COMMUNITY ECOLOGY OF SMALL MAMMALS IN THE SELOUS ECOSYSTEM, TANZANIA

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A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

2022

EXTENDED ABSTRACT

Historically, the protected areas in East Africa and possibly the rest of Africa were for conservation of large mammals. This inheritance approach has led to inadequate attention to other components of the ecosystems including small mammals which play a fundamental role in maintaining ecosystem health. This has resulted in inadequate information on their population dynamics in the tropics and miombo areas. Considering the current anthropogenic development trajectories, various studies have highlighted that, small mammals and other wildlife species are faced with a number of threats which include those related to management practices, economic development, and climate change. For example, as part of a wildlife habitat management tool, prescribed burning is practiced as a natural ecological phenomenon in miombo woodland that highly influences vegetation structure and composition with the aim of providing nourishing pasture. This practice has been reported to affect small mammal distribution and abundance. On the other hand, various studies have reported that climate change is posing an ever-increasing threat to wildlife management around the world making it a primary concern and driver of change. Climate change is also linked with increased zoonotic prevalence, especially with increased contact between humans and small mammals such as plague, hantaviruses pulmonary syndrome, and leptospirosis. Therefore, the current study aimed at investigating the community ecology of small mammals in the Selous ecosystem, Tanzania, as a basis for effective and holistic ecosystem management.

The studies to assess the community ecology of small mammals in the Selous ecosystem, Tanzania, were carried out for two consecutive years from July 2018 to June 2020. The ecosystem constitutes a globally important example of vegetation types that is between

Somali-Masai and Zambezian regional centers of endemism. The area possesses diverse flora with an estimated total of over 2 000 species with an exceptionally high variety of habitats that are ideal for small mammals.

Specifically, the studies were conducted in the northern part of the Selous ecosystem which covers parts of Nyerere National Park (NNP) and Selous Game Reserve (SGR). The study aimed at addressing four key specific objectives; (i) establishing the diversity and distribution of small mammals (ii) determining the effects of prescribed burning on rodents' ecology (iii) estimating the relative home ranges and species – habitat association of small mammal species and, (iv) assessing the current and potential future distribution of small mammals in the Selous ecosystem. To address the specific objectives, various approaches were used; (i) for abundance, diversity, distribution, and home ranges estimations, four main habitats namely closed woodland, forest, seasonal riverine forest, and perennial riverine forest/thicket were selected; (ii) For effects of prescribed burning on rodents' ecology, prescribed burning was set twice during this study, on August of 2018 and 2019 and two grids in each area (burnt and unburnt) were used. Information of interest from this study include abundance, richness, diversity, age structure, sex ratio, breeding patterns, recruitment, and survival proportions; (iii) For current and potential future distribution of small mammals in the ecosystem, a total of 143 sites across nine selected habitats were used in different areas of the Selous ecosystem. In all approaches, Capture Mark Recapture (CMR) using medium-sized (LFA, 7.5 x 9 x 23 cm) Sherman's traps (H.B. Sherman Inc.) and random placement of Havahart traps (60 x 15 x 170 cm) were used. Trapping for estimating the current and potential future distribution of small mammals, two trapping nights were used from December 2018 to November 2019. In

each selected site, a grid of 70 m x 70 m was established with seven parallel lines at 10 m intervals from each line and between traps, and in total, each grid had 49 stations.

Species abundance was estimated using Minimum Number Alive (MNA) for the most captured species from the CMR data history. Shapiro_test function was used to test for normality of data in R software version 3.4. Kruskal Wallis, Wilcoxon, and Friedman's Chi-square tests were used to detect variation between and within habitats and seasons. Also, a non-normal generalized linear model with Poisson error distribution was performed by utilizing the “glm” function with link = log argument to compare mean differences of abundance between areas across seasons. In addition, robust regression by utilizing “rlm” function from MASS and “sfsmisc” packages in R software version 3.4 was used to assess the trend of abundance on monthly basis. To establish the small mammal species – habitat associations, a principle component was used. Ordination technique - Non-metrics Multi-dimensional Scaling (NMDS) using the Sorensen distance measure in vegan package using metaMDS function in R version 3.4.

Age groups were compared using Wilcoxon.test for *M. natalensis* between burnt and unburnt areas. A generalized linear model with non-normal Poisson error distribution was used to compare mean differences between age groups between burnt and unburnt areas. Recruitment and apparent survival were computed from the CMR data history. On all occasions, the assumption was that there was an ability to detect a new and old individual through the marks applied. A generalized linear model (GLM) with logistic regression was used to compare recruitment and survival proportions data by using a built-in function called “family = binomial” in R software version 3.4 to explore the relationship between burnt and unburnt areas. For monthly trend variations, a robust regression model using

"rlm" function from MASS and "sfsmisc" packages was used to assess monthly trends of capture proportions for recruitment and survival. Sex ratio and breeding patterns were compared using Wilcox.test between areas. A generalized linear model with binomial error distribution was used to assess the trends whereby proportions were treated as the response variables, while season and areas (burnt and unburnt) were used as explanatory variables.

Relative home ranges were estimated from small mammals' relocation points from CMR history data. Relative home ranges were estimated using a Minimum Convex Polygon (MCP) using "adehabitatHR" package in R software version 3.4 using "mcp.area" function at 100% of all points. Home range overlaps were estimated using the "adehabitatHR" package by utilizing the "Kernel_overlap" function. Kruskal Wallis.test, one and two-way ANOVA were used to detect variation in home range across sex, habitat, and season.

To assess the current and future distribution of small mammals in the Selous ecosystem, species occurrence (presence data) data and habitat parameters including elevation and location points were recorded from the field to enable mapping of current and projected suitable habitats. Additional data were obtained from the WorldClim dataset for bioclimatic data downloaded in raster (ASCII) format. Additional topographical data were obtained from Digital Elevation Models (DEM). Maxent algorithms were used to estimate the current and future distribution of small mammals in the Selous ecosystem. Models performance was evaluated using Area Under the Receiver Operating Characteristics Curve (AUC). QGIS v.3.10 was used to generate the distribution maps. The suitable habitat categories ranged between 0 and 1, with five classes values; <0.1 unsuitable habitat, 0.1 – 0.2 least suitable, 0.2 – 04 moderately suitable, 0.4 – 0.6 suitable habitat and > 0.6 highly suitable habitat.

The results of this study showed that, abundance of *Acomys ngurui* was statistically significantly different between the four main habitats (χ^2 = 12, df = 3, p = 0.007) and across seasons (χ^2 = 6, df = 2, p = 0.049). Overall, forest habitat recorded the highest species diversity (*H*' = 2.065) and the lowest (*H*' = 1.506) diversity was recorded in perennial riverine forest/thicket. Dry seasons recorded the highest species diversity (*H*' = 1.65) and wet seasons the least (*H'* = 1.445).

On the effects of prescribed burning on rodents ecology, there were statistically significant different (W = 0.892, *p* = 0.0004) in abundance of *A. ngurui* between the burnt and unburnt areas and through seasons (Deviance = 2.644, df = 1, *p* = 0.021). Yet, for *Mastomys natalensis*, although its abundance increased after the prescribed burning events, the differences between the burnt and unburnt areas were not statistically significant (W = 344.5, *p* = 0.226), but significant difference between seasons (Deviance = 3.606, df = 1, *p* = 0.05). Species richness was higher in burnt areas than in unburnt areas suggesting burnt areas promote more species colonozitation compared to unburnt. Seasonality showed effects on richness with more species (5) appearing in the wet season in burnt areas than in unburnt areas. On the other hand, the highest species diversity (*H*' = 1.551) was recorded in burnt areas than in unburnt (*H*' = 0.759). On seasons, higher diversity in both wet and dry seasons was recorded in the burnt area (*H*' = 0.679 and 0.556 respectively) than in unburnt (*H*'= 0.419 and 0.382 respectively) suggesting prescribed burning promotes higher diversity. On age groups, no statistically significant differences (Deviance = 3.507, df = 1 *p* = 0.061) between burnt and unburnt areas and across seasons

(Deviance = 0.301, df = 1, p = 0.583) were recorded. On the other hand, the probability for both *A. ngurui* and *M. natalensis* survival (E = -0.481±11.233, z = -0.428, p = 0.669 and E = 0.377±7.044, z = 0.054, p = 0.957 respectively) and recruitment (E = 7.316±13.876, z = 0.528, p = 0.598 and E = 1.023±11.598, z = 0.088, p = 0.93 respectively) were not statistically significant different between burnt and unburnt areas. This was the same for breeding patterns and sex ratio suggesting that prescribed burning does not promote breeding and sex ratio variations in the Selous ecosystem. Overall, the results showed that prescribed burning as a management tool has effects on the abundance, richness, and diversity of rodents and not on specific demographic characteristics.

On the home range, *A. ngurui* recorded the largest mean home range (1 087.58 m^2) than *L. rosalia* (831.55 m^2) and *M. natalensis* (166 m^2). Home range overlap was not statistically significant different between the two habitats but it was statistically significant difference across seasons in both habitats (χ^2 = 33.5, df = 1, p = 0.000 and χ^2 = 46, df = 1, p = 0.000 respectively). Overall, most small mammals were associated with seasonal riverine forest which is characterized by high canopy and shrub cover while most murid species were associated with closed woodland with leaf litter and dead logs.

The results of the current and future distribution of small mammals in the Selous ecosystem indicate that most of the current highly suitable habitats will be affected and small mammal species will be concentrated in a few areas within and outside the ecosystem.

This study has provided important information for updating the current small mammal distribution maps as most of the small mammal species are reported for the first time from this area with molecular confirmation. Further, *Grammomys selousi* is being reported for the first time in the northern part of Rufiji River and South of Ruaha River. Considering the finding from this study, small mammal species abundance, diversity, and distribution are largely influenced by habitat types and seasonal variations at the community level and at individual species such as *A. ngurui* in the Selous ecosystem.

This study has demonstrated that, overall, prescribed burning as a management tool favors the high abundance, richness, and diversity of small mammals. While for individual species, prescribed burning has shown varying effects both positive and negative. *Acomys ngurui* and *M. natalesis* have shown variations in the effect of prescribed burning on various demographic characteristics, suggesting that, although they share the same habitat, prescribed burning might affect them differently.

The study has also shown a varied effect of habitats and seasons on the abundance of individual species suggesting that they are not uniformly affected. In relatively stable habitats with infrequent large herds of herbivores and prescribed burning, abundance has shown to be higher for *A. ngurui* while for *L. rosalia* and *M. natalensis* their abundance was higher in areas frequented by prescribed burning and large herbivores. In addition, this study indicated that large home ranges were recorded in the seasonal riverine forest for *A. ngurui* and *L. rosalia* which was relatively stable with infrequent disturbances while for *M. natalensis* it was different. Small mammal species have shown a high overlap within closed woodland suggesting shared resources with possible separation of time, i. e. crepuscular (*L. rosalia*) and nocturnal (*A. ngurui* and *M. natalensis*) and feeding behaviors

with others being generalist such as *M. natalensis* and omnivorous (*A. ngurui*). Furthermore, most small mammals were associated with seasonal riverine forest than closed woodland suggesting that areas with limited activities of large mammals and management practices support more species while areas with varied degree of disturbances necessitate an adaptation to be able to survive.

The study has further established the expected climate change effects, especially from the ‘business as usual scenario’ (RCP 8.5) which is expected to shift the small mammal distribution in the Selous ecosystem both positive and negative based on specific species. The model suggests that most of the current highly suitable range will be affected and species will be forced to concentrate in a few areas within the ecosystem. It is important however to consider that, although the model predicted the observed distribution, there is a chance that this will depend on the species' capacity in adapting to the changing environment and the time expected for these changes to occur. All the species studied suggest being able to adapt to a dynamic habitat and can tolerate even the disturbed area.

To address the gaps identified in this study, the following recommendations are made to the managers and policymakers of the protected areas; The information from this study call for an update of various management plans such as General Management Plans (GMP), Prescribed Burning Plan, Infrastructure Development/Management Plans and others to include the distribution of small mammals in the parks/reserves within the Selous ecosystem.

Also, conservation managers are advised to maintain the current cycle of prescribed burning since any alteration might affect rodent species' population dynamics. Although no statistically significant variation in most demographic characteristics was vivid, at assemblage levels such as abundance, richness, and diversity, the effects were obvious.

Furthermore, areas with low protection status such as Kilombero Game Controlled Area (KGCA) should be upgraded to Game Reserve/National Park standard to protect the important areas for species including small mammals' future strongholds.

In addition, the management of different protected areas in the ecosystem are advised to include climate change as a key component in the development of General Management Plans (GMP). This may include a specific chapter to address climate change impacts including intensified patrol to reduce/avoid encroachment of any form and extension services related to the conservation of natural resources in the surrounding villages.

Considering the importance of small mammals to the ecosystems, additional studies on their population dynamics are recommended to cover a wider part of the ecosystem including threatened, endangered, and/or rare/endemic species such as *Grammomys selouis*.

DECLARATION

I, Saanya, Aenea Eliphas do hereby declare to the Senate of Sokoine University of Agriculture that, this thesis 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 institute.

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ACKNOWLEDGEMENTS

I am grateful to the African Center of Excellence for Innovative Rodent Pest Management and Biosensor Technology Development (ACE IRPM&BTD) under the Institute of Pest Management of Sokoine University of Agriculture (SUA), for the financial sponsorship of a PhD program at SUA.

I am thankful to my supervisors, Prof. Rhodes H. Makundi and Prof. Apia W. Massawe of the Insititute of Pest Management (IPM), the Sokoine University of Agriculture for giving me this opportunity and for showing boundless patience and professional guidance throughout the entire process of my study at SUA.

Thanks to Prof. Adolf Mkenda (former Permanent Secretary) of the Ministry of Natural Resources and Tourism, Dr. James Wakibara (former Conservation Commissioner – Tanzania Wildlife Management Authority – TAWA), Mr. Mabula N. Misungwi, and Mr. Henock Msocha (former Selous Game Reserve – SGR, Managers) of TAWA and Tanzania National Parks (TANAPA) for granting me permission and support to attend my studies and conduct my study in SGR and Nyerere National Park (NNP) respectively. I am also indebted to the SGR sector wardens, Mr. Augustino Ngimila (Msolwa), Mr. Lawrence Okode (Matambwe), and Shabani Chande (Kingupira), and to the staff of SGR and NNP for assisting me throughout the data collection period.

I am indisputably indebted to my field team for the sacrifices they made to make this study possible, Mr. Khalid Kibwana, Mr. Ramadhani Kigunguli, and Mr. Omary Kibwana for setting the study grids and leading data collection, and Mr. Salim Mohamed our drive of the Institute of Pest Management – SUA. Thanks to Mr. Joseph John, Mr. Maulidi

Msomolo, Mr. Musa Hassan, Mr. Fikiri Nzegema, and Mr. Paulo Pangani (boat operator) of Kisaki village for helping in data collection. Selous ecologists; Mr. Singira Ngoishie and Mr. Charles Tarimo for security and guidance. This team risked it all and went to the tremendously dangerous and unimaginable area with all kinds of wild creatures that no one could have thought just to make sure this study was possible.

I would like to extend my gratitude to Dr. Christopher A. Sabuni, Prof. Loth S. Mulungu, the late Dr. Geogious F. Mgode, Dr. Abdul Katakweba, and Mr. Ginethon Mhamphi of the Institute of Pest Management for their advice and material support necessary for data collection and assistance in the development of the project and during fieldwork and analysis. It is impossible not to mention Dr. Nsajigwa Mbije (Head of Departement – Wildlife Management) and Dr. Amani Kitegile of Sokoine University for their professional guidance, support, and courage during my studies at SUA. I also acknowledge Miss Neema Magembe for helping in data recording and summaries and Miss Salama Nyundo and Dr. Mirende Kichuki of Virology Laboratory at SUA for guidance and support with sample handling and storage for molecular analysis. I thank Mr. Michael Kimaro and Mr. Simon Chidodo of SUA for assisting in the analysis of the data and Prof. Josef Bryja of the Institute of Vertebrate Biology, Czech Republic for species confirmation using the molecular technique. Also, I thank all others who are not acknowledged in person and anonymous reviewers of this work, their contributions are highly valued. It is from their proficiency that I managed to draw scientific conclusions in this work.

My sincere appreciation goes to my family and best friends, my father (late) Mr. Eliphas Saanya, and my mother Catherine Saanya for laying the foundation of my education.

Thanks to Carin Debora and Peterson Saanya for their endless financial and moral support, courage, and prayers during my studies. It is from their support and patience that I managed to pursue my studies with confidence. I am also thankful to my uncle, Mr. Richard Nkini, and his late wife for contributing significantly to my studies. To my colleagues, Dr. John Ademola, Miss. Stella Kessy, Mr. Kiros Wellegerima, Mr. Sadic Waswa, Miss Cecilia Akoth, and Mr. Babi Nackson, thank you for the precious time shared, courage, and support gained during my studies at SUA.

DEDICATION

I dedicate this thesis to my beloved father, the late Commisoner Eliphas Saanya Sawoka and my mother, Catherine Saanya who have been behind all academic achievements I have made so far.

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LIST OF ABBREVIATIONS AND SYMBOLS

ACE-II - African Center of Excellence

ANOVA - Analysis of variance

AUC - Area under the curve

ASCII - Amrican Standard Code for Information Interchange

ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer

CLW - Closed woodland

CMR - Capture Mark Recapture

CO_2 - Carbon dioxide

DEM - Digital Elevation Model

FOR - Sable Forest

FRT - Forest

GCA - Game Controlled Area

GLM - Generalized Linear Model

GMP - General Management Plan

GPS - Global Positioning System

GSL - Grassland

H’ - Shanno Weiner diversity index

IBA - Important Bird Area

IDW - Inverse Deterministic Weighting

IPCC - Intergovernmental Panel on Climate Change

IRPM-BTD - Innovative Rodent Pest Management and Biosensor Technology Development.

IUCN - Internation Union for Conservation of Nature

KGCA	-	Kilombero Game Controlled Area
MCP	-	Minimum Convence Polygon
MINAPA	-	Mikumi National Park
MNA	-	Minimum Number Alive
MNRT	-	Ministry of Natural Resources and Tourism
MSR	-	Matambwe Seasonal Riverine Forest
MTN	-	Matambwe Mountain
NDVI	-	Normalized Difference Vegetation Index
NMDS	-	Non-metric Multidimensional Scalling
NNP	-	Nyerere National Park
PA	-	Protected Area
PAST	-	Paleontological Statiscitcs Software Package
PCA	-	Principle component analysis
PerMANOVA	-	Permutational Multivariate Analysis of Variance
PR	-	Perennial Riverine Forest/thickets
QGIS	-	Quantum Geographical Information System
RCP	-	Representative Concentration Pathways
RRF	-	Rufiji Riverine Forest
SEI	-	Seasonal Inanduated Grasslands
SGR	-	Selous Game Reserve
SIMPER	-	Similarity Percentages Analysis
IPM	-	Insititute of Pest Management – Sokoine University of Agriculture
Sq	-	Square
SRF	-	Seasonal riverine forest
TANAPA	-	Tanzania National Parks

TAWA	Tanzania Wildlife Management Authority
UNEP-WCMC	United nations environmental programme – world Conservation monitoring center
UNESCO-WHC	United nations Education and Scientific and Cultural Organiation – World Heritage Center
URT	United Republic of Tanzania
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System
W/m^2	Watts per square meter
WL	Woodland
WMA	Wildlife Management Area

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Selous ecosystem

The Selous ecosystem covers an area of about 100 000 km2 (Figure 1). The ecosystem includes various forms of Protected areas (PAs) which are national parks (Nyerere, Mikumi, and the Udzungwa Mountains), Game Reserves (Selous), Forest Reserves (Mkulazi, Magombera, and Undendeule West) about eleven (11) Wildlife Management Areas (WMAs) and Ramsar sites (Kilombero). It is located in southeastern Tanzania between 7°20' to 10°30'S and 36°00' to 38°40'E (MNRT, 2012). The ecosystem harbors significant populations of wildlife including vulnerable (African elephant - *Loxodonta africana africana*) endangered (African hunting dog - *Lycaon pictus*) and critically endangered (Black rhinoceros - *Diceros bicornis minor*) species among many others (UNEP-WCMC, 2011). There are about 450 species of birds among them endemic and rare, which makes the area among the few Important Bird Areas (IBA) in the region (Briggs, 2008). The ecosystem constitutes a globally important example of vegetation types that is between Somali-Masai and Zambezian regional centers of endemism and mostly on the later (URT, 2005). The area possesses diverse flora with an estimated total of over 2 000 species with an exceptionally high variety of habitats (McGinley, 2008). Dominant habitats include riverine forests/thickets along both seasonal and perennial rivers and woodlands mainly dominated by *Brachystegia spicifomis, Julbernardia globiflora,* and *Pterocarpus angolensis* (UNESCO-WHC, 2012). The ecosystem is also covered by forest along the valleys and mountain ranges and patches of grasslands including inundated grasslands (McGinley, 2008; UNEP-WCMC, 2011) that might be holding a major small mammal fauna yet to be discovered (Denys *et al.,* 2011).

1.2 Small mammal ecology

Small mammals play a fundamental role in ecosystem health through their complex interactions with the environment they live through influencing ecosystem structure, their role in the food web and food chain, and seed dispersals (Lobo et al., 2009; Makundi *et al.,* 2009; Heinze et al., 2010; Marrocoli, 2011; Yihune and Bekele, 2012; Bosing *et al.,* 2014). Further, due to their greater diversity in morphology, physiology, feeding behavior, and life history strategies they have managed to thrive in different environmental conditions (Cramer and Willig, 2002; Hope and Parmenter, 2007; Alemayehu and Bekele, 2013). The environmental limiting factors (water, temperature, nutrients, food, and moisture) that shape the physiology of animals are the important determinants of the observed species distribution (Feilhauer *et al.,* 2011; Sabuni *et al.,* 2015). In Africa 395 species of rodents (Happold, 2013) have been described, and 111 in Tanzania (Senzota *et al.,* 2012). However, with advancements in molecular genetics, the figures might increase significantly (Verheyen *et al.,* 2007; Hoffmann *et al.,* 2010; Denys *et al.,* 2011).

1.3 Demographic characteristics of small mammal

1.3.1 Small mammal age structure

Age structure refers to the proportion of individuals at different life stages (Schowalter, 2006). Age structure is among the key determinants of population stability, growth, and/or decline through the determination of the reproductive potential of a population (Tarsi and Tuff, 2012). Age determination in animals is an important parameter that informs wildlife research, and conservation and is a foundational element of population ecology (Schroeder and Robb, 2012; Lichti *et al.,* 2017). Also, age classification provides factors such as age-specific survival and recruitment rates (Lichti *et al.,* 2017). Various methods have been used in determining the age structure of species including pelage, body, and/or morphological measurements (Karels *et al.,* 2004; Lichti *et al.,* 2017), dental patterns (Schroeder and Robb, 2012), and body weight (Leirs and Verheyen, 1995).

