry season.

5.2 Recommendations

i. Further studies need to be carried out in other mountainous areas with intensive field work and many more sample plots and in a wider range in order to have a better understanding of distribution of vegetation communities and plant species along the tropical mountainous areas.

ii. In this study satellite image with resolution of 10 m was used. More studies that will use other remote sensing products with higher spatial resolution and using different algorithms in order to be able to use remote sensing techniques to study the tropical mountainous vegetation, which have proven to be very diverse and complex in nature are required.

iii. Soil was less studied during this study. So it is recommended that future studies of this nature to incorporate Soil knowledge so as to shed more light to these complex ecosystems.

iv. This study did not take seasonality into consideration. So future studies need to highlight on how vegetation communities affect small mammal dynamics seasonally.

v. This study tried to investigate small mammals on mountainous semiarid vegetation communities. Future studies can try to investigate this phenomenon in agroecological landscapes found in other climatic zones.

vi. Lastly, since small mammals seem to prefer herbaceous vegetation particularly grasses, so EBRM in mountainous agroecological landscapes need to take measures that will always reduce herbaceous vegetation from fallowed area and encouraging woody vegetation which will supress grasses in vegetation bordering farms. Also, abandoning fallow practices by integrating livestock in the farming system could provide multiple benefits in these agroecological landscapes. Example, livestock will get fodder from agricultural fields while farmers will get organic manure to improve fertility of their farms. By doing so, fallow periods will not be required, yet crop production will increase and there will be no rodent habitats during dry season and hence during farming season rodent populations will be low and tolerable.

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APPENDICES

Appendix 1: List of tree species with their scientific names

No	Local name	Scientific name
1	Eucalyptus	*Eucalyptus sp.*
2	Leuceana	*Leucaena leucocephala*
3	Mbadilo	*Combretum molle*
4	Mbata	*Acacia gerrardii*
5	Mbuyu	*Adansonia digitate*
6	Mdawi	*Cordia sinensis*
7	Mduguya	*Balanites aegyptiaca*
8	Mfudu	*Vitex iringensis*
9	Mgegele	*Dichrostachys cinerea*
10	Mgulumo	*Lannea humilis*
11	Mjohoro	*Senna siamea*
12	Mkalala	*Albizia petersiana*
13	Mkalati	*Burkea Africana*
14	Mkambala	*Acacia nigrescens*
15	Mkole	*Grewia sp.*
16	Mkongolo	*Commiphora ugogensis*
17	Mkula	*Pterocarpus holtzii/ pterocarpus tinctorius*
18	Mkungugu	*Acacia tortilis*
19	Mkwata	*Cordyla densiflora*
20	Mkwe/ myombo	*Brachystegia longifolia*
21	Mlama mweupe	*Combretum zeyheri*
22	Mlama mweusi	*Combretum molle*
23	Mlimbo	*Euphorbia matabelensis*
24	Mnyaluhanga	*Crotalaria agatiflora/ pseudolachnostylis maprouneifolia*
25	Mpalala	*Macaranga kilimandscharica*
26	Mpalapande	*Strychnos potatorum*
27	Mpapala	*Maytenus undata*
28	Mpingo	*Dalbergia melanoxylon*
29	Mpululu	*Terminalia kilimandscharica*

30	Msada	*Rytigynia sp./ Vangueria infausta/ Vangueria madagascariensis*
31	Msanzauki	*Leonotis sp.*
32	Msasa	*Acacia mellifera*
33	Msisina	*Albizia harveyi*
34	Mtalawanda	*Markhamia puberula/ Markhamia platycalyx*
35	Mtama	*Afzelia quanzensis*
36	Mtangadasi	*Strychnos spinose*
37	Mtangadasi	*Strychnos spinose*
38	Mtela	*Rauvolfia caffra*
39	Mtelela	*Brachystegia microphylla*
40	Mtono	*Commiphora africana/ Commiphora mossambicensis*
41	Mtowo	*Azanza garckeana*
42	Mtumbatumba	*Ximenia Americana*
43	Mtundwa	*Ximenia Americana*
44	Muhwisa	*Boscia mossambicensis/ maerua parvifolia*
45	Mulyasenga	*Combretum zeyheri*
46	Muvanga	*Zanha Africana*
47	Mvambadutsi	*Maytenus sp.*
48	Mzinga	*Cordia africana/ commiphora africana*
49	Tumbulafigi	*Tinnea aethiopica*

Appendix 2: List of tree species with local names whose scientific names were not identified during the study

No	Species	No	Species
1	Madunyanga	18	Mnala
2	Mboliboli	19	Mngaaangana
3	Mbwangubwangu	20	Mnyali
4	Mbwegule	21	Mpambadua
5	Mdaganyigu	22	Mraka
6	Mdwendwe	23	Msangala
7	Mfleti	24	Mselia
8	Mfugala	25	Mtabagla
9	Mgiha	26	Mtafuta
10	Mgodule	27	Mtimbwi
11	Mgombala	28	Mtoho
12	Mgundi	29	Mtulisege
13	Mhavava	30	Mtulo
14	Mkobula	31	Mtumbata
15	Mlanamwasi	32	Mugosa
16	Mlutse	33	Muhanza
17	Mmulimuli	34	Muhondo

Appendix 3: List of herbaceous plants in vernacular language

Harbaceous plants	
Forbs	**Grass**
Mbadikila	Lipelele
Vanivani	Kidilu
Sanzauki	Sigi
Madukani	Likuvi
Chunga	Hungo/Mahungo
Ndula	Tuukula
Mlenda	Mabalule
Vinguzuguni	Bungwilu
Shona Nguo	Masowasi
Dumba	Ndenyanga
Nyalusako	