1.3.2 Small mammal recruitment and survival

Recruitment is defined as the number of newly captured individuals that have entered the marked population on each occasion during trapping sessions. Apparent survival is defined as the probability of recapturing the marked animal on different occasions after treatment (Griffiths and Brook, 2015). Various factors affect the recruitment and survival of small mammals including fire and habitat type (Massawe *et al.,* 2006; Mlyashimbi *et al.,* 2020). Areas that practice prescribed burning might promote high recruitment due to increased biomass yield at the onset of rain (Maishanu *et al.*, 2017). On contrary, the prescribed burning application might elevate predation due to decreased cover (Morris *et al.*, 2011; Block *et al.*, 2016; Namukonde, *et al.*, 2018). Overall, fluctuating habitats favor rodent survival and breeding due to their ability to adjust to the changing environment (Mulungu *et al.*, 2013; Mulungu *et al.*, 2015).

1.3.3 Small mammal sex ratio and breeding patterns

Sex ratio is an important parameter that might affect small mammal community ecology (Fryxell *et al.,* 2015). When the sex ratio is significantly skewed towards males the probability of that population collapsing or going extinct increases (Ancona *et al.*, 2017). On the breeding patterns, rodents’ breeding reach peaks towards the end of the rain season when resources are plenty in both, quality and quantity (Kingdon, 1974; Alemayehu and Bekele, 2013; Bantihun and Bekele, 2015). Rainfall affects the availability of resources in a given habitat and therefore species performance in terms of breeding and activity patterns. However, breeding and rainfall are extremely variable and depend chiefly on the area and species (Mrosso, 2004; Bantihun and Bekele, 2015). For example, *Arvicanthis neumanni* breeding responds to seasonal changes in central Tanzania (Massawe *et al.,* 2007). Further, females' sexual activity is mostly synchronized with the availability of resources as opposed to males which might be active throughout the year regardless of essential resources availability (Mulungu *et al.,* 2013). Most rodents' litter sizes range from 11 to 13 offspring at a time and the maximum is 24 (Bantihun and Bekele, 2015).

1.4 Home range of small mammal species

Animals usually restrict their activities to a specific area, be it territory, home range, or region (Stamps, 1995). Home range is an area traversed by an individual in its normal activities and that can provide relatively all necessary resources that can sustain the animal's life such as food, potential mates, safety, and caring for the young (Powell, 2000; Powell and Mitchell, 2012; Cooney *et al.,* 2015; Aiken, 2019). Home range is an important ecological parameter in small mammals in understanding the driving factors for their variation between species and across habitats and seasons. Further, it helps in identifying important factors such as mating patterns, foraging behavior, and habitat use modeling/predicting species distribution in an ecosystem (Aiken, 2019). Animals will incur all the costs to establish and maintain home ranges only if the benefits of maintaining them are greater than the cost (Stamps, 1995). In addition, having a knowledge of an area is particularly important to small mammals in escaping potential predators and it increases fitness (Stamp, 1995). Home rangers may differ between and within species and between habitats across seasons (Powell and Mitchell, 2012). According to Byrne and Chamberlain (2011), resources fluctuations are the key reasons for a shift in size and position in home ranges of small mammals. It can also be linked to the level of competition, niche separation, and predation (Morris *et al.,* 2011). In addition, home range sizes might be affected by habitat fragmentation which can alter the spatial structure of the vertebrate population and this is dangerous to restricted species which if not checked can go extinct due to various factors such as inbreeding depression (Gehring and Swihart, 2004). Grazing pressure from large herbivores has been reported to affect the home range of small mammals in different ecological zones (Ogada *et al.,* 2009).

1.5 Factors influencing small mammal species abundance and diversity

Knowledge of animal species' habitat requirements is a landmark for managing and conserving them (Kneib, 2007). Small mammals in particular rodents' abundance and diversity are influenced by vegetation type and density, rainfall patterns, temperature variability, and soil types through shaping their habitat (Massawe *et al.,* 2008; Makundi *et al.,* 2009; Bantihun and Bekele, 2015). Temperature is especially the main determinant of small mammals' activity in a given area (Alemayehu and Bekele, 2013). Furthermore, their results suggest that recent climate warming increased the biodiversity of small rodents by providing more benefits to the population growth of rare or less abundant species than that of more abundant species (Alemayehu and Bekele, 2013). This means changing any of these parameters in particular temperature and rainfall might have a significant effect on small mammal distribution. On the other hand, various habitats might favor species depending on the time of the year/season such as during harsh climates. For example, mountains have been reported to play an important role as a refuge for many small mammals during harsh climates (Mulungu *et al.*, 2008). However, these factors are not conclusive and they only portray a glimpse of reality (Araujo and Guisan, 2006).

Anthropogenic activities through the transformation and fragmentation of once continuous natural habitats are a major threat to species survival and distribution worldwide

(Feilhauer *et al.,* 2011). Any kind of habitat change has serious effects on species composition, abundance, diversity, total biomass, and distribution of small mammals (Heinze *et al.,* 2010). Throughout the world, land use/cover change has caused about 20% loss of species richness in around 28.8% of the world's terrestrial ecosystems including effects on small mammal distribution, diversity, and abundance (Hagenah, 2006; Jetz *et al.,* 2007; Acevedo-Whitehouse and Duffus, 2009; Heinze *et al.,* 2010; Marrocoli, 2011; Feilhauer *et al.,* 2011; Ofori *et al.,* 2013; Newbold, 2018). In tropic habitats alone, habitat alteration has accounted for about 80% of species loss worldwide (Chazal and Rounsevell, 2009). According to future projections, about 50% of species' suitable habitats will be reduced for about 400 species by 2050, and for more than 900 species by 2100 (Jetz *et al.,* 2007). Considering the small mammal role in the ecosystems, these impacts might cause a serious effect on the functioning of the ecosystems in the future (Shenko *et al.,* 2012).

On the other hand, various management practices including prescribed burning in PAs and in farm preparation have been implemented. Fire is a natural ecological phenomenon in miombo woodland that highly influences vegetation structure and composition which in turn affects small mammal distribution and abundance (Witecha, 2011). In many PAs prescribed burning is conducted at the beginning of the dry season. In the Selous ecosystem, prescribed burning is performed mainly between late June and early August (URT, 2005). Prescribed burning is mainly meant for nourishing pasture, and enhances germination of some species of miombo trees, reducing pest load and improving access to wildlife (Morris *et al.,* 2011; Green *et al.,* 2015). According to Block *et al.* (2016), there are more positive effects of prescribed burning than negative. For instance, the frequency of prescribed burning has positive effects on tree and herbaceous species richness and contributes to a heterogeneous habitat which is ideal for high abundance and richness of fauna (Sheuyange *et al.*, 2005). In addition, it has been reported that vegetation biomass yield is higher in the burnt than unburnt areas suggesting a positive effect for herbivores (Maishanu *et al.*, 2017).

Furthermore, climate change as a product of anthropogenic activities is posing an ever-increasing threat to wildlife management around the world and primary concern and driver of change (Jetz *et al.*, 2007; Newbold, 2018). It is expected to alter the current ecosystem arrangement including shifting the species poleward and to higher areas as a coping mechanism (Baltesperger and Huettamann, 2014; Shamsabad *et al.*, 2018). Currently, climate change has been highlighted to significantly affect biodiversity around the world (Newbold, 2018). This includes, increased zoonotic prevalence, especially with increased contact between humans and small mammals such as plague, hantavirus pulmonary syndrome, and leptospirosis (Stenseth *et al.*, 2006; Young *et al.*, 2017). In addition, it has been associated with shaping species' genetic composition as a result of species shift (Wroblewska and Mirski, 2018). However, the effect of climate change on small mammals is variable and it is species and area-specific, especially with current unpredictable climatic events which shape the diversity and distribution from time to time (Witecha, 2011).

1.6 Justification of the Study

Historically the PAs in East Africa were meant for large mammals (Caro, 2001). This inheritance approach has led to inadequate attention to other important components of an ecosystem such as small mammals and herparto-fauna (Van Deventer and Nel, 2006; Venance, 2009; Heinze *et al.*, 2010). For example, in Vietnam, various species of rodents have become endangered (Giant flying squirrel-*Petauristas elegans* and Chapa pygmy dormouse-*Typhlomys chapensis*) and rare (Tree squirrel-*Callosciurus finlaysoni*) due to habitat destruction by converting forestlands into cultivation and settlement areas (Tam *et al.*, 2003). In addition, management practices such as prescribed burning and construction of various infrastructures within PAs might have been impacting different ecosystems components differently from those which are not known to be highly endangered. In Selous ecosystem like all other miombo ecosystems have been practicing prescribed burning for years with various aim including pest suppression, improving pasture, particularly for large herbivores, and protecting the ecosystem from late detrimental fires. However, if not checked, it might be negatively affecting small mammals which play an engineering role in ecosystem health through pollination, dispersal, and maintaining the food web and food chain (Lobo *et al.*, 2009; Heinze *et al.*, 2010; Yihune and Bekele, 2012; Bosing *et al.*, 2014).

On the other hand, the effect of climate change around the world is calling for its inclusion in the setting of conservation priorities (Jetz *et al.*, 2007; Newbold, 2018). Currently, climate change has been highlighted to significantly affect biodiversity by increasing diseases prevalence such as plague and leptospirosis due to increased contact between wildlife and human around the world (Stenseth *et al.*, 2006; Young *et al.*, 2017; Newbold, 2018). Climate is expected to alter the current ecosystem arrangement including shifting the species poleward and higher areas as a coping mechanism (Baltesperger and Huettamann, 2014; Shamsabad *et al.*, 2018). This is especially dangerous to a pristine ecosystem like Selous which lacks adequate information on its small mammal fauna composition, diversity, and distribution.

Selous ecosystem forms a major part of southeastern Tanzania. The ecosystem possesses diverse flora dominated by miombo woodland (McGinley, 2008; UNEP-WCMC, 2011). The PAs within the ecosystem, especially Nyerere National Park (NNP) and Selous Game Reserve (SGR), there is no specific study that has been focused on the composition, diversity, and distribution of small mammal fauna and how various factors are affecting their survival including management actions and current climate trend. Most studies conducted inside Mikumi National Park (MINAPA) (Venance, 2009), in Selous – Niassa wildlife corridor (URT, 2010), and in the Kichi coastal forest adjacent to SGR (Denys *et al.,* 2011) were short and only focusing on abundance and distribution, and presence/absence and genetic focus. This has led to inadequate information on small mammal fauna in the southeastern part of Tanzania and most tropical and miombo ecosystems (Fitzherbert *et al.,* 2006; Denys *et al.,* 2011; Marrocoli, 2011). This rich miombo ecosystem might be holding a major cryptic component of small mammals yet to be discovered (Denys *et al.,* 2011). Considering the complexity of the Selous terrain, the assertion of Denys *et al.* (2011) might hold with the discovery of new Murid species (*Grammomys selousi*) was described in the Selous ecosystem in the Kichi coastal forest adjacent to SGR. This is further supported by a number of authors that infrastructure development and complex terrain might influence gene flow and therefore structure genetic variation in a natural population (Keller *et al.,* 2004; Coulon *et al.,* 2006; Giordano *et al.,* 2007; Gauffre *et al.,* 2008). The missing information was a hindrance to scientific-led and holistic management of the Selous ecosystem. Thus, there was an urgent need for a study to generate information and fill the existing gap in the diversity and distribution of small mammals in the Selous ecosystem.

1.7 Objectives

1.7.1 General objective

The general objective of this study was to generate the missing information on the community ecology of small mammals in the Selous ecosystem, Tanzania, for a scientific-led and holistic management and conservation of this ecosystem.

1.7.2 Specific objectives

i. To establish the diversity and distribution of small mammals in different habitats across seasons in the Selous ecosystem.

ii. To determine the effect of management practices especially prescribed burning on rodents' community ecology (diversity, distribution, abundance, and demographic characteristics for dominant species) in the Selous ecosystem.

iii. To determine home ranges of the most dominant small mammal species and how they associate with the habitat they live in the Selous ecosystem.

iv. To assess the current (2019) and future (2050) distribution of small mammals under the Representative Concentration Pathways 8.5 climate change scenario in the Selous ecosystem

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CHAPTER TWO

PAPER ONE

Small mammals Species Diversity and Distribution in Selous Ecosystem, Tanzania

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Published: African Journal Zoology**;**

ID: DOI:**10.1080/15627020.2022.2034040**

Abstract

Threats on ecosystems are ever increasing from different drivers mostly being linked to anthropogenic activities. This has brought about various measures to restore/protect the wildlife in these areas. Considering the background of most protected areas in East Africa, small mammals have been given least attention as compared to large mammals, although they play a fundamental role in maintaining ecosystem health. It is therefore necessary to understand how small mammals are distributed in any given ecosystem as a baseline information to enable holistic and informed management. We investigated the diversity and distribution of small mammals in Selous ecosystem, Tanzania. Two methods were used; Capture Mark Recapture (CMR) using grids of 70 m x 70 m and random placement of havahart traps in the selected habitats. Between July 2018 and June 2020, a total of 887 small mammals belonging to 20 species were captured in 28,224 trap nights with 3% trap success. The small mammal species captured comprised of rodents (91.8%), Macroscelidea (3.9%), Carnivores (2.4%) Eulipotyphla (1.6%), and Primates (0.3%). *Acomys ngurui* (36%), *Aethomys chrysophilus* (17%), were the most captured species while *Atilax paludinosus* (0.23%), *Helogale pervula* (0.23%) and *Galerella sanguinea* (0.11%) were the least contributing species. *Acomys ngurui*, and *Lemniscomys rosalia*, were the most distributed species occurring in all four habitats, while *Cricetomys ansorgei*, *Rattus rattus*, *Mungos mungo*, and *Genetta genetta* were the least occurring species. *Grammomys selousi* is reported for the first time in the northern part of Rufiji River. *Acomys ngurui* abundance differed significantly ($\chi^2 = 12$, df = 3, $p = 0.007$) between the four habitats being higher in seasonal riverine forest and across seasons ($\chi^2 = 6$, df = 2, $p = 0.049$) with more individuals occurring in wet season. Forest habitat had the highest species diversity (H’ = 2.065) and the lowest (H’ = 1.506) diversity was recorded in perennial riverine forest/thicket. Dry season recorded the highest species diversity (H’ = 1.65) and wet season the least (H’ = 1.445). Most small mammals were associated with seasonal riverine forest than other habitats. Overall, the results from this study show that, the park is rich in small mammal fauna. Therefore, considerations in updating the General Management Plan (GMP) and other plans to include the small mammals in the park management actions is recommended.

Key Words: Abundance, Diversity, Mammalia, Small-fauna, riverine-forest.

1.0 Introduction

Historically the protected areas (PAs) in East Africa were meant for large mammals (Caro, 2001). This inheritance approach has led to inadequate attention to other components of ecosystems such as small mammals and herpetofauna (Van Deventer and Nel, 2006; Venance, 2009; Heinze et al. 2010). According to Fitzherbert et al. (2006) and Marrocoli, (2011), little has been done on small mammals particularly in the tropics and miombo areas. Small mammals play a fundamental role in ecosystem health through their interactions with the habitat in which they live through maintaining food webs and chains (Makundi et al. 2009; Heinze et al. 2010; Marrocoli 2011; Yihune and Bekele 2012; Bosing et al. 2014). Further, due to their greater diversity in morphology, physiology, behavior and life history strategies (Cramer and Willig 2002), and their feeding behavior (most of them are omnivorous, consuming vegetation, fruits, seeds, and animal prey), they have managed to thrive successfully in different environmental conditions (Hope and Parmenter 2007; Alemayehu and Bekele 2013). In Africa 395 species of rodents have been described and 111 in Tanzania (Senzota et al. 2012; Happold 2013). Nevertheless, with advancement in molecular genetics the figures might increase significantly (Verheyen et al. 2007; Hoffmann et al. 2010; Denys et al. 2011).

Small mammal species in particular rodent abundance and diversity are influenced by a number of factors which include vegetation type and density, rainfall patterns, temperature variability and soil types (Massawe et al. 2008; Makundi et al. 2009; Alemayehu and Bekele 2013). For example, in central Tanzania, *Arvicanthis neumanni* breeding has been reported to respond to seasonal changes (Massawe et al. 2007). This is due to the influence of rainfall on food which increases in terms of quality and quantity which however depend on species and habitat (Kingdon 1974; Mrosso 2004). Overall, rodents’ breeding reaches peaks towards the end of the rain season when resources are plenty and thus rainfall is viewed as the ultimate source of variation (Alemayehu and Bekele 2013). Nevertheless, the resources in a given habitat are further determined by other environmental variables such as slope, aspect, elevation and soils among others. During harsh weather conditions, mountains play the role of refuge to many small mammals (Mulungu et al. 2008). Also, the current unpredictable climatic events have been reported to shape the diversity and distribution of small mammals from time to time (Witecha 2011).

Selous ecosystem occupies a major part of southeastern Tanzania. The ecosystem is formed by various categories of protected areas which include National Parks (Nyerere, Mikumi and Udzungwa), Game Reserve (Selous), Forest Reserves (Mkulazi and Magombera) about eleven (11) Wildlife Management Areas (WMAs) and Game Controlled Area (GCA) which harbors a Ramsar site (Kilombero). The ecosystem possesses diverse flora dominated by miombo woodland (McGinley 2008; UNEP-WCMC, 2011). Although various studies on small mammals fauna in Selous ecosystem have been conducted including Mikumi National Park (Venance 2009) in Selous – Niassa corridor, southern Tanzania (URT 2010) and in the North eastern part at Kingupira area (Denys et al. 2011), the southeastern part of Tanzania is among the least researched areas on small mammals ecology (Denys et al. 2011). Considering its size and diverse habitats, it might be holding a major cryptic component of small mammals yet to be discovered, for example, a new Murid species *Grammomys selousi* (Denys et al. 2011), was described in Selous ecosystem in a small area around Kingupira. On the other hand, the current climate change trend is reported to pose a serious threat to small mammals and their habitat (Witecha, 2011). Therefore, this study aimed at filling the missing information, with a detailed study on diversity and distribution of small mammals in the ecosystem for informed and holistic ecosystem management. Specifically, the study was conducted in the Nyerere National Park (NNP) which is the largest national park in Tanzania. The established park forms part of the former Selous Game Reserve (SGR), a renowned World Heritage Site since 1982 (UNESCO–WHC 2014). Our study aimed at answering the following key questions (i) What species of small mammals are represented in the NNP (ii) How are they distributed in different habitats within the park (iii) How does habitat and seasons affect their distribution in the park.

2.0 MATERIALS AND METHODS

2.1 Study Area

The study was conducted between July 2018 and June 2020 in four habitats in the Selous ecosystem, specifically in the Nyerere National Park (NNP) (Figure 1), which covers an area of about 32,000 km^2. It is located in the southeastern part of Tanzania between 7°20' to 10°30'S and 36°00' to 38°40'E (MNRT 2012). The park falls within the bimodal rainfall belt of southern Tanzania and annual rainfall ranges from 750 mm in the east to about 1 300 mm in the west, falling mainly between mid-November and mid-May (Jihnson 2003). The park forms part of the former Selous Game Reserve (SGR) which constitutes a globally important example of vegetation types that is between Somali-masai and Zambezian regional centers of endemism and mostly on the later (URT 2005). The area possesses diverse flora with an estimated total of over 2 000 species with exceptionally high variety of habitats (McGinley 2008). The ecosystem harbors significant populations of wildlife including vulnerable (African elephant - *Loxodonta africana africana*) endangered (African wild dog - *Lycaon pictus*) and critically endangered (Black rhinoceros - *Diceros bicornis minor*) species among many others (UNEP-WCMC 2011). There are about 450 species of birds among them endemic and rare, which makes the area among the few Important Bird Areas (IBA) in the region (Briggs 2008). The miombo woodland is dominated by *Brachystegia spicifomis*, *Julbernardia globiflora*, *Afzelia quanzensis*, *Pterocarpus angolensis*, and *Salvadora perisca.* Common grasses are *Hyparrhenia newtonii, Andropogon gyanus* and *Hyparthelia dissoluta* (URT 2005). The dominant soils are black cotton with rough slopes characterized by rock outcrops in most parts.

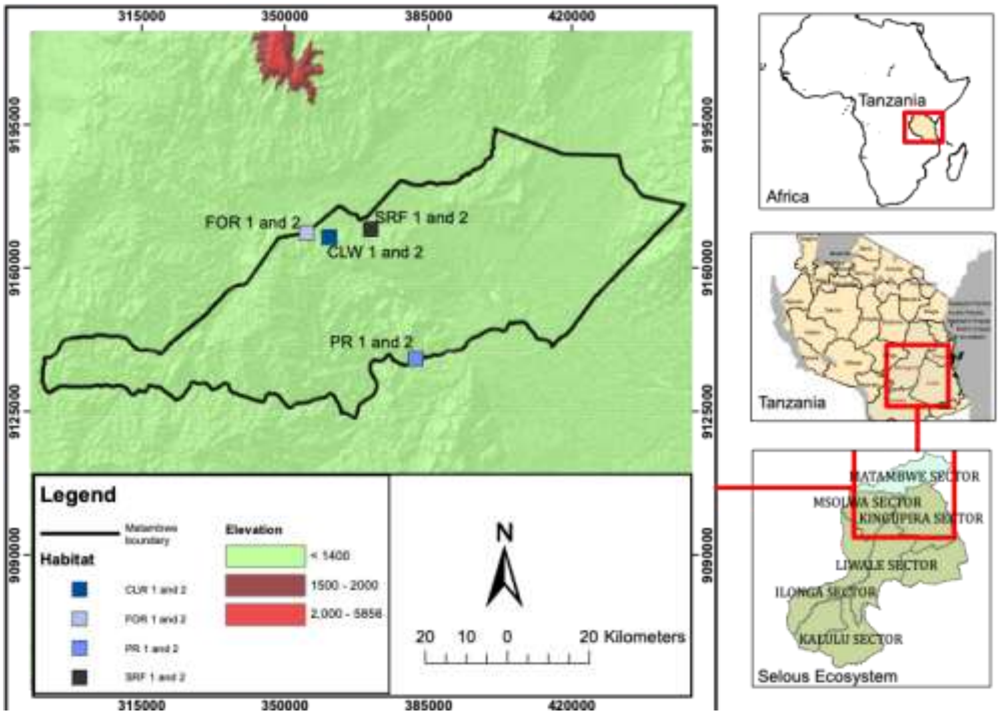

Figure 1: Northern Nyerere National Park in the Selous ecosystem, Tanzania.

2.2 Study habitats

Matambwe closed woodland (CLW) located at 37M 345750 UTM 9169377, elevation 324 m. a.m.s.l. the habitat is associated with mountains which form a large part of the northern part of NNP. Nyamambi and Matambwe are within the Eastern Arc Mountain ranges about 50 km south of Uluguru Mountain ranges. The area is characterized by mixed vegetation dominated with *Brachystegia spicifomis*, *Julbernardia globiflora*, *Afzelia quanzensis*, *Pterocarpus angolensis, and Salvadora perisca* and the common grasses are *Hyparrhenia newtonii*, *Andropogon gyanus* and *Hyparthelia dissoluta.* The dominant soils are black cotton with rough slopes characterized by rock outcrops in most parts (URT 2005).

Sable forest (FOR) located at 37M 353900 UTM 9169029, elevation 239 m. a.m.s.l. The area is within a forest that is dominated by *Afzelia quanzensis, Sclerocarya birrea,* and *Markhamia zanzibarica*. Soils are mostly black cotton (URT 2005).

Matambwe seasonal riverine (SRF); located at 37M 363761 UTM 9167451, elevation 176 m. a.m.s.l. is dominated by *Steculia apendiculatas, Kigelia africana, Markhamia zanzibarica and Adansonia digitata* and *Combretum* spp. thicket. The habitat is characterized by high percent of leaf litter in dry season and soils are dominated by sandy loam in most parts (URT 2005).

Rufiji riverine forest/thickets (PR) located at 37M 381990 UTM 9139584, elevation 79 m. a.m.s.l. expands along the Rufiji River on both SGR and Nyerere NNP for about 50 km. The area is characterized by *Adansonia digitata, Combretum* spp. thickets, *Borassus aethiopum* and *Hyphaene* sp. palms as the dominant vegetation (URT 2005). The area is limited in undergrowth in most parts with rock outcrops and rough terrain caused by sporadic runoffs in some areas.

2.3 Small mammals trapping

Although a number of definitions of small mammals have been proposed by considering weight; 5 kg and less and 500 grams or less (Lidicker 2011; Lim and Pacheco 2016), in this study, small mammals were defined as all mammal species that could be trapped using medium sized (LFA, 7.5 x 9 x 23 cm) Sherman traps (H.B. Sherman Inc.) and Havahart traps (60 x 15 x 170 cm). Capture-Mark-Recapture (CMR) were used in this study. In each habitat, two grids of 70 m x 70 m were established with seven parallel lines at a distance of 10 meters apart. Each line had seven trapping stations and in total 49 stations were established in each grid following Hoffmann et al. (2010). Each trapping station was marked by coordinates using Global Positioning System (GPS) to help locate the traps because most of them were set under herbs/cover to protect them from direct sunlight and predators. Every trap was baited using a mixture of peanut butter and maize bran. All traps were checked before 10:00hrs. Trapping was conducted at four weeks interval for three consecutive nights in each trapping session from July 2018 to June 2020. Slices of carrot/sweet potatoes and banana were used as bait in Havahart traps. Identification of captured species in the field followed available distribution maps as provided by Kingdon (1997, 2015) and experts from the Sokoine University of Agriculture - Pest Management Center. Sex, reproductive condition and weight (to the nearest gram) were recorded. The animals were marked by toe clipping and released at the site of capture. Toe clipping was used because it provides an additional advantage for genotyping and it has been proved to cause minimal impact to animals (Borremans et al. 2015). The clipped toes were preserved in 70% alcohol and shipped to Czech Republic for species confirmation using molecular (Cytochrome *b*) technique. The remaining samples are stored at Sokoine University of Agriculture – Institute of Pest Management, Morogoro, Tanzania for further analysis.

2.4 Habitat characterization

Habitats covariates were collected at five meters radius (modified from Decher and Bahian (1999) from each trapping station. The recorded variables were number of termite mounds, trees (the dominant species in the specific habitat) and dead logs, visual estimation of percentage canopy cover, shrubs and herbs cover and grass cover and rock outcrops and bare ground percentage. The collected information was used to assess the relative species habitat association.

2.5 Data Analysis

2.5.1 Species composition and trap success

Small mammal species composition was estimated as the total number of different species and their percentage contribution in that community in different habitats.

2.5.2 *Acomys ngurui* abundance

Species abundance was estimated using Minimum Number Alive (MNA) for the most captured species and occurring in all four habitats using CMR history data. We used Shapiro_test function in R software (R Core Team 2020) to test for normality of our data. Our data were not normally distributed (W = 0.83, *p* = 0.021), therefore we used Kruskal Wallis Test to compare the abundance between different habitats. We used Friedman Chi-square Test to detect *Acomys ngurui* abundance variation between habitat types and season categories. We used robust linear regression model by using rlm () function in R (R Core Team 2020) to assess monthly abundance trend of *A. ngurui*.

2.5.3 Species richness, diversity and evenness

Species richness was estimated as number of different species captured in the study area. We used Kruskal Wallis to test for variations between habitats and seasons using R software. To assess sampling effort of small mammals, species accumulation curves were constructed using PAST. Estimation of species was done using Jackknife and Bootstrap estimators in PAST.

Diversity was computed using Shannon-Wiener Index (H') expressed as:

$$H' = -\sum_{i=1}^{s} (p_i)\,(\mathrm{In}\,p_i)$$

Where; *P*i is the proportion of individuals of the ith species or the abundance of the ith species expressed as the proportion of the total individuals and *In* is natural log of individual proportion. Species evenness (E) was estimated as follows;

$$E = H'/H_{max}$$

Where; $H_{max} = \mathrm{In}(s)$

2.5.4 Small mammals' community similarity and species habitat association

Species community similarity was determined using Bray-Curtis dissimilarity index (0-1) where 0 indicates identical communities and 1 means different communities. A hierarchical clustering analysis was used to show the community similarity. We used principle component analysis to assess the species – habitat variables association. Ordination technique - Nonmetric Multidimensional Scaling (NMDS) was used to present the association between habitat covariates and species in different habitats using vegan package in R version 3.4 (R Core Team 2020).

2.6 Ethical Statement

This animal study was reviewed and approved by Sokoine University of Agriculture (SUA) via Permit Number: SUA/ADM/R.1/8/204 dated May, 2018 and Tanzania Wildlife Management Authority (TAWA) via Permit Number: AC.517/625/01.

3.0 Results

3.1 Species composition and distribution

A total of 887 small mammal individuals belonging to 20 species were captured in 28 224 trap nights with 3.1% trap success between July 2018 and June 2020. Closed woodland recorded the highest (6%) trap success whereas forest and perennial riverine forest/thicket had the least with 1%. Species accumulation curves suggest the sampling effort to be adequate for three habitats (CLW, FOR and SRF), while for perennial riverine forest still some effort was needed (Figure 2). The asymptote for the three habitats was reached at around 100 individuals. Bootstrap estimated species in the northern NNP to be 21 (SD = 2) while Jackknife estimated a maximum of 24 species (SD = 4.5).

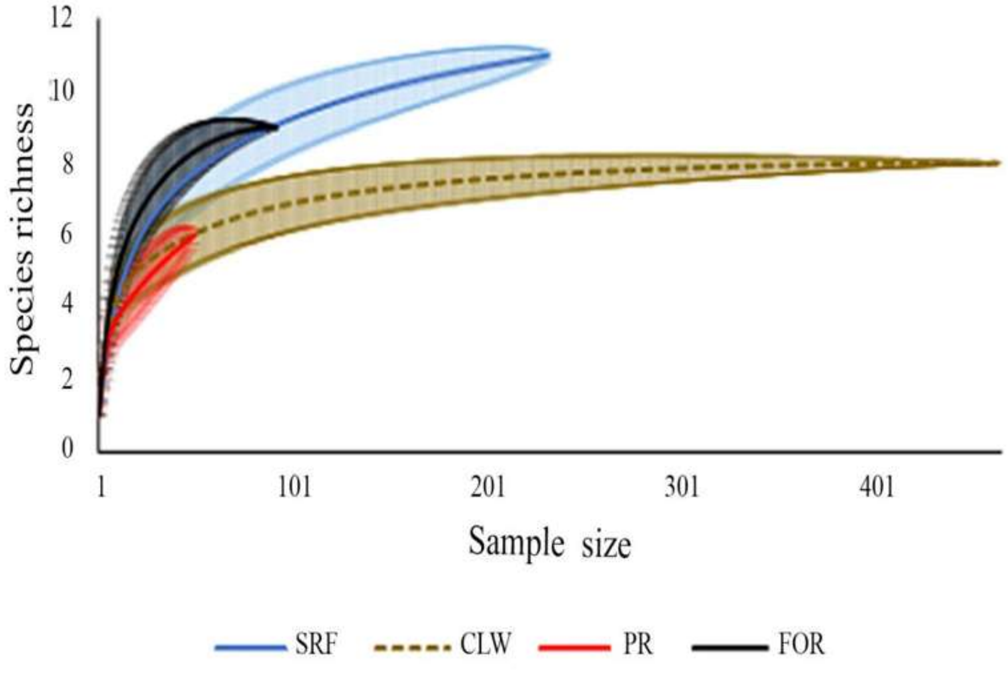

Figure 2: Species accumulation curve of small mammals in different habitats in the Nyerere National Park, Tanzania. (SRF = Seasonal riverine forest, CLW = Closed woodland, PR = Perennial riverine forest/thicket and FOR = Forest).

Overall, 91.8% of all trapped small mammals were rodents, and other groups were comprised of Macroscelidea (3.9%), Carnivores (2.5%), Eulipotyphla (1.7%), and

Primates (0.37%). *Acomys ngurui* (36%) and *Aethomys chrysophilus* (17%) were the most captured species occupying 53% of all captured small mammals (Table 1). *Galerella sanguinea, Rattus rattus, Helogale parvula,* and *Atilax paludinosus,* were the least captured species with ≤ 0.2% (Table 1). Closed woodland recorded the highest species composition (53%) while PR had the least (7%) (Table 1).

Table 1: Species composition and percentage contribution (in parentheses) of small mammals in different habitats in Nyerere National Park, Tanzania. (SRF = Seasonal riverine forest, CLW = Closed woodland, PR = Perennial riverine forest/thicket and FOR = Forest).

sn	Species	Habitats				
		CLW	FOR	PR	SRF	Total
1	*Acomys ngurui* Verheyen *et al.,* 2011	149(32%)	31(32%)	14(24%)	126(48%)	320(36%)
2	*Aethomys chrysophilus* de Winton, 1897	131(28%)	4(4%)	16(28%)	0	151(17%)
3	*Mastomys natalensis* Smith, 1834	89(19%)	12(13%)	0	29(11%)	130(15%)
4	*Lemniscomys rosalia* Thomas, 1904	67(14%)	2(2%)	17(29%)	21(8%)	107(12%)
5	*Petrodromus tetradactylus* (Peters, 1846)	15(3%)	13(14%)	0	4(2%)	32(4%)
6	*Crocidura hitra* Peters, 1852	1(0.2%)	2(2%)	0	19(7%)	22(2%)
7	*Paraxerus palliatus* (Peters, 1852)	0	6(4%)	0	16(6%)	22(2%)
8	*Mus minutoides* Smith, 1834	11(2%)	8(8%)	0	0	19(2%)
9	*Paraxerus flavovittis* (Peters, 1852)	4(1%)	0	3(5%)	11(4%)	18(2%)
10	*Cricetomys ansorgei* Thomas, 1904	0	0	0	15(6%)	15(2%)
11	*Beamys hindei* Thomas, 1909	0	10(10%)	0	3(1%)	13(1%)
12	*Grammomys surdaster* Thomas and Wroughton 1908	0	4(4%)	2(3%)	7(3%)	13(1%)
13	*Genetta genetta* (Linnaeus, 1758)	0	1(1%)	6(10%)	0	7(1%)
14	*Grammomys selousi* Denys *et al.,* 2011	0	2(2%)	0	3(1%)	5(1%)
15	*Mungos mungo* (Gmelin, 1788)	0	0	0	3(1%)	3(0.34%)
16	*Otolemur garnetti* (E. Geoffroy 1812)	0	2(2%)	0	1(0%)	3(0.34%)
17	*Atilax paludinosus* F. Cuvier 1826	0	0	0	2(1%)	2(0.23%)
18	*Helogale pervula* Sundevall 1847	0	0	0	2(1%)	2(0.23%)
19	*Rattus rattus* Linnaeus, 1758	0	0	0	2(1%)	2(0.23%)
20	*Galerella sanguinea* Ruppell 1836	0	0	0	1(0%)	1(0.11%)
	Total	**467(100%)**	**97(100%)**	**58(100%)**	**265(100%)**	**887(100%)**
	Habitat contribution	**53%**	**11%**	**7%**	**30%**	
	Species richness	**8**	**13**	**6**	**17**	

On distribution, *A. ngurui* and *L. rosalia* were the most captured species in all habitats (Table 2). While, *A. paludinosus*, *Cricetomys ansorgei*, *R. rattus*, *H. parvula* and *Mungos mungo* were restricted in one habitat (Seasonal riverine forest) (Table 2).

Table 2: Small mammal species distribution in different habitats in Nyerere National Park, Tanzania. (SRF = Seasonal riverine forest, CLW = Closed woodland, PR = Perennial riverine forest/thicket and FOR = Forest).

Species	**Habitats**			
	CLW	**FOR**	**PR**	**SRF**
Acomys ngurui Verheyen *et al.,* 2011	x	x	x	x
Aethomys chrysophilus de Winton, 1897	x	x	x	
Atilax paludinosus F. Cuvier 1826				x
Beamys hindei Thomas, 1909		x		x
Cricetomys ansorgei Thomas, 1904				x
Crocidura hitra Peters, 1852	x	x		x
Galerella sanguinea Ruppell 1836				x
*Genetta genetta (*Linnaeus, 1758)		x	x	
Grammomys surdaster Thomas and Wroughton 1908		x	x	x
Grammomys selousi Denys *et al.*, 2011		x		x
Helogale pervula Sundevall 1847				x
Lemniscomys rosalia Thomas, 1904	x	x	x	x
Mastomys natalensis Smith, 1834	x	x		x
Mungos mungo (Gmelin, 1788)				x
Mus minutoides Smith, 1834	x	x		
Otolemur garnetti (E. Geoffroy 1812)		x		x
Paraxerus flavovittis (Peters, 1852)	x		x	x
Paraxerus palliatus (Peters, 1852)		x		x
Petrodromus tetradactylus (Peters, 1846)	x	x		x
Rattus rattus Linnaeus, 1758				x

3.2 *Acomys ngurui* abundance

Acomys ngurui abundance was significantly different ($\chi^2 = 12$, df = 3, $p = 0.007$) between the four habitats being higher in seasonal riverine forest than in the other three habitats (Figure 3). However, its abundance was not significantly different ($\chi^2 = 2$, df = 2, $p = 0.367$) between seasons although being higher in wet seasons (Figure 3). There was a significant difference in *A. ngurui* abundance between habitats across season ($\chi^2 = 8.2$ df = 3, $p = 0.04$). However, there was statistically insignificant difference on the monthly trend of *A. ngurui* for both sine circle ($F = 1.9009$, $p = 0.171$ and cosine circle ($F = 0.0003$, $p = 0.984$).

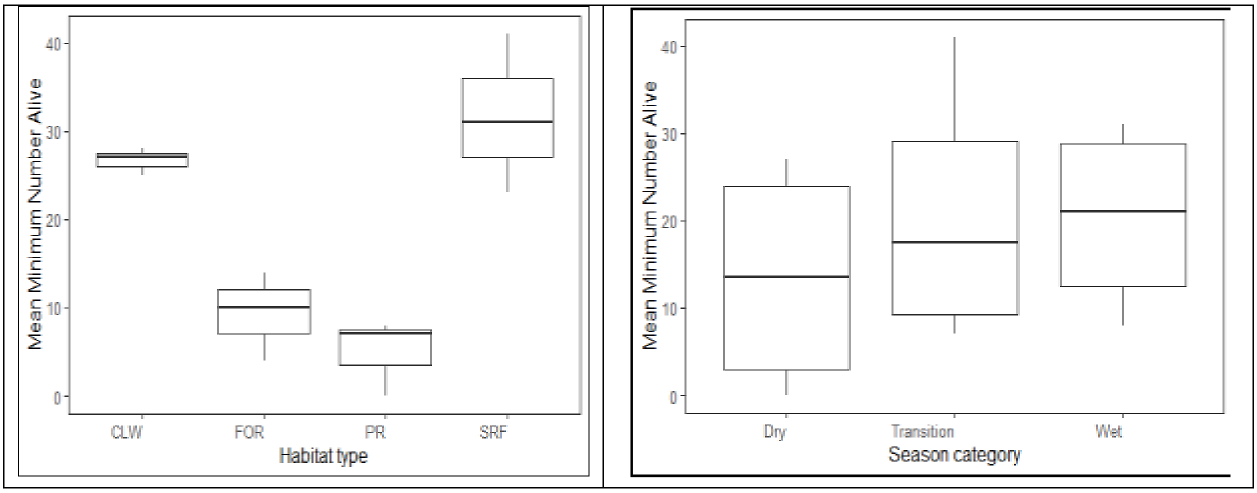

Figure 3: *Acomys ngurui* abundance in different habitats and seasons in Nyerere National Park, Tanzania. (SRF = Seasonal riverine forest, CLW = Closed woodland, PR = Perennial riverine forest/thicket and FOR = Forest).

3.3 Species richness, diversity and evenness

Seasonal riverine forest recorded the highest species richness (17) compared to other habitats (Table 3). Overall, there was no statistically significant differences in species richness between habitats across seasons ($\chi^2 = 7$, df = 3, $p = 0.071$) (Table 3). On diversity, FOR recorded the highest species diversity (H′ = 2.065) and PR had the least (H′ = 1.506) (Table 3). The dry season (July – October) had the highest species diversity (H′ = 1.65) compared to short rains (November – February) and wet (March – June) seasons. Evenness was high in PR (75%) as a result of low trap success while in other habitats it was low especially in SRF, where, *A. ngurui* dominated the catch thus affecting evenness (Table 3).

Table 3: Species richness and diversity of small mammals in Nyerere National Park, Tanzania. (SRF = Seasonal riverine forest, CLW = Closed woodland, PR = Perennial riverine forest/thicket and FOR = Forest).

Habitat/Seasons	Richness	Dominance_D	Simpson_1-D	Shannon_H	Evenness_e^H/S
SRF Overall	17	0.2715	0.7285	1.79	0.3992
SRF Dry	10	0.2502	0.7498	1.785	0.5958
SRF Wet	10	0.2676	0.7324	1.703	0.5492
SRF short rain	10	0.3141	0.6859	1.566	0.4785
CLW Overall	8	0.2384	0.7616	1.572	0.6020
CLW Dry	5	0.2660	0.7340	1.382	0.7970
CLW Wet	8	0.2802	0.7198	1.457	0.5366
CLW short rain	8	0.2225	0.7775	1.645	0.6475
PR Overall	6	0.2536	0.7464	1.506	0.7515
PR Dry	4	0.3058	0.6942	1.264	0.8846
PR Wet	4	0.4545	0.5455	1.034	0.7028
PR Short rain	5	0.3039	0.6961	1.323	0.7508
FOR Overall	13	0.1709	0.8291	2.065	0.5630
FOR Dry	12	0.1488	0.8512	2.17	0.7299
FOR Wet	7	0.2531	0.7469	1.586	0.6975
FOR Short rain	9	0.209	0.7910	1.829	0.6919

3.4 Communities similarity and small mammals’ habitat association

Bray-Curtis similarity index generated four clusters of small mammal communities with a cluster accuracy of 95%. The highest similarity (85%) was recorded between perennial riverine sites A and B (Figure 4). A second cluster was formed by forest sites A and B with a similarity of 70% while the third cluster was between closed woodland site B, seasonal riverine sites A and B with a similarity of 53%. The fourth cluster was closed woodland site A which was isolated from other clusters especially closed woodland site B which was closely similar to those in seasonal riverine A and B habitat.

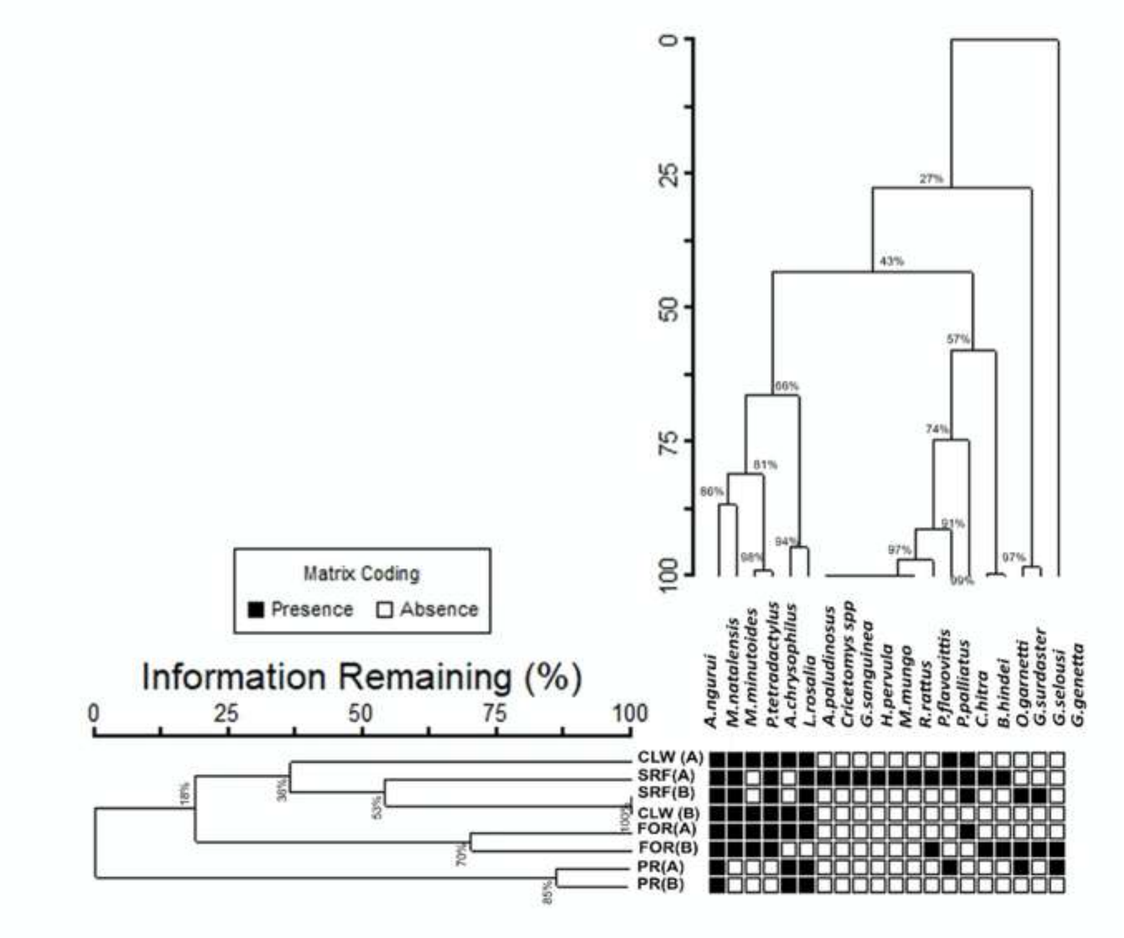

Figure 4: Hierarchical clustering dendrogram from Bray-Curtis dissimilarity analysis of small mammals' communities and species in Nyerere National Park, Tanzania. (SRF = Seasonal riverine forest, CLW = Closed woodland, PR = Perennial river forest/thicket and FOR = Forest).

The selected variables using principle components were able to explain the habitat variation by 82.3%. PCA 1 was positively correlated with shrub, grass and canopy cover, while it was negatively correlated with leaf litter and number of trees. This means the areas with high grass cover and shrub diversity were CLW. PCA 2 was positively correlated with tree density, leaf litter and shrub cover and negatively associated with grass cover. These areas are seasonal riverine and forest habitats and the two habitats were relatively identical (Figure 5). Small mammal species showed different habitat preferences. *Genetta genetta* was isolated from all other species and was associated with perennial riverine forest/thickets while herbivore-murids were associated with closed woodland which is more ideal for most of these species (Figure 5). *Aethomys chrysophilus* was associated with closed woodland while *L. rosalia*, *M. minutoides*, *P. flavovittis*, *P. tetradactylus* were associated with forested areas. The rest of small mammals were associated with forest and seasonal riverine (Figure 5).

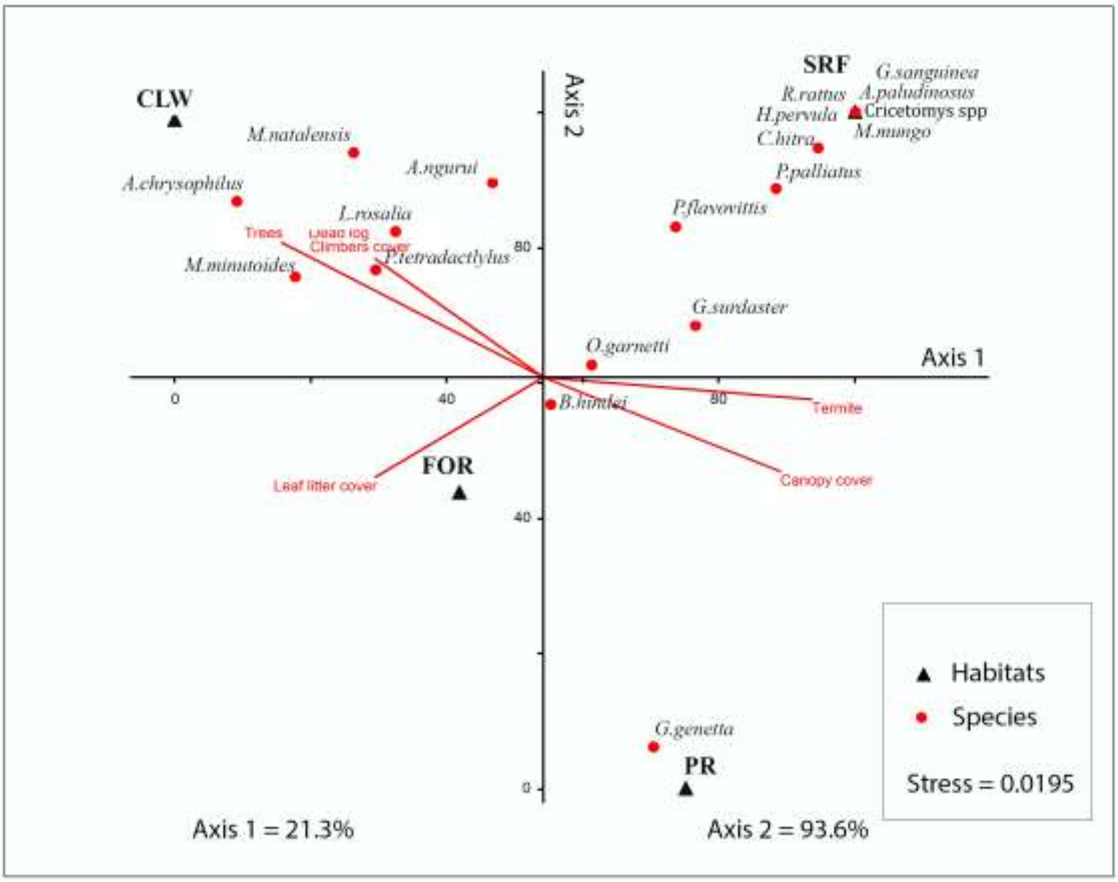

Figure 5: Non-metric multidimensional Scaling (NMDS) on small mammals - habitat association. SRF = Seasonal riverine forest, CLW = Closed woodland, PR = Perennial riverine forest/thicket and FOR = Forest.

4.0 Discussion

4.1 Species composition and distribution

Throughout the study, the trap success was low compared to other studies on small mammals in the areas outside PAs. This might be attributed to low population densities especially considering the observed overall nature of the area which is mostly dry and associated with various forms of disturbances including prescribed burning and large herds of herbivores in particular buffaloes. However, low catch within PAs has been attributed to high predation and large mammals grazing as compared to areas outside these PAs (Caro 2001, 2002). Frequency of disturbance especially by large herds of herbivores (buffaloes) observed in the study area could influence the vegetation and consequently small mammal densities (Mulungu et al. 2008). According to Hoffman and Zeller (2005), large mammal activities influence small mammal distribution through removal of cover, food and competition. Other factors include unstable food supply in the PAs and resources competition with large herbivores (Caro 2001; Hoffman and Zeller 2005; Ogada et al. 2009). Predators including hyenas and leopards were observed while four different mongooses and *Genetta genetta* were captured.

High capture in closed woodland was a result of four dominant small mammal species; *A. ngurui, M. natalensis, L. rosalia and A. chrysophilus.* High catch of these species might be caused by effects of prescribed burning on pasture which is suitable for herbivore murids (Namukonde and Simukonda 2018). In addition, these areas were higher as compared to other habitats which affirms the theory that higher areas like mountains are good habitat for small mammals during harsh climates (Mulungu et al. 2008). Population fluctuation was observed in closed woodland suggesting an effect of habitat changes with season, prescribed burning effects and large herbivore activities. Low catch recorded in perennial riverine forest/thickets was possibly due to sparse undergrowth which might affect food and shelter that are key to small mammal survival. This is in line with report by various authors (Monadjem and Perrin 2002; Makundi et al. 2005; Mulungu et al. 2008; Venance 2009; Mohammadi 2010), that environmental factors can shape co-existing species differently depending on localities and seasons thus affecting their occurrence and fluctuation in a given habitat. For example, some species might have died due to erratic runoffs caused by heavy rain and presence of water lodged areas.

On distribution, *A. ngurui* and *L. rosalia* were captured in all four habitats. The genus *Acomys* has been reported to be widely distributed in tropical Africa (Mbugua 2002; Kingdon 2015). However, Venance (2009) reported the species to be restricted on one habitat (Acacia-Dalbergia woodland) was possibly caused by sampling intensity. *Lemniscomys rosalia* is established in the ecosystem and well adapted to prescribed burning, a common management phenomenon in most tropical African PAs characterized by miombo woodland. In addition, fire does not affect survival of this species and they tend to change their home ranges and activity patterns to accommodate its effects (Kingdon 1997; Monadjem and Perrin 1997; Yarnell et al. 2008). On the other hand, *M. natalensis* appeared in late September 2018 in closed woodland after a prescribed burning incidence and dominated the catch in this habitat until January 2019. Its occurrence after fire affirms the species to be a recolonize after disturbance (Monadjem and Perrin 2002; Massawe et al. 2005; Massawe et al. 2008). However, its density decreased with increasing vegetation cover in the wet season. On contrary, as *M. natalensis* catch decreased, *A. chrysophilus* and *L. rosalia* dominated the catch during this time suggesting a variation in habitat suitability by seasons between these murid species.

Rattus rattus, *A. paludinosus*, *G. sanguinea* and *C. ansorgei* were the least occurring species in this study. Restriction of *Cricetomys ansorgei* to seasonal riverine forest is contrary to Kingdon (2015), who suggested they vary extensively on their habitats. A possible reason for its occurrence may be habitat suitability in seasonal riverine forest which is characterized by sandy-loamy soils in most areas and dense vegetation and associated with human (rangers base camp). Although there were no agriculture activities in the area, the possibility that could be deduced is that, it was associated with humans. The other three habitats are mainly rocky areas and might not support this species especially considering their requirement of extensive burrows (Kingdon 2015). *Genetta genetta* occurred in forest and perennial riverine forest/thickest might be associated with its territorial, solitary and semi-arboreal life which the two habitats are suitable (Amroun et al. 2014).

Grammomys selousi is reported for the first time in the northern part of Rufiji River. This species was first reported by Denys et al. (2011) in the southern part of Rufiji River in Kichi Coastal Forest and since then, no records have been in place out of this area. The species was captured in all four habitats which *G. surdaster* was captured. Availability of this species in the northern part of Rufiji River suggests that the species is a common resident in the entire northern part of the Selous ecosystem necessitating a further study on this species and its relative *G. surdaster*.

4.2 *Acomys ngurui* abundance

Acomys ngurui was the most captured species in this study. The high catch of *A. ngurui* can be explained by dry and hot with rocky outcrops habitat which is suitable for this species (Ogada et al. 2009; Kingdon 2015). Low abundance in perennial riverine was possibly caused by sparse undergrowth. High abundance of *A. ngurui* in wet season affirm the effects of rainfall on rodent species abundance through increased food and cover (Alemayehu and Bekele 2013; Bantihun and Bekele 2015). In all habitats, *A. ngurui* abundance was higher in January 2019 and except for seasonal riverine forest, abundance was also higher in January 2020 suggesting consistent patterns in the three habitats. In general, although no statistically significant variation was noted in monthly trend, there is a clear pattern of abundance fluctuation with slight changes in the four habitats mostly being in January which covers end of short rains and May which end of wet season. Variation in abundance in each habitat suggests a possible varied effect resulting from different environmental factors such as cover, predation, food and competition as reported by Makundi et al. (2005). The occurrence of this species in such high numbers in the four habitats suggest a possibility that, there might be more than one species of *Acomys* in this area.

4.3 Species richness and diversity

The observed high richness and diversity in the seasonal riverine forest and forest habitat can be explained by availability of cover and food which are reported to determines the level of competition and niche differentiation. The niche theory suggests that different species are confined in their specific niche and are limited by different environmental factors thus allowing coexistence (Hubbell, 2001; Tews *et al.*, 2004; Stein *et al.* (2014). In addition, various authors have pointed out that floristic diversity, spatial and temporal heterogeneity and habitat complexity in a given habitat influence food and shelter and thus species occurrence (MacArthur and MacArthur, 1961; Wright, 2002; Makundi *et al.,* 2005; Mukinzi *et al.,* 2005; Mulungu *et al.,* 2008; Elmouttie, 2009; Venance, 2009; Yihune and Bekele, 2012). The habitat complexity provides species with variable feeding options which are necessary in energy reduction in foraging (Elmouttie, 2009; Garshong *et al.,* 2013). Low diversity in perennial riverine forest/thickets could be due to the nature of the area (a cliff riverine with rock outcrops in most areas and sparse undergrowth and frequent disturbances from large herbivores mainly buffalos). Low diversity in closed woodland was caused by occurrence of four dominant species i. e. *A. ngurui*, *L. rosalia*, *A. chrysophilus* and *M. natalensis* which affected evenness as compared to other habitats.

Seasonal effect on diversity was notable in seasonal riverine forest and perennial riverine/thickets habitats which recorded only one species (*A. ngurui*) in May 2019, possibly due to heavy rainfall between March and June 2019, thus affecting the species diversity. Transition period recorded the highest species diversity in the three habitats except in seasonal riverine forest suggesting this season to favor small mammals in the ecosystem. The difference observed in seasonal riverine might be due to vegetation cover hence food supply in a small area. In addition, there were no erratic runoffs in wet season which might impose direct mortality to small mammals as observed in closed woodland and perennial riverine/thickets habitats. Low number of individuals might also be the reason for low trappability and thus affecting diversity. Another possible reason that might affect diversity can be reduced home range due to resource availability in a smaller area in wet season as pointed out by Borremans (2013) and thus affecting trappability. However, these results are contrary to what was reported by Assefa and Srinivasulu (2019).

4.4 Communities similarity and small mammals' species habitat association

Most species in this study were associated with closed woodland and seasonal riverine forest. Most murids, except *R. rattus* were associated with closed woodland which was characterized by tall grass cover an ideal habitat for both shelter and food for murids. The occurrence of *R. rattus* in the seasonal riverine forest can be explained by association with human where this area is close to main ranges camp in the Selous ecosystem. These two habitats were relatively complex in terms of vegetation cover and microhabitats which were possibly the factor for preference of more species. According to Mukinzi et al. (2005), a complex habitat will provide for niche separation and hence reduced competition in relatively small area due to availability of constant food supply and shelter. Liu et al. (2018), reported that, species will be successful in a given habitat in terms of dominance and abundance only if it associates well with its habitat. This means, it will be able competitively dominate the area over other species or coexist. Species usually coexist through evolution by occupying different resources through time and space which is a driver for species habitat association (Chuyong et al. 2011). On contrary, few species including *B. hindei, G. surdaster*, *G. selouis* and *O. garnetti* suggests to be habitat generalist as they occurred almost at the center of all habitats. Another species with a different occurrence was *G. genetta*, although captured in more than one habitat and a carnivore which was expected to associate with murid species as a predator, it was associated with perennial riverine forest/thickets suggesting a preference to other sources of food other than small mammals.

5.0 Conclusions and Recommendations

This study has provided an important information for updating the current small mammal distribution maps with a new species of murid (*G. selousi)* being reported for the first time in the northern part of Rufiji River. In addition, findings of this study show that small mammal species abundance, diversity and distribution are largely influenced by habitat types, seasonal variations and a community and at individual species such as *A. ngurui*. Overall, the results from this study suggests the management actions including prescribed burning, infrastructure development and general management plans (GMP) should be updated to include the distribution of small mammals in the park. In addition, considering the importance of this component to the ecosystem, additional studies on small mammals ecology are recommended in this ecosystem.

Acknowledgements

We are grateful to the African Center of Excellence for Innovative Rodent Pest Management and Biosensors Technologies Development (ACE-II) under the Institute of Pest Management of Sokoine University of Agriculture (SUA) for funding this research work which is part of Aenea Saanya PhD study. We are grateful to Tanzania Wildlife Management Authority (TAWA) and Tanzania National Parks (TANAPA) for granting us permission to work in Selous ecosystem. We are indebted to our field team; Khalid Kibwana and Ramadhani Kigunguli of Insitute of Pest Management - SUA and Selous Game Reserve/Nyerere National Park ecologists; Singira Ngoishie and Charles Tarimo for security and guidance. We thank Michael Kimaro and Simon Chidodo of SUA for assisting in the data analysis and Prof. Josef Bryja for species confirmation using molecular technique.

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CHAPTER THREE

PAPER TWO

Effects of prescribed burning on rodents’ ecology in a miombo woodland ecosystem in the Nyerere National Park, Tanzania

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Submitted to African Journal of Ecology – ID: AFJE – 21 – 107 (Under review)

Abstract

Prescribed burning is a common management practices in most miombo woodland protected areas that highly influences vegetation structure and composition which in-turn influence small mammals’ distribution and abundance. This practice if not checked might significantly affect the ecosystems. We investigated the effects of prescribed burning on rodent’s ecology in the miombo woodland ecosystem in Nyerere National Park in the Selous ecosystem, Tanzania, between July 2018 and June 2020. Two sites (burnt and unburnt) were selected and a Complete Randomized Design (CRD) was used. In each site, two grids of 70 m x 70 m were established. The Capture Mark Recapture (CMR) technique with Sherman's traps was used. All the captured animals were identified to species level, sexed, weighed and marked by toe clipping and released at the site and point of capture. A total of 514 individuals comprising of six rodents and two insectivorous were captured out of 14 112 trap nights. There were statistically significant differences in abundance of *A. ngurui* between burnt and unburnt areas (W = 0.892, p = 0.0004) and between habitats across seasons (Deviance = 5.356, df = 1, p = 0.021). *Mastomys natalensis* abundance increased after the prescribed burning although its abundance was not statistically significant different between burnt and unburnt areas (W = 344.5, p = 0.225) but significant across seasons (Deviance = 3.606, df = 1, p = 0.05). The burnt sites had the highest species diversity (H' = 1.551) than unburnt in both wet and dry seasons. *Acomys ngurui* and *M. natalensis* survival (E = -0.481±11.233, z = -0.428, p = 0.669 and E = 0.377±7.044, z = 0.054, p = 0.957 respectively) and recruitment (E = 7.316±13.876, z = 0.528, p = 0.598 and E = 1.023±11.598, z = 0.088, p = 0.930 respectively) were not statistically significant different between burnt and unburnt sites. The study show that prescribed burning has an effect on specific species and demographic characteristics and the effects vary with species and site. Therefore, conservation managers are advised to maintain the current cycle of prescribed burning in the Northern Nyerere National Park since any alteration might affect some small mammal species.

Key Words: Small-mammals, Abundance, Richness, Diversity, Breeding-patterns, Distribution, Selous ecosystem

1.0 Introduction

Fire is a natural ecological phenomenon in miombo woodland that highly influences vegetation structure and composition which in-turn affects small mammal distribution and abundance (Witecha, 2011). In Nyerere National Park, prescribed burning is performed mainly between late June and early August. Prescribed burning is mainly meant for nourishing pasture, and enhance gemination of some species of miombo trees, in addition to reducing pest load and improving access to wildlife (Morris *et al.*, 2011; Green *et al.*, 2015). Block *et al.* (2016) reported that, there are more positive effect of fire than negative. Frequency of fire has positive effects on tree and herbaceous species richness and contributes to a heterogeneous habitat (Sheuyange *et al.,* 2005), which is ideal for high abundance and richness of fauna. Maishanu *et al.* (2017) reported that, vegetation biomass yield is higher in the burnt than unburnt areas suggesting a positive effect for herbivores.

Small mammals play an important role in ecosystem health through their interactions with the biotic and abiotic factors within their habitat (Mulungu *et al.,* 2008; Makundi *et al.,* 2009; Marrocoli, 2011). They are crucially involved in maintaining food web and chain (Heinze *et al.,* 2010; Yihune and Bekele, 2012). Their interactions with the environment have complex effects on ecosystems (Makundi *et al.,* 2009). Among the factors influencing rodents' distribution include, vegetation type and density, rainfall patterns, temperature and soil types (Massawe *et al.,* 2008; Makundi *et al.,* 2009). Their greater diversity in morphology, physiology, behavior and life history strategies have made small mammals to thrive successful in different wide-reaching conditions (Hope and Parmenter, 2007). Thus, any population fluctuation within small mammal communities may affect energy and nutrient transfer through the food web, ultimately affecting the overall energy and dynamics of ecosystems (Shenko *et al.,* 2012). Among the key factors for these fluctuations is habitat disturbance and destruction (Shenko *et al.,* 2012). In the tropics, vertebrates exhibit certain ecological characteristics including rarity, endemicity, uneven distribution and specialization which are susceptibility to habitat destruction/fragmentation (Lawrence, 1994).

Knowledge on animal species' habitat requirements is a requirement towards managing and conserving them (Kneib, 2007). According to Feilhauer *et al.* (2011) and Sabuni *et al.* (2015), the environmental limiting factors (water, temperature, nutrients, food and moisture) that shape the physiology are important determinants of species distribution. However, the driving factors for species distribution are not yet clearly known in the ecological world (Araujo and Guisan, 2006). Habitat disturbances are a major threat to species survival and distribution (Feilhauer *et al.*, 2011). Any kind of habitat change has serious effects on small mammal community composition, abundance, diversity, total biomass and distribution (Heinze, *et al.*, 2010). It impacts the general health condition of mammal species through compromising sex ratio, reproduction and endocrine disruption (Acevedo-Whitehouse and Duffus, 2009). Fragmentation and transformation of once contiguous natural habitat can cause increase in species extinction (Hagenah, 2006; Marrocoli, 2011; Ofori *et al.,* 2013). For example, in Costa Rica, primary forests have decreased significantly due to conversion of forests to pasture lands leading to dramatic decline in wildlife species (Marrocoli, 2011).

According to Fitzherbert *et al.* (2006) and Marrocoli, (2011), few studies have been conducted on small mammals particularly in the tropic and miombo areas. Studies on small mammal fauna in southern Tanzania are limited (Denys *et al.*, 2011). Selous ecosystem forms a major part of southeastern Tanzania and practice prescribed burning as a management tool. However, information on the effect of prescribed burning on rodents' ecology in the Selous ecosystem is inadequate. For effective and efficient management of ecosystems, knowledge on important components of the ecosystem is important. Rodents contribute about 40 percent of all known mammals and it is important to know how they are affected by habitat alteration including various management practices (Cusack, 2011; Happold, 2013) such as prescribed burning. This study aimed at determining the effect of prescribed burning on rodents' ecology in the Nyerere National Park (NNP). We hypothesized that prescribed burning is not a determinant factor in rodents' abundance and diversity in the NNP.

2.0 Materials and Methods

2.1 Study area

The study was conducted between July 2018 and June 2020 in the miombo woodland in the Selous ecosystem, specifically in the NNP (Figure 1), which covers an area of about 32,000 km^2. It is located in the southeastern part of Tanzania between 7°20' to 10°30'S and 36°00' to 38°40'E (MNRT, 2012). The area falls within the bimodal rainfall belt of southern Tanzania and annual rainfall ranges from 750 mm in the east to about 1 300 mm in the west, falling mainly between mid-November and mid-May (Jihnson, 2003). The park forms part of the former Selous Game Reserve (SGR) which constitutes a globally important example of vegetation types that is between Somali-masai and Zambezian regional centers of endemism and mostly on the later (URT, 2005). The area possesses diverse flora with an estimated total of over 2 000 species with exceptionally high variety of habitats (McGinley, 2008). The ecosystem harbors significant populations of wildlife including vulnerable (African elephant - *Loxodonta africana africana*) endangered

(African wild dog - *Lycaon pictus*) and critically endangered (Black rhinoceros - *Diceros bicornis minor*) species among many others (UNEP-WCMC, 2011). There are about 450 species of birds among them endemic and rare, which makes the area among the few Important Bird Areas (IBA) in the region (Briggs, 2008). The miombo woodland is dominated by *Brachystegia spicifomis*, *Julbernardia globiflora*, *Afzelia quanzensis*, *Pterocarpus angolensis*, and *Salvadora perisca.* Common grasses are *Hyparrhenia newtonii*, *Andropogon gyanus* and *Hyparthelia dissolute* (URT, 2005). The dominant soils are black cotton with rough slopes characterized by rock outcrops in most parts.

2.2 Fire treatment

The aim was to establish the effect of prescribed burning on rodent community ecology in NNP. A Complete Randomized Design experiment was set up within two sites in the miombo woodland particularly open woodland each with two unburnt (Plate 1) and two burnt (Plate 2) grids. The prescribed burning was conducted during August of 2018 and 2019. The distance between burnt and unburnt sites were ten kilometers apart and the replicates were about 500 meters apart to ensure no species overlap between grid in the same site since the home range of the most species in a free range were between 200 and 2000 m^2 (Mulungu *et al.*, 2015).

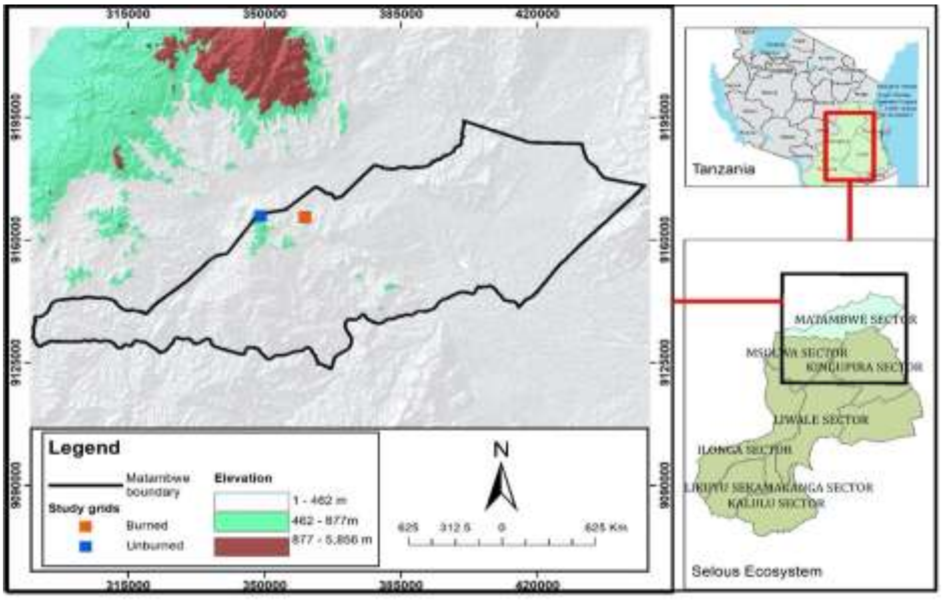


Figure 1: Study area in Nyerere National Park in the Selous ecosystem, Tanzania

Plate 1: Unburnt area

Plate 2: Burnt area

2.3 Small mammals trapping

We defined small mammals as all mammal species that could be trapped using medium sized (LFA, 7.5 x 9 x 23 cm) Sherman’s traps (H.B. Sherman Inc.). We used Capture-Mark-Recapture (CMR) as a method of choice for this study. In each site, we established a grid of 70 m x 70 m with seven parallel lines at a distance of 10 meters apart. In each line, there were seven trapping stations and in total 49 stations in each grid following Hoffmann, *et al.* (2010). Each trapping station was marked by coordinates using Global

Positioning System (GPS). A mixture of peanut butter and maize bran were used as bait. All traps were checked before 10:00hrs in each trapping day at four weeks interval for three consecutive nights in each trapping session from July 2018 to June 2020. Identification of captured species in the field followed available distribution maps as provided by Kingdon (1997 and 2015) and experts from the Institute of Pest Management, Sokoine University of Agriculture. Reproductive condition, weight (to the nearest gram) and sex were documented. We used toe clipping to mark the capture animals and animals were released at the site and point of capture. The clipped toes were preserved in 70% alcohol and were used for species confirmation using molecular (Cytochrome *b*) technique. The remaining samples are stored at Sokoine University of Agriculture – Institute of Pest Management Morogoro, Tanzania, for further studies.

2.4 Data Analysis

Species composition and abundance

Small mammals' species composition was expressed as the total number of different species and their contribution in that community in both burnt and unburnt sites. Small mammal species abundance was estimated using Minimum Number Alive (MNA) index for the most abundant species in this study. MNA refers to number of individuals captured and survived (recaptured) in the next events during trapping sessions (Krebs, 1966). Data normality test was performed using Shapiro_test function in R software version 3.4 (R Core Team, 2020). Sicne our data were not normally distributed (W = 0.892, p = 0.0004), we used Wilcox_test to compare abundance of *Acomys ngurui* and *M. natalensis* between burnt and unburnt areas. Similarly, we performed non-normal generalized linear model with Poisson error distribution by utilizing glm function with link = log argument to compare mean differences of abundance between seasons and burnt and unburnt areas. We performed robust regression by utilizing rlm function from MASS and sfsmisc packages in R software version 3.4 (R Core Team, 2020), to assess trend of abundance of *A. ngurui* and *M. natalensis* on monthly basis. To extract *p* values from rlm, we utilized f.robftest function. We used abundance as response variable and months as explanatory variable.

Species richness and diversity

Species richness was estimated as number of different species in the sample during this study. The Shannon-Wiener Index (H') was used to establish species diversity across months and seasons.

The Shannon – Wiener diversity index (H′) is estimated as follows;

$$H' = -\sum_{i=1}^{s} (p_i)\,(\mathrm{In}\,p_i)$$

Where; H′ is information content of a sample, species diversity index, *s* is number of species, *P*i is the proportion of individuals of the i^{th} species or the abundance of the i^{th} species expressed as the proportion of the total individuals and *In* is natural log of individual proportion.

Age structure

In this study, the age structure was determined for *M. natalensis* only because its age structure is correlated with its weight (Leirs and Verheyen, 1995). Age groups were juvenile (≤ 20 g), Sub – adults (between 21 – 24 g) and adults (> 24 g). Age groups were compared using Wilcox.test of *M. natalensis* between burnt and unburnt sites. We used generalized linear model with non-normal Poisson error distribution, to compare mean differences between age for *M. natalensis* in burnt and unburnt sites. Similarly, we used generalized linear model with non-normal Poisson error distribution to compare mean differences between age groups and seasons.

Recruitment and Survival

Recruitment and apparent survival were computed from the CMR history. Recruitment is defined as the number of new captured individuals that have entered the marked population in each occasion. Apparent survival is defined as the probability of recapturing the marked animal in different occasions after treatment (Griffiths and Brook, 2015). In all occasions the assumption was that there is ability to detect new and old individual through the marks applied. We used generalized linear model (GLM) with logistic regression for recruitment and survival proportions data by using built-in function called “family = binomial” in R software to explore relationship between burnt and unburnt sites with recruitment and survival proportions. Burnt site was coded as “1”, and unburnt site was coded as “0”. For monthly trend variations, we used robust regression model by using rlm function from MASS and sfsmisc packages to assess monthly trends of capture proportions for *A. ngurui* and *M. natalensis* recruitment and survival. Treatment (burnt and unburnt areas) were treated as response variable, while months were explanatory variable.

Sex ratio and breeding patterns

Sex ratio is defined following Mulungu *et al.* (2013). Females sexual activity in most cases are synchronized with availability of resources as opposed to males which might be active throughout the year regardless of essential resources availability (Mulungu *et al.*, 2013). The female population is expressed as follows;

$$r = f/m + f$$

Where; r = sex ratio, f is number of females in the sample and m is males in the sample.

Sex ratio and breeding patterns of *A. nguri* and *M. natalensis* were compared using wilcox.test between treatments. We used generalized linear model with binomial error distribution, in which proportions were treated as response variable, while season and treatment with burnt and unburnt categories were treated as explanatory variables.

3.0 Results

3.1 Species composition and trap success

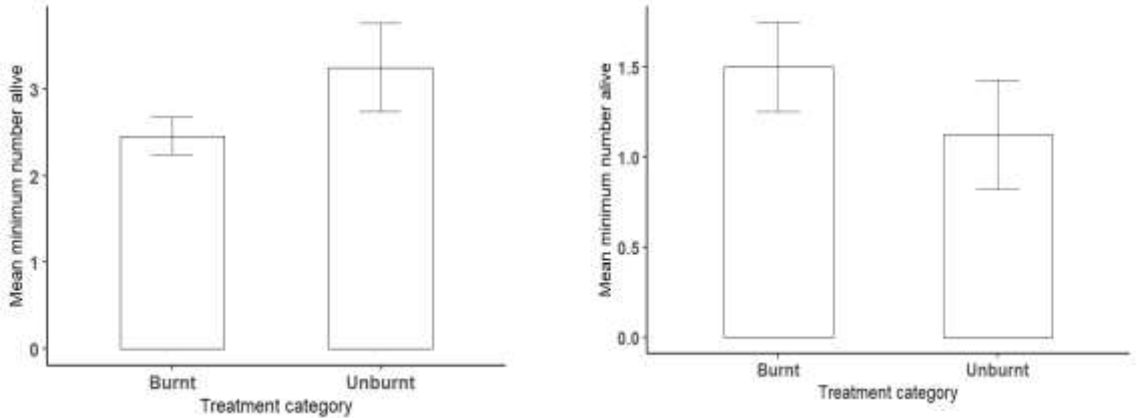
A total of 514 individuals from eight species were captured from July 2018 to June 2020 from 14 112 trap nights with 3.6% trap success. Six rodent species and two insectivorous (with their percentage contribution in the brackets) were captured (Table 1).

3.2 Species abundance

There was statistically significant difference in abundance of *A. ngurui* between burnt and unburnt areas (W = 0.892, $p = 0.0004$) (Figure 2a) and between seasons (D = 2.644, df=1, $p = 0.021$) (Figure 2c). The abundance of *M. natalensis* was not statistically significant difference between burnt and unburnt areas (W = 344.5, $p = 0.226$) (Figure 2b) but significantly difference between seasons (D = 3.606, df = 1, $p = 0.05$) (Figure 2d).

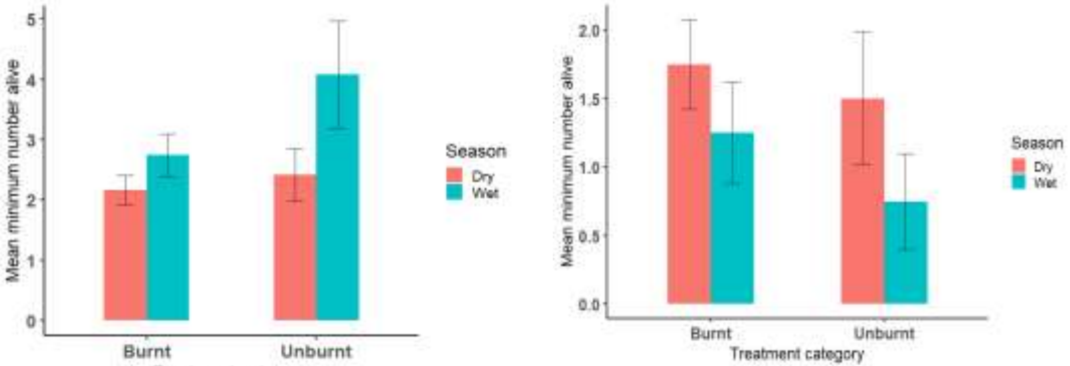
Table 1: Small mammals' species composition and percentage contribution of each species in Nyerere National Park, Tanzania

sn	Species	Site					
		Burnt	**%**	**Unburnt**	**%**	**Overall**	**%**
1	*Acomys ngurui* Verheyen *et al.*, 2011	47	14%	102	60%	149	28.99%
2	*Aethomys chrysophilus* de Winton, 1897	137	40%	9	5%	146	28.40%
3	*Mastomys natalensis* Smith, 1834	59	17%	37	22%	96	18.68%
4	*Lemniscomys rosalia* Thomas, 1904	69	20%	7	4%	76	14.79%
5	*Petrodromus tetradactylus* (Peters, 1846)	15	4%	7	4%	22	4.28%
6	*Mus minutoides* Smith, 1834	9	3%	5	3%	14	2.72%
7	*Paraxerus flavovittis* (Peters, 1852)	7	2%	2	1%	9	1.75%
8	*Crocidura hitra* Peters, 1852	2	1%	0	0%	2	0.39%
	Total captures	**345**		**169**		**514**	
	Species richness	**8**		**7**		**8**	
	Trap success	**5%**		**2%**		**3.6%**	



a. A. ngurui

b. M. natalensis



c. A. ngurui

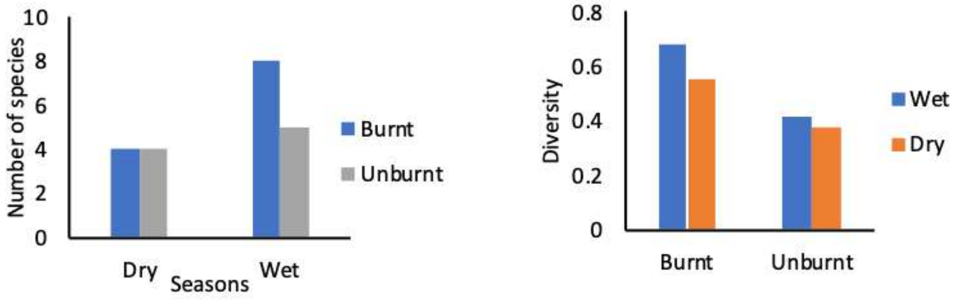
d. M. natalensis

Figure 2: Abundance of *A. ngurui* and *M. natalensis* between burnt and unburnt areas and seasons in Nyerere National Park, Tanzania.

The variation in monthly abundance patterns of *A. ngurui* in the burnt area was not statistically significant different ($F_{(1, 22)} = 1.459$, $p = 0.240$), as well as in unburnt area ($F_{(1, 22)} = 2.182$, $p = 0.154$). There were no statistically significant difference in monthly patterns of *M. natalensis* abundance in the burnt ($F_{(1, 22)} = 0.873$, $p = 0.360$) and in unburnt areas ($F_{(1, 22)} = 1.221$, $p = 0.281$).

3.3 Species richness and diversity

Species richness was statistically significant difference ($\chi^2 = 20.21$ df = 1 $p = 0.001$) between the two sites suggesting burnt areas to promote more species compared to unburnt areas. Seasonality had a statistically significant effect on the species richness ($\chi^2 = 11.65$, df = 1, $p = 0.0006$) with more species appearing in wet season (Figure 3a) although the difference statistically insignificant across months. The effect of prescribed burning on small mammals was statistically significantly notable ($\chi^2 = 17.12$ df = 1, $p = 0.0000$) in burnt areas across seasons and insignificant in unburnt sites. Highest species diversity (H' = 1.551) was recorded in burnt sites than in unburnt sites (H' = 0.759). Diversity differed with seasons where, wet season had the highest diversity (H' = 0.687) while dry season had the least (H' = 0.592). Diversity differed with season where in both burnt and unburnt, wet season showed higher diversity (H' = 0.679 and 0.419 respectively) than the dry season (H'= 0.556 and 0.382 respectively) (Figure 3b).



a. Richness

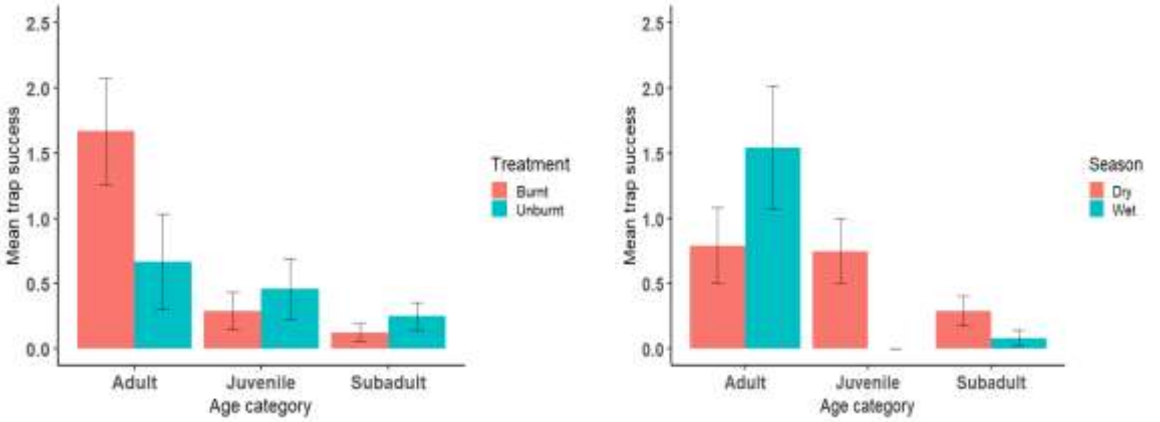
b. Diversity

Figure 3: Seasonal differences in small mammals' (a) richness and (b) diversity in burnt and unburnt sites in Nyerere National Park, Tanzania.

3.4 Demographic characteristics

Age structure

Adults were the most captured group in both burnt and unburnt sites. There was statistically significant difference between age categories (Deviance = 43.225, df = 2, $p <$ 0.000) and not between treatment categories (Deviance = 3.507, df = 1 $p = 0.061$) (Figure 4a). Overall, there were no statistically significant difference between age groups between treatment across seasons (Deviance = 0.301, df = 1, $p = 0.583$) (Figure 4b). Monthly occurrences of juveniles were restricted between late dry and early September to November in both sites suggesting breeding was at the beginning of wet season. Sub-adults showed the same distribution pattern as juveniles occurrence was higher in unburnt areas than in burnt sites.

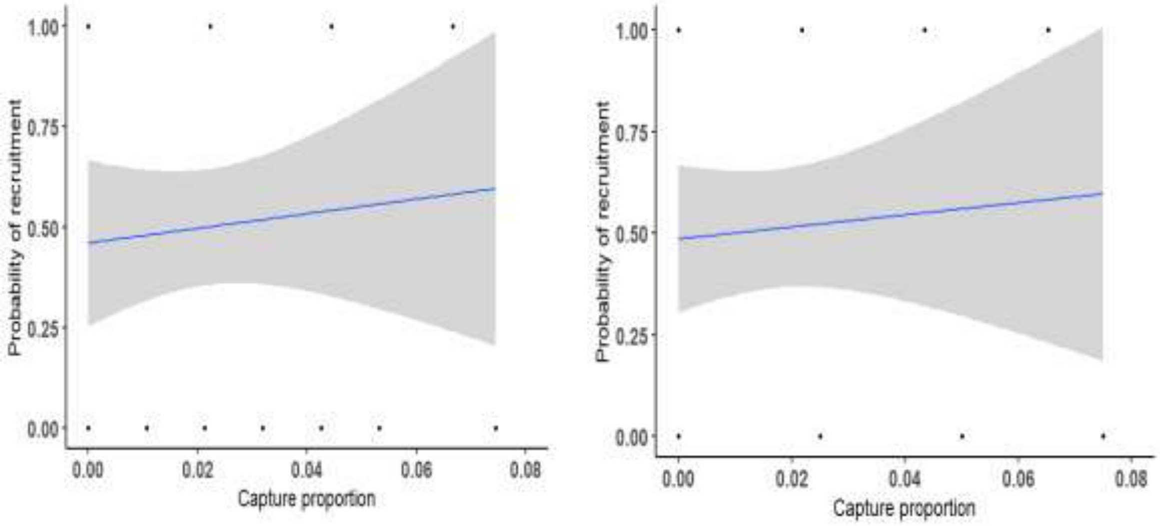


a. Treatment b. Seasonal variation

Figure 4: Mean age structure (±SE) of *M. natalensis* per treatment (a) and seasonal (b) variation in Nyerere National Park, Tanzania

Recruitment

Acomys ngurui recruitment occurred throughout the study period in all sites. Monthly recruitment probability for *A. ngurui* in burnt and unburnt sites was not statistically significant (E = 7.316 ± 13.876, z = 0.528, $p = 0.598$) (Figure 5a) and monthly patterns (E = 1.819 ± 3.504, t = 0.519, $p = 0.606$). *Mastomys natalensis* showed two peaks of recruitment in both sites between August and April. However, *M. natalensis* monthly recruitment probability in burnt and unburnt sites was not statistically significant (E = 1.023 ±11.598, z = 0.088, *p* = 0.930) (Figure 5b). There were no statistically significant difference in monthly patterns of survival for *A. ngurui* (E = 1.819 ± 3.504, t = 0.519, *p* = 0.606) and *M. natalensis* (E = -1.197 ±2.84, t = -0.421, *p* = 0.675) between burnt and unburnt areas.



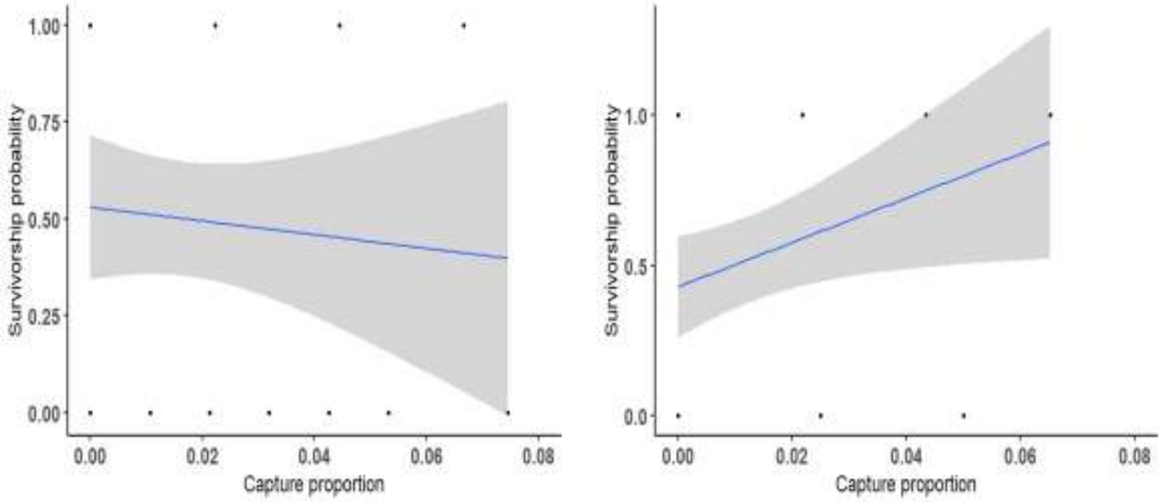
a. *A. ngurui*

b. *M. natalensis*

Figure 5: Probability of recruitment for *A. ngurui (*a) *and M. natalensis* (b) observed in Nyerere National Park, Tanzania.

Apparent Survival

Acomys ngurui had higher survival in the wet season between February and May 2020 than the rest of the years. Monthly survival probability for *A. ngurui* in burnt and unburnt sites was not statistically significant (E = -0.481 ± 11.233, z = -0.428, *p* = 0.669) (Figure 6a). *Mastomys natalensis* recorded high survival rates in January 2019 and February 2020, but the monthly survival probability for *M. natalensis* was not statistically significant between burnt and unburnt areas (E = 0.377 ± 7.044, z = 0.054, *p* = 0.957) (Figure 6b). There were no statistically significant difference in monthly patterns of survival for *A. ngurui* (E = 1.819 ± 3.504, t = 0.519, *p* = 0.606) and *M. natalensis* (E = -0.256 ±2.961, t = -0.086, *p* = 0.931) between burnt and unburnt areas.



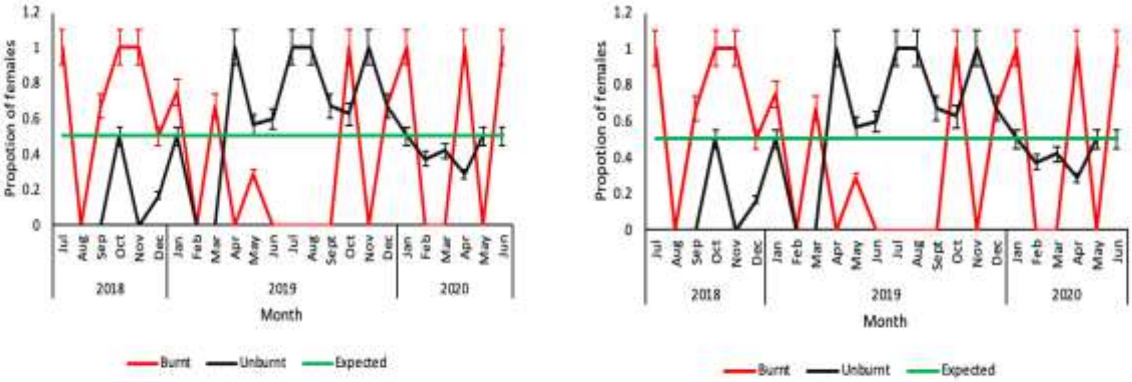
a. *A. ngurui* b. *M. natalensis*

Figure 6: Survival probability of *A. ngurui* (a) and *M. natalensis* (b) in burnt (1) and unburnt (0) treatments observed in Nyerere National Park, Tanzania.

Sex ratio

Acomys ngurui sex ratio was not statistically significant different between burnt and unburnt areas (W = 254, *p* = 0.473). There were no statistically significant differences in monthly trend of sex ratio between burnt and unburnt (E = 0.063±0.124, t = 0.513, *p* = 0.61) for *A. ngurui* (Figure 7a). *Acomys ngurui* sex ratio did not differ significantly between dry and wet season (E = 0.619 ± 0.591, z = 1.05, *p* = 0.294). *Mastomys natalensis* sex ratio differences were not statistically different between burnt and unburnt areas (W = 300, *p* = 0.772). The difference in *M. natalensis* sex ratio monthly trend were not statistically significant in between burnt and unburnt areas (E = 0.008 ±0.03, t = 0.277, *p* =

0.783) (Figure 7b). Seasonality showed no significant effect on *M. natalensis* sex ratio between burnt and unburnt areas (E = 0.39 ± 0.707, z = 0.553, *p* = 0.58).



a. A. ngurui

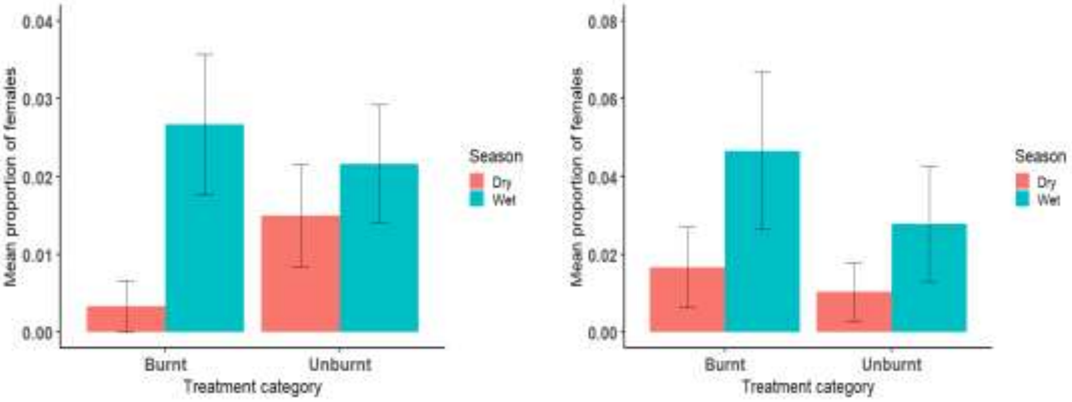
b. M. natalensis

Figure 7: Mean (±SE) monthly and seasonal sex ratio for *A. ngurui* (a) *and M. natalensis* (b) observed in Nyerere National Park in Tanzania.

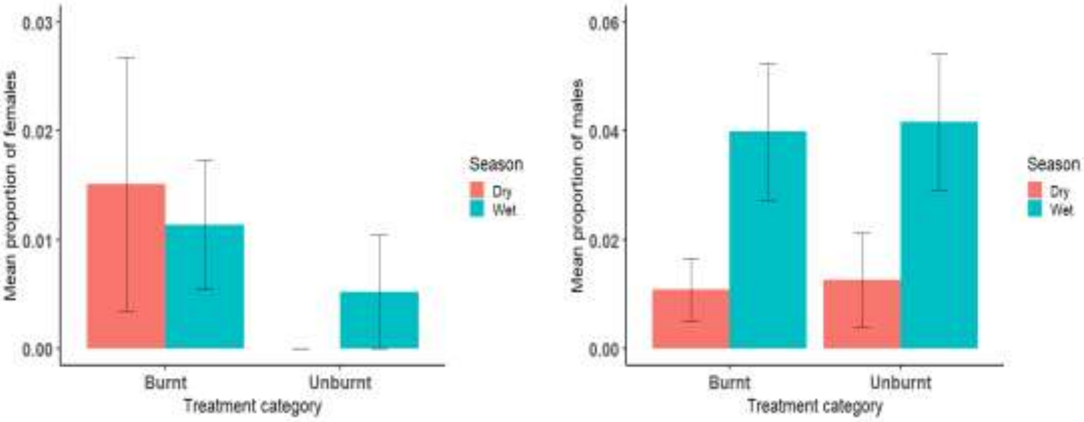
Breeding patterns

There were no statistically significant variation in the reproductive activity of females (W = 230, *p* = 0.163) and males (W = 256, *p* = 0.466) between burnt and unburnt sites of *A. ngurui*. Seasonal effect on female reproductive activities of *A. ngurui* were not statistically significant (E = 0.985 ± 0.2.521, z = 0.391, *p* = 0.696) (Figure 8a), and on males (E = 1.272 ± 2.156, z = 0.59, *p* = 0.555) (Figure 8b).

There were no statistically significant variation observed in females and males reproductive activities of *M. natalensis* (W = 338.5, *p* = 0.072 and W = 335, *p* = 0.221 respectively). The differences in reproductive activity between burnt and unburnt areas across season for females (E = 0.091 ± 3.264, z = 0.028, *p* = 0.977) (Figure 8c) and males (E = 1.037 ± 2.071, z = 0.501, *p* = 0.617) (Figure 8d) were not statistically significant.



a. *A. ngurui* females b. *A. ngurui* males



c. *M. natalensis* females d. *M. natalensis* males

Figure 8: Mean (±SE) breeding patterns (Reproductive active males and females) of *A. ngurui* and *M. natalensis* observed in burnt and unburnt sites in Nyerere National Park Tanzania.

4.0 Discussion

Fires in heterogenous mosaic habitat affect species differently and can be positive, negative or neutral (Block *et al.,* 2016). The current study has shown that prescribed burning has positive effect on the abundance, richens and diversity of small mammal communities in Nyerere National Park. Burnt areas favored higher species richness than unburnt areas throughout the trapping sessions except in the first two months when fire was applied. Small mammal species recolonized the burnt areas immediately after fire suggesting species adaption to fire. The peak recolonization was far in the mid wet season suggesting small mammals to be more relaxed in the wet season when resources are abundant. The observed small mammals' responses to prescribed burning in Nyerere National Park conforms to reports by various authors (Yarnell *et al.,* 2008; Massawe *et al.*, 2006) that small mammals might have developed strategies of avoiding, changing activity patterns or hibernating in barrows. Generally, prescribed burning is in favor of herbivore-murids in Nyerere National Park as compared to other groups like insectivores which were captured in low numbers. The results from this study agree with those reported by Manyonyi *et al.* (2020) who recorded high abundance of rodents in burnt than in unburnt areas. The areas experiencing prescribed burning could probably be rich in food especially due to the natural cycle of miombo vegetation recovery. According to Namukonde and Simukonda (2018) prescribed burning is meant for various purposes among them is improving pasture and accessibility for wildlife. According to Witecha (2011) fire is a natural ecological phenomenon in miombo woodland that highly influences vegetation structure and composition which in-turn influence small mammals' distribution and abundance.

Species richness has been reported to increase with decreased fire frequencies and intensity (Legge *et al.*, 2019). The results from this study do not support this conclusion as richness was higher in burnt areas than in unburnt areas throughout the trapping session. Species were not affected by fire age (months) since diversity increased as the period between the last fire treatment and trapping event increased. These results are supported by those reported by Namukonde *et al.* (2017). Species in unburnt sites were trapped in low numbers suggesting accumulation of vegetation in miombo woodland could affect small mammal diversity. A slight alteration of prescribed burning cycles can affect the small mammal communities and may cause local extinction due to vegetation succession (Morris *et al.,* 2011; Bowman *et al.,* 2017).

Acomy ngurui was captured throughout the study period in both burnt and unburnt areas. Habitat suitability (dry areas and rocky areas) favored high catch of *A. ngurui* in Nyerere National Park as reported by Kingdon (2015) and Aghova *et al.* (2019). These findings are in line with several other studies in miombo woodland such as Block *et al.* (2016) and Namukonde and Simukonda (2018). The occurrence of *A. ngurui* in burnt areas might be associated with its recolonization ability in areas once subjected to fire especially taking into consideration the differences in dispersal ability, body size, habitat association and home range size (Buskirk, 2016) compared to species like *A. chrysophilus* and *L. rosalia* which prefer burnt than unburnt areas.

Mastomys natalensis recolonized the burnt areas in high numbers after prescribed burning treatments in the park. Other studies including Monadjem and Perrin (2002) in Swaziland reported that *M. natalensis* densities increased significantly after fire incidences. However, fire age showed a negative effect on *M. natalensis* as the species densities decreased significantly in the mid wet season. These results conform with those reported by Monadjem and Perrin (2002) and Massawe *et al.* (2006) who found *M. natalensis* to negatively correlate with vegetation cover.

Age structure is among the key determinants of populations stability, growth or decline through determination of reproductive potential of a population (Tarsi and Tuff, 2012). Age structure has been studied widely in small mammals and *M. natalensis* is among the species of which its body weight has been used to categorize age groups using its body weight (Leirs and Verheyen, 1995). The current findings suggest that age groups are affected by prescribed burning in Nyerere National Park. Adults were present throughout the trapping period in the unburnt area except in May, June and October 2019, while in burnt sites no adults were captured between April and October 2019. All juveniles were only captured between September and October in the two treatments suggesting there was no effect of fire on this group. These results are contrary to those reported by Manyonyi *et al.* (2020) suggesting that sub-adults were affected by decreased cover and probably increased predation.

Acomys ngurui and *M. natalensis* recruitment were high in unburnt than in the burnt areas although the differences were not statistically significant. Namukonde *et al.* (2018) reported that, competition for resources might be more relaxed in burnt areas since fire acts as a temporary and spatial disturbance in the context of stochastic community process. In addition, Maishanu *et al.* (2017) reported that, burnt areas have higher biomass yield than unburnt areas and might promote higher recruitment. The observed results might be a function of increased predation in the burnt sites regardless of improved food quality (Morris *et al.,* 2011; Block *et al.,* 2016; Namukonde *et al.*, 2018), thus affecting the recruitment rates. Seasonality favored higher recruitment in burnt compared to unburnt areas. This might not necessarily reflect the sole effect of prescribed burning, instead it could be associated with some other factors. Monthly recruitment varied between species with *A. ngurui* recruitment occurring throughout the year while *M. natalensis,* showed high recruitment in both late dry season and in the middle of wet season. Generally, higher proportional recruitments were recorded in the wet seasons in all site for the two species suggesting fire to not necessarily determine recruitment level.

Apparent survival of *A. ngurui* and *M. natalensis* species were more prominent in the burnt than in unburnt areas. These results agree with those reported by Block *et al.* (2016). However, there is no proof that fire promotes survival. In the current study no individuals of either species were captured in the burnt areas during August 2018 possibly due to immediate but short-term effect of fire. Fire might have caused the species to avoid the areas due to increased predation as a result of reduced cover (Morris *et al.*, 2011; Block *et al.*, 2016). This was obvious especially with the first recolonizes of both *A. ngurui*, and *M. natalensis.* Recaptures of *A. ngurui* which survived the fire were observed in September 2018. The survival of *A. ngurui* throughout the study period is consistent with Massawe *et al.* (2006) who reported that, fire has no detrimental effect to rodents and recolonization is a common phenomenon especially after the first rain.

Sex ratio is an important parameter that might affect small mammal community ecology (Fryxell *et al.*, 2015). When the sex ratio is significantly skewed towards males the probability of that population to collapse or go extinct increases (Ancona *et al.*, 2017). The more females are present in the community, the higher a healthier future is guaranteed. In the current study, overall, more males were captured than females possibly due to their activeness in search of mate as compared to movement of females. These findings conform with those reported by Tilahun *et al.* (2012), Bantihun and Bekele, (2015) and Mlyashimbi *et al.* (2020). From the results of this study, fire had no notable influence on the sex ratio of *A. ngurui* in the park but strongly influenced that of *Mastomys natalensis.* Although in both areas there were large numbers of *M. natalensis* their sex ratio were more pronounced in the burnt than in the unburnt areas.

In miombo woodland, the role of prescribed burning is to provide nutrients to soils and in combination with rainfall the availability of quality forage is achieved. In the present study, *A. ngurui* and *M. natalensis* reproductive activities were pronounced in the burnt than in unburnt areas, suggesting burning in combination with other factors do promote breeding activities in the park. This is due to improved quality and quantity of forage as reported by Maishanu *et al.* (2017). *Acomys ngurui* were almost sexually active throughout the year in both bunt and unburnt areas except for *M. natalensis* which were active in the wet season. In contrary, reproductive active females were mostly restricted to the wet seasons. Logically, females will confine reproductive activity to when resources are in full supply. Furthermore, it has been shown that rodent reproduction is affected by rainfall patterns (Odhiambo *et al.,* 2005). According to Alemayehu and Bekele (2013) rodents breeding reach peaks towards the end of the rain season when resources are plenty.

5.0 Conclusions and Recommendations

This study has demonstrated that, overall, prescribed burning as a management tool favors high abundance, richness and diversity of small mammals in Nyerere National Park. While for individual species, prescribed burning has shown varying effects both positives and negatives. *Acomys ngurui* and *M. natalesis* have shown variations in the effect of fire on various demographic characteristics, suggesting that, although they share the same habitat, prescribed burnig might affect them differently. Therefore, conservation managers are advised to maintain the current cycle of prescribed burning since any alteration might affect rodent species population dynamics.

Acknowledgement

We are thankful to the African Center of Excellence for Innovative Rodent Pest Management and Biosensors Technologies Development (ACE-II) of Sokoine University of Agriculture (SUA) for funding this research work which is part of Aenea Saanya PhD study. We are grateful to Tanzania Wildlife Management Authority (TAWA) and Tanzania National Parks (TANAPA) for granting us permission to work in Selous ecosystem. We are indebted to our field team; Khalid Kibwana and Ramadhani Kigunguli of Insitute of Pest Management – SUA and Selous ecologists; Singira Ngoishie and Charles Tarimo for security and guidance. We thank Michael Kimaro and Simon Chidodo of SUA for assisting in the data analysis and Prof. Josef Bryja for species confirmation using molecular technique.

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CHAPTER FOUR

PAPER THREE

Abundance, home range and species - habitat association of small mammal species in Nyerere National Park, Tanzania

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Submitted to Journal of Ecology and Evolution – ID = ECE-2021-08-01306 (Under review)

Abstract

We investigated the abundance, relative home ranges and species-habitat association of small mammal species in Nyerere National Park, Tanzania. Two habitats; closed woodland and seasonal riverine forest were selected and in each habitat two grids of 70m x 70m were established. A Capture Mark Recapture technique was deployed. All the captured animals were marked by toe clipping and released at the site of capture. From July 2018 to June 2020 a total of 732 small mammal individuals belonging to 19 species were captured in 14,112 trap nights with 5% trap success. Of the 19 species captured, 12 were rodents, two insectivorous, four carnivores; and one primate. *Acomys ngurui* abundance was not statistically significant different between habitats (W = 220, df = 1, p = 0.144) and across seasons ($F_{(2,\ 45)}$ = 1.41, p = 0.2547). While, *Mastomys natalensis* and *Lemniscomys rosalia* were statistically significant different (W = 407, p = 0.01 and W = 430.5, p = 0.002, respectively) between habitats and across seasons ($F_{(2,45)}$ = 4.352, p = 0.019 and $F_{(2,45)}$ = 6.321, p = 0.0038, respectively). *Acomys ngurui* had the largest mean home range size (1,087.58 m^2) than *L. rosalia* (831.55 m^2) and *M. natalensis* (166 m^2) with overlaps being recorded in habitats and across seasons. Most small mammals were associated with seasonal riverine forest. We conclude that small mammal species abundance and home ranges vary with habitats and seasons for individual species in Nyerere National Park. We recommend to the management of the park to consider small mammals in the management plans of the protected area especially on management practices such as infrastructure development and fire management.

Key Words: Rodents, Miombo woodland, Selous ecosystem, Capture-mark-recapture

1.0 Introduction

Animals usually restrict their activities to a specific area be it territory, home range or region (Stamps, 1995). Home range is defined as an area traversed by an individual in its normal activities and that can provide relatively all necessary resources that can sustain the animal’s life such as food, potential mates, safety and caring for young (Powell, 2000; Powell and Mitchell, 2012; Cooney *et al.*, 2015; Aiken, 2019). Animals will incur all the cost to establish and maintain home ranges only if the benefits of maintaining them are greater than the cost (Stamps, 1995). In addition, having a knowledge of an area is particularly important to rodents in escaping potential predators and it increases fitness (Stamps, 1995).

Home ranges play an important role in the ecology of small mammals (Ofstad, 2016). It is an important ecological parameter in understanding the driving factors for variations between species across habitats and seasons. In addition, home range helps in identifying important factors such as mating patterns, foraging behavior and habitat use (Aiken, 2019). Additionally, it helps in modeling/predicting species distribution in an ecosystem. Home ranges may differ between and within species and between habitats across seasons (Powell and Mitchell, 2012). According to Byrne and Chamberlain (2011), resources fluctuation are the key reasons for shift in size and position in home ranges of small mammals. It can also be linked to level of competition, niche separation and predation (Morris *et al.*, 2011). In addition, home range sizes might be affected by habitat fragmentation which can alter spatial structure of vertebrate population and this is particularly dangerous to restricted species which if not checked can go extinct due to various factors including inbreeding depression (Gehring and Swihart, 2004). Other factors influencing home range sizes include food supply, sex, age, breeding, rearing of offspring, shelter, dispersal ability and body mass (Burt, 1943; Powell, 2000; Schmidt, 2002; Cutrera *et al.,* 2006; Cooney *et al.,* 2015; Lee and Rhim, 2016; Ofstad, 2016; Aiken, 2019).

Knowledge on animal species' habitat requirements is a landmark towards managing and conserving them (Kneib, 2007). Species habitat association reflect how the species use certain areas while avoiding other due to number of factors including food, shelter, and avoidance of predators. Species will be successful in a given habitat in terms of dominance and abundance only if it associates well with its habitat (Liu *et al.,* 2018). This means it will be able competitively dominate the area over other species or coexist (Liu *et al.,* 2018). Species usually coexist through evolution by occupying different resources through time and space (Chuyong *et al.,* 2011). This process brings about the species habitat association in a given community (Chuyong *et al.,* 2011). However, habitat disturbances are the major threat to species survival and distribution (Feilhauer *et al.,* 2011). Heinze *et al.* (2010) reported that, any kind of habitat change has serious effects on species composition, abundance, diversity, total biomass and distribution of small mammals.

This information is necessary for guiding management actions such as infrastructure development, prescribed burning plan and any other habitat management actions. Species-habitat association is key in management and conservation of species. It helps in prioritizing areas for conservation of specific species in particular restricted or endangered species in a given ecosystem including trends of changes in that ecosystem (Redhead *et al.,* 2016). However, in Selous ecosystem, there is inadequate information on the small mammals' home ranges and how they associate with their habitat which necessitate a detailed study of this parameters for informed ecosystem management. This is particularly necessary considering the importance of small mammals in the ecosystem which include the role as indicator species of forest ecosystem, their role in food chain and web and overall ecosystem health (Rhim *et al.,* 2012; Heinze *et al.,* 2010; Yihune and Bekele, 2012; Bosing *et al.,* 2014). We hypothesized that habitat association were determinant factors of abundance and home range.

2.0 MATERIALS AND METHODS

2.1 Location, size and climate

The study was conducted between July 2018 and June 2020 in two habitats in the Selous ecosystem, specifically in the Nyerere National Park (NNP) (Figure 1), which covers an area of about 32,000 km^2. It is located in the southeastern part of Tanzania between 7°20' to 10°30'S and 36°00' to 38°40'E (MNRT, 2012). The park falls within the bimodal rainfall belt of southern Tanzania and annual rainfall ranges from 750 mm in the east to about 1 300 mm in the west, falling mainly between mid-November and mid-May (Jihnson, 2003). The ecosystem constitutes a globally important example of vegetation types that is between Somali-masai and Zambezian regional centers of endemism and mostly on the later (URT, 2005). The area possesses diverse flora with an estimated total of over 2 000 species with exceptionally high variety of habitats (McGinley, 2008). The most dominant habitats include, riverine forests, thickets and woodlands mainly dominated by *Brachystegia spicifomis, Julbernardia globiflora* and *Pterocarpus angolensis* (UNESCO-WHC, 2012). The ecosystem harbors significant populations of wildlife including vulnerable (African elephant - *Loxodonta africana*) endangered (African hunting dog - *Lycaon pictus*) and critically endangered (Black rhinoceros - *Diceros bicornis minor*) species among many others (UNEP-WCMC, 2011). There are about 450 species of birds among them endemic and rare, which makes the reserve among the few Important Bird Areas (IBA) in the region (Briggs, 2008).

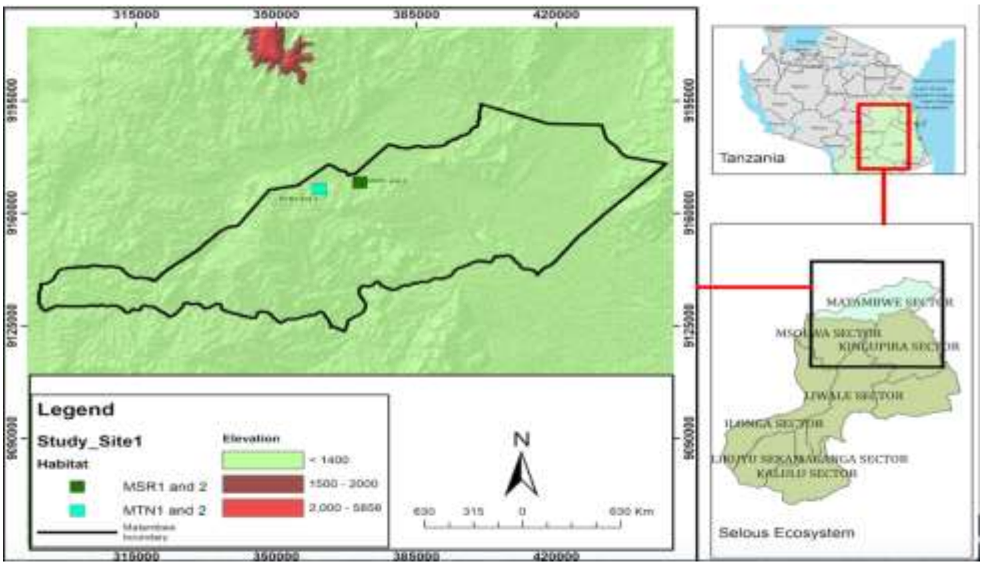


Figure 1: Northern Nyerere National Park in the Selous ecosystem, Tanzania.

2.2 Study Sites

The study was conducted in two habitats with replication in each making a total of four (4) sites. Trapping was conducted in the following habitats: Closed woodland (MTN**)** located at 37M 360216 UTM 9167330; elevation 324 m. a.m.s.l. The site is characterized by mixed vegetation mostly *Brachystegia spicifomis, Julbernardia globiflora, Afzelia quanzensis, Pterocarpus angolensis,* and *Salvadora perisca* and the common grasses are *Hyparrhenia newtonii, Andropogon gyanus* and *Hyparthelia dissoluta*. African elephants, yellow baboons and African cape buffaloes, zebras and impalas were the commonest wild animals regularly seen. The dominant soils are black cotton with rough slopes characterized by rock outcrops in most parts. Seasonal riverine with human association (MSR) located at 37M 364168 UTM 9167451; elevation 176 m. is dominated by *Steculia apendiculatas, Kigelia Africana, Markhamia zanzibarica and Adansonia digitata and Combretum* spp. thicket. The habitat is characterized by high percentage of leaf litter in dry season and soils are sandy loam in most parts. African elephant (residents), baboons, warthogs, wild pigs, carnivores such as common genet and mongoose (dwarf and banded) are the most common species of wild animals.

2.3 Small mammals trapping

Capture-Mark-Recapture (CMR) using medium-sized (LFA, 7.5 x 9 x 23 cm) Sherman’s traps and Havahart traps were used for this study. In each site, two (2) grids of 70 m x 70 m were established with seven (7) parallel lines and seven (7) trapping station at a distance of 10 m apart following Hoffmann *et al.* (2010). Each trapping station was marked using coordinates and every Sherman’s trap was baited using a mixture of peanut butter and maize bran. For small mammal species which were not possible to be captured using Sherman’s, Havahart were used instead and were distributed in the same habitats away from CMR grid. All traps were checked before 10:00hrs, for three consecutive nights for 24 consecutive months. Identification of captured species followed available distribution maps as provided by Kingdon (1997 and 2015) to genus level in the field and confirmation of species was done through molecular (Cytochrome *b*) technique. Sex, reproductive condition and weight (to the nearest gram) were recorded. The animals were marked by toe clipping and released at the site of capture. The collected samples were preserved in 70% alcohol and are stored at Institute of Pest Management – Sokoine University of Agriculture, Morogoro, Tanzania. To increase trappability, all traps were re-baited daily using a mixture of peanut butter and maize bran for Sherman’s traps and slices of carrot/sweet potatoes/bananas or raw maize for Havahart traps.

2.4 Habitat sampling

Habitats covariates were collected at five meters radius (modified from Decher and Bahian (1999)) from the center each trapping station. The recorded variables include number of termite mounds, density of trees, and shrubs, herbs, dead logs, visual estimation of percentage tree canopy cover and grass cover and rock outcrops. The collected information was used to assess the relative species habitat association.

2.5 Data Analysis

Species composition and abundance

Small mammals' species composition was estimated as the total number of different species and their percentage contribution in that community in different habitats. *A*comys *ngurui*, *Lemnisocmys rosalia* and *Mastomys natalensis* were the only species eligible for this study by considering their relocation from the CMR data history. Species abundance was estimated using Minimum Number Alive (MNA) index for species with high catch and occurring in the two habitats. MNA refers to number of individuals captured and survived (recaptured) in the next events during trapping sessions (Krebs, 1966). We used Shapiro.test function to assess the normality of our data and our data revealed a normal distribution (W = 0.938, p = 0.52). However, we used Wilcox.test function in R to compare means of species of interest in the two habitats. We used two-way ANOVA with robust estimation by employing WRS2 package with pbad2way () function in R software version 3.4 to detect variations between habitats across seasons for our species of interest.

Home range and home range overlap estimation

Relative home ranges were estimated from small mammals' relocation points from CMR history data. For home range estimation, only those species which met the minimum relocations of five (5) points and in both habitats were used for this study. Home ranges for selected individual were calculated using a Minimum Convex Polygon (MCP) and processed using adehabitatHR package in R software version 3.4 (R Core Team, 2020) using mcp.area function at 100% of all points because of few relocations of individuals from the CMR history data. Home range overlap was estimated using R software version 3.4 in the package adehabitatHR, using the Kernel_overlap function (R Core Team, 2020).

The percent overlap was calculated as;

$$HR_{ij}= 100 * A_{ij}/A_i$$

Where; HR_{ij} is the proportional of home range its hat is overlapped by home range j. A_{ij} is the area of home range i and A_i is the area of overlap between the two-home ranges (Fieberg and Kochanny, 2005). The home range size results data from mcp_area function was used to determine the home range overlap percentage. Kruskal Wallis test one and two factor analysis of variance (ANOVA) were used to detect the variation in home range and home range overlap for the selected species across species, sex, habitat and season using R version 3.4 (R Core Team, 2020).

Species habitat association

To establish the small mammal species – habitat association, habitats covariates were collected at five meters radius (modified from Decher and Bahian (1999)) from each trapping station. The recorded variables include number of termite mounds, trees, herbs, and shrub density shrubs, number of dead logs, visual estimation of percentage tree canopy cover and grass cover and rock outcrops and bare ground. The collected information was used to assess the species habitat association using principle component. Ordination technique - Nonmetrics Multidimensional Scaling (NMDS) using the Sorensen distance measure in R version 3.4 using vegan package; metaMDS function (R Core Team, 2020).

3.0 Results

3.1 Species composition

A total of 732 small mammal individuals belonging from 19 species were captured in 14,112 trap nights with 5% trap success from July 2018 to June 2020 (Table 1). Closed woodland (MTN) recorded the highest trap success and seasonal riverine forest (MSR) the least (Table 1). Of the 19 species captured; 12 were rodents, two insectivorous, four carnivores and one primate (Table 1). Species richness was higher in seasonal riverine (17) than in closed woodland only with eight species were recorded (Table 1).

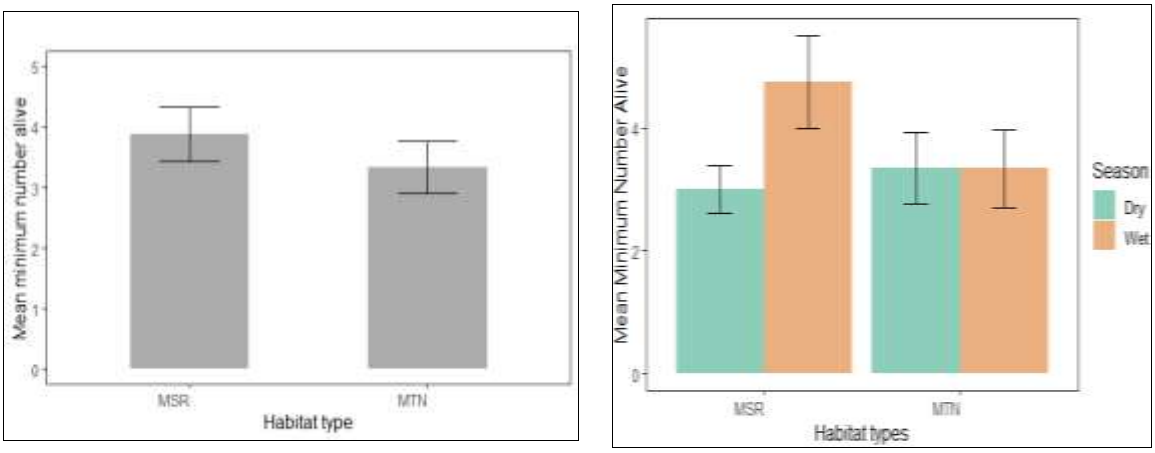
3.2 Abundance of *Acomys ngurui, Mastomys natalensis* and *Lemniscomys rosalia*

There were no significant differences in *A. ngurui* abundance between closed woodland and season riverine habitats (W = 220, df = 1, $p = 0.144$) and across habitats and seasons ($F_{(2, 45)} = 1.41$, $p = 0.254$) (Figure 2a and 2b). There were significant differences in *M. natalensis* abundance between closed woodland and seasonal riverine forest (W = 407, df=1, $p = 0.01$) and with habitat across seasons ($F_{(2, 45)} = 4.352$, $p = 0.019$) (Figure 2c and 2d). There was significant difference in *L. rosalia* abundance between closed woodland and seasonal riverine forest (W = 430.5, df = 1, $p = 0.002$) and across habitats and seasons ($F_{(2, 45)} = 6.321$, $p = 0.003$) (Figure 2e and 2f).

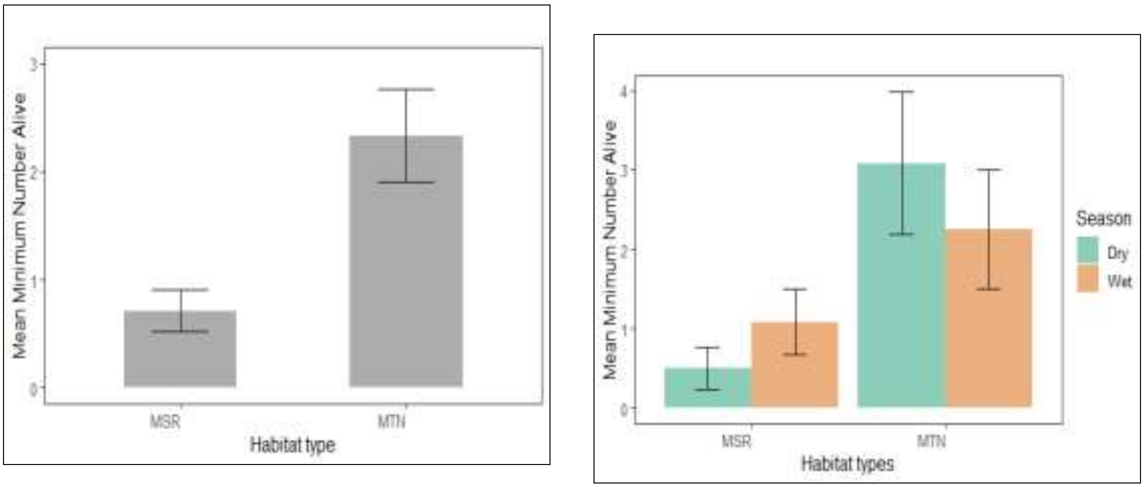
Table 1: Small mammal species composition and contribution in Selous ecosystem, Tanzania (MTN = Closed woodland and MSR = Seasonal riverine forest).

s/n	Species	Habitats		
		MTN (N=467)	**MSR (N=265)**	**Overall (N=732)**
1	*Acomys ngurui* Verheyen *et al.*, 2011*	32%	48%	37.60%
2	*Aethomys chrysophilus* de Winton, 1897	28%	0	17.90%
3	*Mastomys natalensis* Smith, 1834*	19%	11%	16.10%
4	*Lemniscomys rosalia* Thomas, 1904*	14%	8%	12%
5	*Crocidura hitra* Peters, 1852	0.20%	7%	2.70%
6	*Petrodromus tetradactylus* (Peters, 1846)	3%	2%	2.60%
7	*Paraxerus palliatus* (Peters, 1852)	0	6%	2.20%
8	*Paraxerus flavovittis* (Peters, 1852)	1%	4%	2%
9	*Cricetomys anssorgei* Thomas 1904	0	6%	2%
10	*Mus minutoides* Smith, 1834	2%	0	1.50%
11	*Grammomys surdaster* Thomas and Wroughton 1908	0	3%	1%
12	*Mungos mungo* (Gmelin, 1788)	0	1%	0.40%
13	*Grammomys selousi* Denys *et al.*, 2011	0	1%	0.40%
14	*Beamys hindei* Thomas, 1909	0	1%	0.40%
15	*Rattus rattus* Linnaeus, 1758	0	1%	0.30%
16	*Helogale pervula* Sundevall 1847	0	1%	0.30%
17	*Atilax paludinosus* F. Cuvier 1826	0	1%	0.30%
18	*Otolemur garnetti* (E. Geoffroy 1812)	0	0	0.10%
19	*Galerella sanguinea* Ruppell 1836	0	0	0.10%
	Species richness	**8**	**17**	
	Trap success	**6%**	**3%**	**5%**

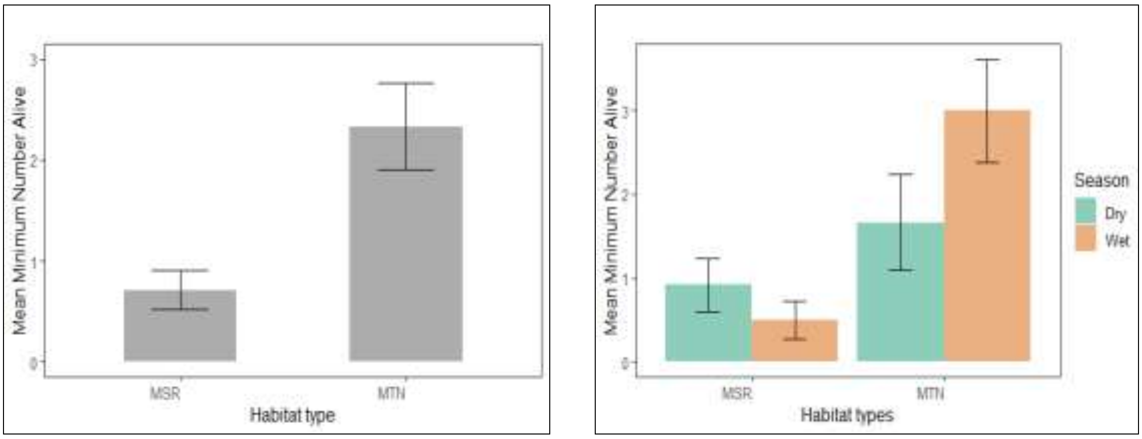
* Species used for home range study



a. *A. ngurui* b. *A. ngurui*



c. *M. natalensis* d. *M. natalensis*



e. L. rosalia *f. L. rosalia*

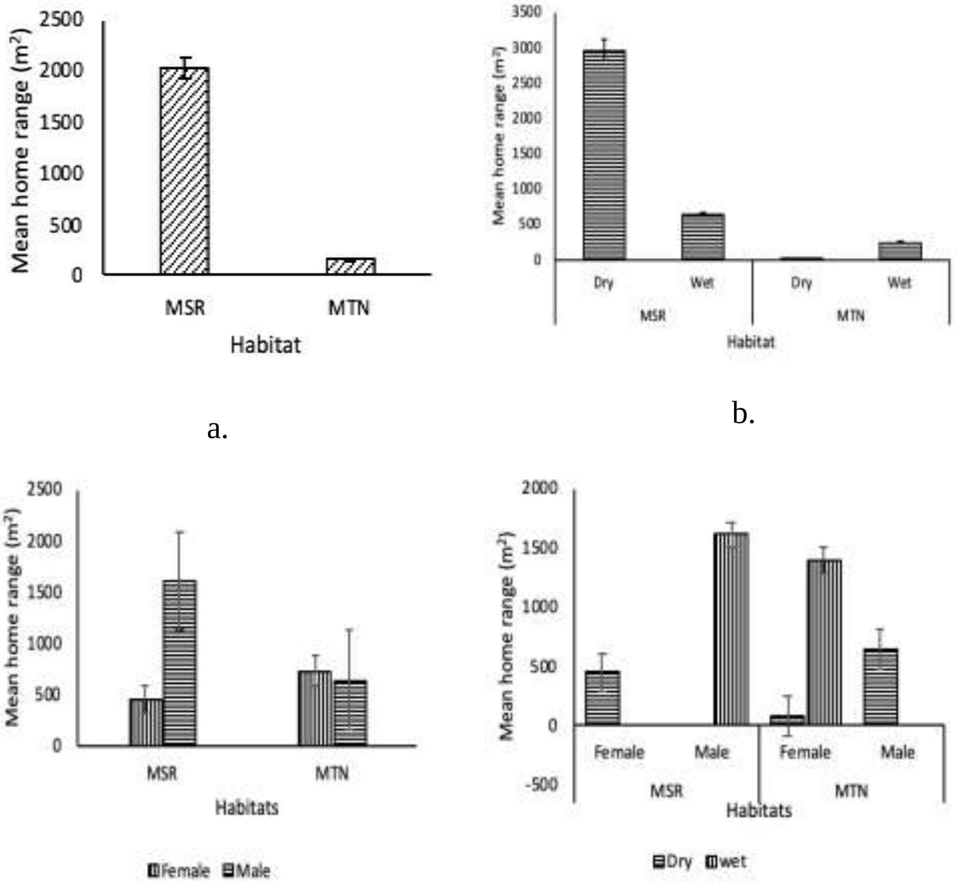
Figure 2: Habitats (a, c and e) and seasonal (b, d and f) variations of *A. ngurui, M. natalensis* and *L. rosalia* in Selous ecosystem, Tanzania. (MTN = Closed woodland and MSR = Seasonal riverine forest)

3.3 Home range

Acomys *ngurui*, *L. rosalia* and *M. natalensis* were the only species eligible for this study by considering their relocation from the CMR data history. On average, *A. ngurui* had relatively largest mean home range size (1,087.58 m^2) compared to *L. rosalia* (831.55 m^2) and *M. natalensis* (166 m^2). However, these differences were statistically insignificant between habitats (χ^2 = 2 df = 2, p = 0.367) and across seasons ($F_{(3, 2)}$ = 0.716, p = 0.146). Female *A. ngurui* had the largest mean home range in dry season compared to the other two species while *L. rosalia* had the largest mean home range (1,350.8 m^2) in wet season compared to *A. ngurui and M. natalensis.* In both dry (542.75 m^2) and wet (627.87 m^2) seasons, males *L. rosalia* had larger mean home range than male *A. ngurui and M. natalensis*. However, the differences in mean home range between species in different habitats and sex across season were insignificant ($F_{(4, 7)}$ = 1.304, p = 0.196).

Acomys ngurui

Mean home ranges of *A. ngurui* were not significantly different between habitats (χ^2 = 1, df = 1, p = 0.317) being larger in MSR than in MTN (Figure 3a). Statisitically insignificant differences were also observed between the two habitats across seasons ($F_{(2, 1)}$ = 42.22, p = 0.108) although large home ranges were recorded in MSR in both dry and wet season than in MTN (Figure 3b). Males *A. ngurui* had relatively large home range in MSR than in MTN, while females had larger mean home range in MTN than in MSR (Figure 3c). Home range differed between sex and habitats across seasons with males having larger mean home ranges in MSR in dry season while there were limited activities in the wet season. Home ranges were larger for females in MTN in the wet season (Figure 4d). However, the differences were statistically insignificant ($F_{(2, 1)}$ = 0.513, p = 0.702) (Figure 3d).



a.

b.

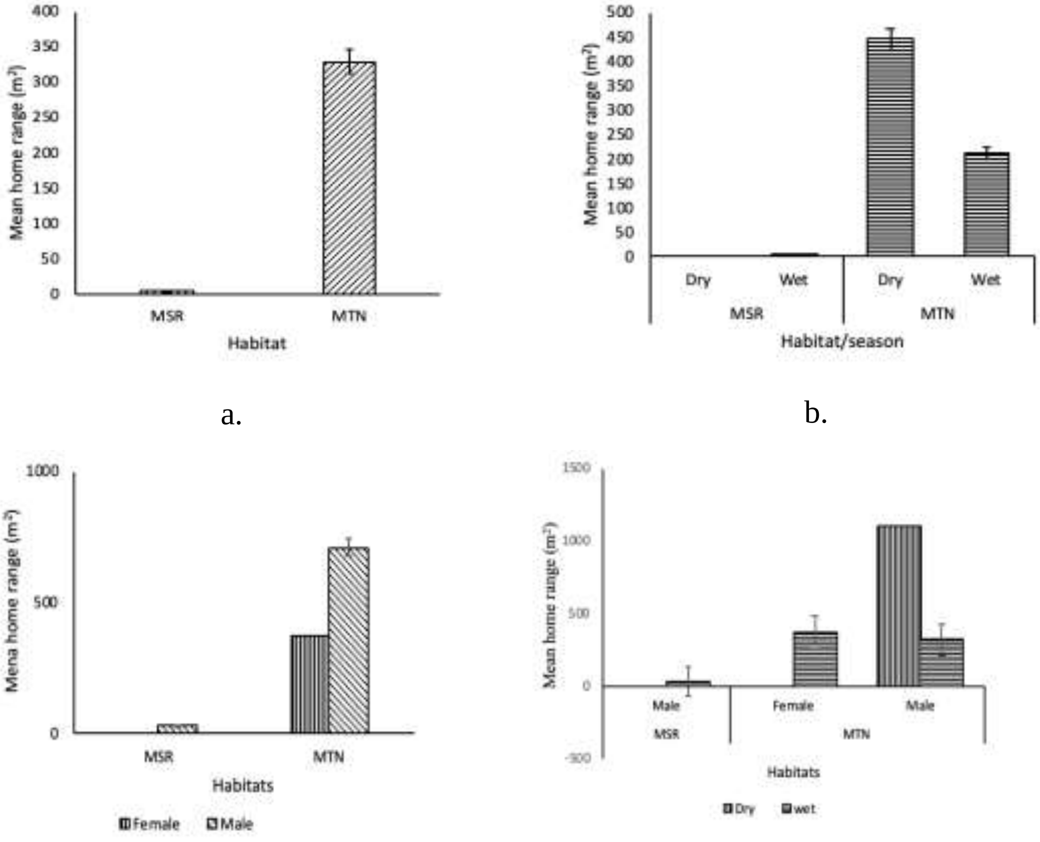
c.

d.

Figure 3: Variation in mean home ranges (±SE) of *A. ngurui* between sex, habitats and seasons in Selous ecosystem, Tanzania. (MTN = Closed woodland and MSR = Seasonal riverine forest)

Mastomys natalensis

Mastomys natalensis mean home range differed significantly between the two habitats (χ^2 = 185.07, df =1, *p* = 0.0000), being lager in MTN than MSR (Figure 4a). Mean home ranges were not statistically significant different between habitats across seasons (χ^2 = 2, df = 1, *p* = 0.157) although larger mean home ranges were recorded in dry and wet seasons in MTN (Figure 4b). Males *M. natalensis* recorded the largest relative home ranges in MTN compared to MSR while females had larger home ranges in MTN. In MSR female were found in a relatively small area with less than two relocations (Figure 4c). However, there were no statistically significantly difference in home range between sexes across seasons ($F_{(2, 1)}$ = 6.475, p = 0.267) (Figure 4d).



a.

b.

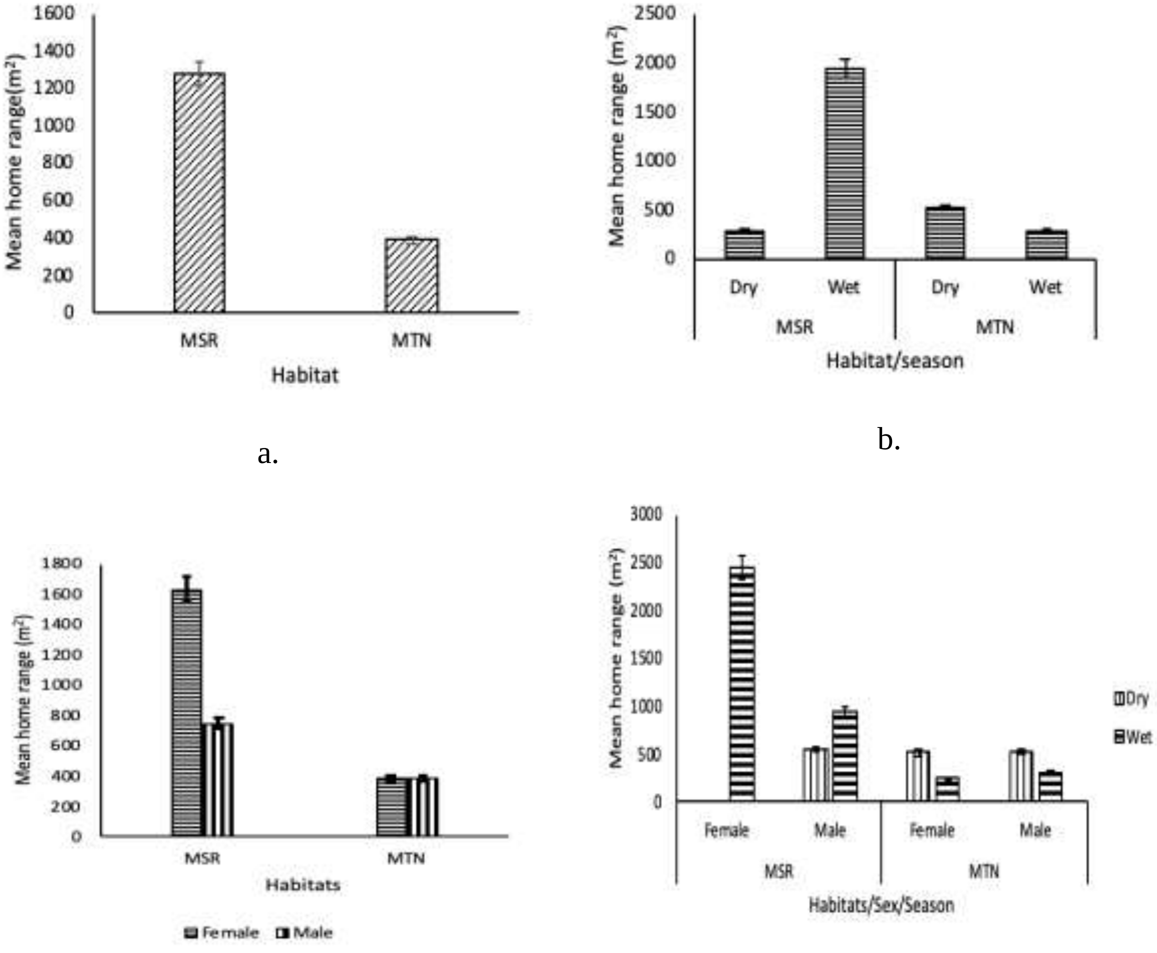
c.

d.

Figure 4: Variation in mean home ranges (±SE) of *M. natalensis* between sex, habitats and seasons in Selous ecosystem, Tanzania. (MTN = Closed woodland and MSR = Seasonal riverine forest)

Lemniscomys rosalia

Mean home ranges of *L. rosalia* differed significantly (χ^2 = 239.9, df = 1, p = 0.0000) between habitats being larger in MSR than in MTN (Figure 5a). Seasonal variations were notable ($F_{(2, 1)}$ = 0.388, p = 0.75) in mean home range in both habitats where in wet season MSR recorded the largest mean home range compared to MTN, while it was larger in dry season in MTN (Figure 5b). Mean home range were not statistically significantly different ($F_{(2, 1)}$ = 8.48, p = 0.235) between sexes across habitats, although females recorded larger mean home ranges than males (Figure 5c). Dry season recorded the lowest mean home ranges in both males and females in MTN (Figure 5d).



a.

b.

c.

d.

Figure 5: Variation in mean home ranges (±SE) of *L. rosalia* between sex, habitats and seasons in Selous ecosystem, Tanzania. (MTN = Closed woodland and MSR = Seasonal riverine forest)

3.4 Home range overlap

The average home range overlaps between the three species (*A. ngurui* and *L. rosalia* and *M. natalensis*) were not statistically significant different between habitats ($F_{(1,\ 2)}$ = 1.02, p = 0.418) although relatively higher overlap were recorded in MTN than in MSR (Table 2). Although average overlap was higher between *L. rosalia* and *A. nguru* and between *M. natalensis* and *A. ngurui* in MTN than MSR, no statistically significant variation was recorded in both pairs ($F_{(2,\ 1)}$ = 1.938, p = 0.452 and $F_{(2,\ 1)}$ = 1.165, p = 0.548, respectively) (Table 2).

Table 2: Mean home range overlap between *A. ngurui* and other species in different habitats and seasons. (MTN = Closed woodland and MSR = Seasonal riverine forest)

Species	Habitats	Seasons	% Overlap	Average overlap (%)
L. rosalia - A. ngurui	MTN	Dry	75	68.5
		Wet	62	
M. natalensis - A. ngurui		Dry	55	63.5
		Wet	72	
L. rosalia - A. ngurui	MSR	Dry	67	33.5
		Wet	0	
M. natalensis - A. ngurui		Dry	0	46
		Wet	92	

Overall, home range overlap of *A. ngurui* was not statistically significant different between habitats both with 65%. Average home ranges overlap for males was not statistically significant different between habitats and across seasons ($F_{(1,\ 2)}$ = 0.223, p = 0.682 and $F_{(1,\ 2)}$ = 0.390, p = 0.749 respectively) (Table 3). Also, there was no statistically significant difference in overlap between female across habitats and ($F_{(1,\ 2)}$ = 0.577, p = 0.526 and $F_{(2,\ 1)}$ = 0.391, p = 0.749 respectively). Same for males – females across habitats and seasons ($F_{(1,\ 2)}$ = 0.279, p = 0.65 and $F_{(2,\ 1)}$ = 1.337, p = 0.521 respectively) (Table 3).

Table 3: Mean home range overlap of *A. ngurui* between sex in different habitats and seasons. (MTN = Closed woodland and MSR = Seasonal riverine forest)

Habitat	Seasons	Percentage area of overlap (m^2)			Average area overlapped (%)
		Male - Male	Female - Female	Males - Females	
MTN	DRY	52.6	68	33	51.2
	WET	68	88.72	83.7	80.14
Average		60.3	78.36	58.35	65.67
MSR	DRY	100	88	67	85
	WET	62	0	77	46.33
Average		81	44	72	65.66

3.5 Small mammal species – habitat association

Most small mammals were associated with seasonal riverine forest (MSR A) which is characterized by high canopy and shrub cover while most murid species were associated with closed woodland (MTN A) with leaf litter and dead logs (Figure 6).

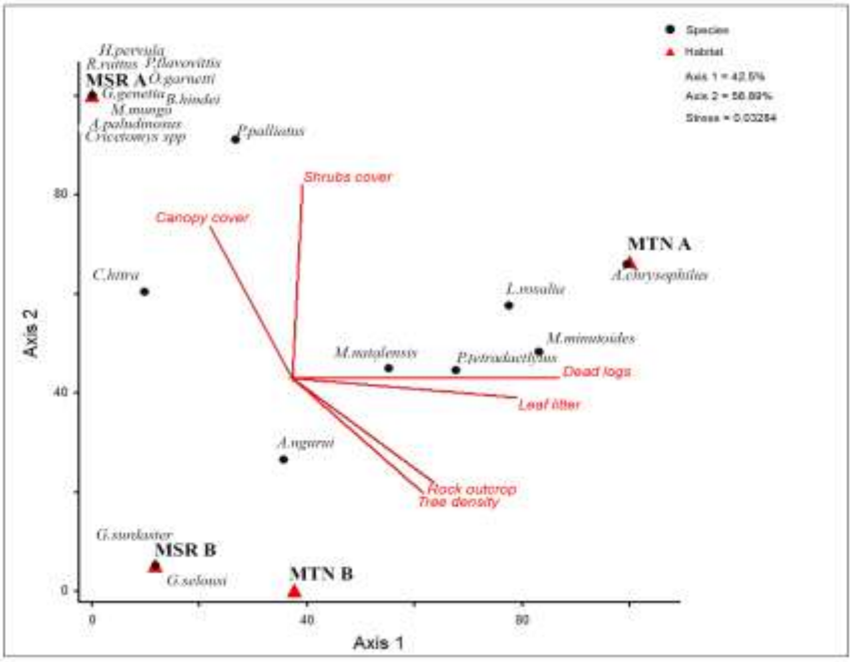


Figure 6: Nonmetric multidimensional Scaling (NMDS) on small mammals – habitat association (MSR = Seasonal riverine forest, MTN = Closed woodland). (MSR A & B = Seasonal riverine forest, MTN A & B = Closed woodland).

4.0 Discussion

4.1 Species composition and abundance

In this study, the occurrence of most species in the seasonal riverine forest habitat can be attributed to habitat heterogeneity/complexity as opposed to closed woodland which had open areas which could reduce the cover and food for small mammals. However, although closed woodland recorded highest catch of individuals in closed woodland, species richness was lower compared to seasonal riverine forest. The increased number of animals was accounted for by few species (*A. ngurui*, *M. natalensis* and *A. chrysophilus*) at the beginning of rain season in both years. This is in line with other studies in the miombo woodland which reported an explosion of some species during wet season particularly *M. natalensis* and *A. chrysophilus* (Fitzherbert *et al.,* 2006). The overall low trap success of 3% in this study might be attributed to overall nature of the area which is mostly dry and associated with recurrent fire and large aggregates of herbivores particularly buffaloes and wildebeests. This conform with other studies in miombo woodland (Caro, 2001; Caro, 2002; Fitzherbert *et al.,* 2006) which highlighted a possible effect of grazing pressure from large herbivore as a competition factor.

The observed abundance success of *A. ngurui,* in the two habitats, suggests that, both habitats and season does not affect its occurrence. This is contrary to *Mastomys natalensis* which was successful in closed woodland which is associated with varied degree of disturbances from large herbivores and prescribed burning. As well, low catch in wet season suggests an effect of season especially wet. This is supported by previous studies that have shown habitat disturbance to favor *M. natalensis* (Monadjem and Perrin, 2002; Massawe *et al.,* 2005). Closed woodland was an ideal habitat for *L. rosalia* than in seasonal riverine as it has been reported to associate with tall grasses and prescribed burning Yarnell *et al.* (2008). The species is capable of changing activity patterns to accommodate fire effects (Yarnell *et al.*, 2008).

4.2 Home ranges and home range overlap

In the current study, most species recorded fewer than five relocations from the CMR history data with most of them never surviving/occurring four consecutive trapping sessions suggesting a possible high predation levels or other factors not observed. Only three species, *A. ngurui*, *L. rosalia* and *M. natalensis* were selected for this study by considering their relocation from the CMR data history. Each species showed varied responses in their home range sizes in different habitats and seasons. The difference in home between the two habitats was probably associated with presence of large herds of large mammals especially buffaloes and management practices particularly prescribed burning. To some degree large herbivores cause disturbance through grazing and their aggregation behaviors (Hoffman and Zeller, 2005). In addition, habitat management practices such as prescribed burning tends to reduce food and cover which in turn could affect small mammals home ranges differently depending on the adaptation variability between species. This theory is supported by Gebresilassie *et al.* (2006), that, rodents tend to have wider home ranges in areas with fewer resources and cover suggesting that wider home range justifies search of necessary resources to enable survival. This is in line with the current study for specific species (*M. natalensis*) which recorded relatively larger home ranges in closed woodland which was associated with some degree of disturbances. This affirms that, *M. natalensis* is associated with some degree of disturbances and will recolonize areas previously disturbed as reported by Monadjem and Perrin (1998) and Massawe *et al.* (2005). In addition, increase disturbance favors more generalist species like *M. natalensis* while affecting specialists (Buchi and Vuilleumier, 2014). On contrary, this study has shown that areas seen to have less disturbances especially due to large herds of buffaloes and prescribed burning, *A. ngurui* and *L. rosalia* had larger mean home ranges than in areas with those activities. Thus, the conclusion based on disturbance should be species specific and not generalized to small mammal community.

Considering other hypotheses such as body mass (Schmidt *et al.,* 2002; Koshev *et al.,* 2005), the recorded home range sizes of *M. natalensis* were relatively smaller in all habitats and seasons compared to that of *A. ngurui* and *L. rosalia*. This is contrary to the body mass hypothesis considering the sizes of *M. natalensis* and that of *A. ngurui*. The overall small home ranges relative to other studies in different areas are probably a result of habitat suitability in the ecosystem with food availability in relatively smaller areas. It is also possible that species are being restricted by high level of predation especially in seasonal riverine where various predators were captured (*Genetta genetta, Atilax paludinosus, Mungos mungo and Helogale pervula*) and/or observed (*Crocuta crocuta*) including praying on captured rodents in the traps or destructed. In all habitats, for females *M. natalensis* few relocations might be attributed to rearing of offspring while for males' large home ranges could be attributed to searching of mates. Similar differences in *M. natalensis* have been reported by Mlyashimbi *et al.* (2020) in semi-arid areas in Tanzania.

Furthermore, although males showed a slightly large home range in the dry season no significant variations were recorded in mean home range sizes between the three small mammals' species across seasons. The larger home ranges of males in dry seasons however, were possibly promoted by competition from new recruits throughout the year in the area which necessitate the males to wander far to accomplish their reproductive requirements (Mulungu *et al.,* 2013; Cooney *et al.,* 2015). For females, large home ranges in the wet season were possibly in search of food as an investment for breeding season as most of them were reproductively active during wet season. Males however, were mostly active throughout the year with their reproductive peaks conforming to those of females in wet season. This is contrary to our results, considering that, seasonality has been reported to influence small mammals home range and breeding indirectly through influence on vegetation which provides food and cover (Powell and Mitchell, 2012; Cooney *et al.*, 2015).

Home range overlap both intra and interspecific corresponds to breeding season and or shared resource especially food and cover. High overlaps were obvious in this study in both males and females of *A. ngurui, L. rosalia* and *M. natalensis*. Murid species have shown highly overlapping home ranges in the closed woodland habitat which suggests shared resources with a possible separation of time, i.e. crepuscular/diurnal (*L. rosalia*) (Monadjem *et al.,* 2016) and nocturnal (*A. ngurui* and *M. natalensis*) (Haughton *et al*., 2016) and feeding behaviors with others being generalists/opportunistic such as *M. natalensis* (Odhiambo, *et al.*, 2008) and omnivorous (*A. ngurui*) (Haughton *et al*., 2016). Other factors might be associated with reduced food and cover due to prescribed burning and lager herbivores activities in the area, thus necessitating species to wonder around to fulfill their survival needs.

The seasonal riverine forest habitat was relatively stable with no prescribed burning and therefore resources might have been supplied within a smaller range as suggested by Byrne and Chamberlain (2011). With a relatively stable habitat, resources partitioning become possible and niche theory might apply to this habitat. In addition, the variation recorded as a result of seasonality have a different interpretation as for *A. ngurui* and *M.*

natalensis the overlap was high in wet season, while for *A. ngurui* and *L. rosalia* was high in dry season suggesting a non-consistent conclusion on the seasonality hypothesis. This suggests a varying effect on activity patterns of different species. Sex overlaps between female/females and male/females for *A. ngurui* was higher in seasonal riverine forest habitat in wet season than in dry season suggesting a breeding season effect. While in closed woodland habitat overlap was pronounced in dry season and are inconsistent with the seasonality theory.

4.3 Small mammal species – habitat association

Overall, most small mammals were associate with seasonal riverine forest which is characterized by high canopy and shrub cover while, most murid species were associated with closed woodland with leaf litter and dead logs. The genus *Gramommys* is reported to be arboreal and they are well associated with forests and closed woodland (Fitzherbert, 2006; Kingdon, 2015). In this study *G. selousi, G. surdater* and *A. ngurui* were found to associate with closed woodland and seasonal riverine which are characterized by high tree density. *Acomys* species are omnivorous consuming a wide range of food including small arthropods and occurring over a wide area including rocky outcrops in Africa, South-west Asia and Middle East (Haughton *et al*., 2016; Pinheiro *et al.,* 2018). *Acomys ngurui* is well adapted to various habitats and it was captured in all habitats in Selous ecosystem.

Petrodromus tetradactylus is also an omnivorous species and it will occupy all areas with leaf litters from forest, dense woodland and thickets (Rathbun and Smit-Robinson, 2016). *Petrodromus tetradactylus, M. minutoides* and *M. natalensis* were found to associate with closed woodland with dead logs and leaf litter. According to Mulungu *et al.* (2011), *M. natalensis* is a generalist species and they occupy various habitats in tropical Africa.

Paraxerus flavovittis, and *P. palliatus* were associated with seasonal riverine forest together with *C. ansrogei, B. hindei* which are mostly arboreal species and other small mammals which are non-rodents. According to Viljoen (1977), genus *Paraxerus* are primarily herbivores (frugivore and granivore) and are forest and woodland dwellers. *Lemniscomys rosalia* and *A. chrysophilus* were associated with closed woodland which is characterized by high grass cover. This is in line with various other studies in the miombo woodland (Fitzherbert *et al.,* 2006) which reported heavy grass cover as a primary habitat for *L. rosalia*.

5.0 Conclusions and Recommendations

The results from this study have shown a varied effect of habitats and seasons on abundance of individual species suggesting that, they are not uniformly affected. In relatively stable habitats with infrequent large herds of herbivores and prescribed burning, abundance have shown to be higher for *A. ngurui* while for *L. rosalia* and *M. natalensis* their abundance was higher in areas frequented by prescribed burning and large herbivores. This study has also shown that, large home ranges were recorded in the seasonal riverine forest for *A. ngurui* and *L. rosalia* which was relatively stable with infrequent disturbances while for *M. natalensis* it was different. Small mammal species have shown a high overlap within closed woodland suggesting shared resources with a possible separation of time, i.e. crepuscular (*L. rosalia*) and nocturnal (*A. ngurui* and *M. natalensis*) and feeding behaviors with others being generalist such as *M. natalensis* and omnivorous (*A. ngurui*). Most small mammals were associated with seasonal riverine forest than closed woodland suggesting that areas with limited activities of large mammals and management practices support more species while areas with varied degree of disturbances necessitates an adaptation to be able to survive. We therefore recommend to the management of the park to consider small mammals in the management plans of the protected area especially on management practices such as infrastructure development and fire management.

Acknowledgement

We are grateful for the financial support and sponsorship of Aenea Saanya for a PhD program by the African Center of Excellence for Innovative Rodent Pest Management and Biosensor Technology Development (ACE-IRPM and BTD), Sokoine University of Agriculture. We are grateful to Tanzania Wildlife Management Authority (TAWA) and Tanzania National Parks (TANAPA) for granting us permission to work in Selous Game Reserve and Nyerere National Park. We are indebted to our field team; Mr. Khalid Kibwana, Mr. Ramadhani Kigunguli of Institute of Pest Management and Selous ecologists; Mr. Singira Ngoishie and Mr. Charles Tarimo for security and guidance. I thank Mr. Michael Kimaro and Mr. Simon Chidodo of Sokoine Univeristy of Agriculture for assisting in the analysis of data and Prof. Josef Bryja for species confirmation using molecular technique.

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CHAPTER FIVE

PAPER FOUR

Current and potential future distribution of small mammals in Selous Ecosystem, Tanzania

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Running head: Small mammals of Selous ecosystem

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Submitted to Journal of East Afrcian Natural History – Reference No. **JEANH 22-01**.

Abstract

Climate change is posing an ever-increasing threat to wildlife around the world making it a primary concern and driver of change and therefore important towards setting of conservation priorities. We investigated the relative abundance and current and future distribution of small mammal species in the Selous ecosystem, Tanzania. We captured a total of 674 small mammal individuals belonging to 22 species, including 16 rodents, 2 insectivores, 3 carnivores and 1 primate. *Acomys ngurui* was the most dominant species *Steatomys parvus* was the rarest. Abundance was significantly difference between habitats. Our model suggests that most of the current highly suitable habitats will shrink and small mammal species will be forced to concentrate in few areas within and outside the ecosystem. It is recommended that climate change should form a key component in developing conservation areas general management plans and planning for new areas.

Key Words: Distribution, climate-change, environmental niche modelling, maximum-entropy, Small fauna

1.0 Introduction

Small mammals, rodents in particular, contribute to about 40% of all known mammals (Happold, 2013). They play an important role in maintaining healthier ecosystems through their interaction with the environment (Mulungu *et al.*, 2008; Makundi *et al.*, 2009; Heinze *et al.*, 2010; Yihune & Bekele, 2012). However, small mammals and other wildlife species are faced with a number of threats which include those related to management practices, economic development and climate change. Land use/cover changes and fragmentation/transformation of land has caused about 20% loss of species richness in the world terrestrial habitat due to effects on small mammal distribution, diversity and abundance (Jetz *et al.*, 2007; Acevedo-Whitehouse & Duffus, 2009; Hagenah, 2009;

Heinze, *et al.*, 2010; Marrocoli, 2011; Feilhauer *et al.*, 2012; Ofori *et al.*, 2013; Newbold, 2018). In tropical habitats alone, habitat alteration has accounted for about 80% of species loss worldwide (Chazal & Rounsevell, 2009). In addition, about 50% of suitable habitat will be reduced for about 400 species by 2050, and for more than 900 species by 2100 (Jetz *et al.,* 2007). Considering small mammal roles in the ecosystems, these impacts might cause a serious effect in the functioning of the ecosystems in future (Shenko *et al.*, 2012). Species distribution is controlled by various factors including light, water, temperature, food and disturbances (Feilhauer *et al.*, 2012; Guisan & Thuiller, 2005; Sabuni *et al.,* 2015). This means, changing any of these parameters in particular temperature, and rainfall might have a significant effect on small mammal distribution. However, these factors are not conclusive and they only portray glimpse of reality as suggested by Araujo and Guisan (2006).

Specifically, climate change is posing an ever-increasing threat to wildlife management around the world making it a primary concern and driver of change and therefore important towards setting of conservation priorities (Jetz *et al.,* 2007; Newbold, 2018). Currently, climate change has been highlighted to significantly affect the biodiversity around the world (Newbold, 2018). This includes, increased zoonotic prevalence especially with increase contact between human and small mammals for diseases such as plague, hantavirus pulmonary syndrome and leptospirosis (Stenseth *et al*., 2006; Young *et al*., 2017). In addition, it has been associated with shaping species genetic composition as a result of species shift (Wroblewska & Mirski, 2017). It is expected to alter the current ecosystem arrangement including shifting the species poleward and higher areas as coping mechanism (Baltensperger & Huettamann, 2014; Shamsabad *et al.,* 2018).

Climate change projections has been determined in various ways. However, the most commonly used projection is Representative Concentration Pathways (RCPs). Over the years, four RCPs have been estimated including; RCP 2.6, also referred as mitigation scenario, RCP 4.5 and 6.0 also referred as medium stabilization scenarios and RCP 8.5 W/m^2 which is very high baseline emission climate change scenarios (Vuuren *et al*., 2011; IPCC 2013). RCPs are key in providing a vital foundation for current trend of climate change impacts and future preparedness on climate change impacts (Vuuren *et al*., 2011). All these scenarios are projected to significantly affect the global terrestrial ecosystems (Jetz *et al.,* 2007). Of these four scenarios, RCP 8.5 W/m^2 is the worst emission scenario and rapid climate change to be expected and is termed as a business as usual scenario (Vuuren *et al*., 2011; IPCC, 2013; Newbold, 2018). The RCP 8.5 W/m^2 (~1370 ppm CO_2 eq.) greenhouse gas emission scenario is estimated to increase the global surface temperature range between 3 to 5.5^{o}C warming by year 2100 (Vuuren *et al*., 2011; IPCC 2013). This will significantly affect the ecosystems than all other scenarios. The species are expected to be affected in different ways including increasing stress, increased competition and change in specialization due to competition. This will lead to extinction of some species especially those with limited dispersal ability.

Environmental/ecological niche modelling (ENM) or bioclimatic modelling and species distribution modelling algorithms like Maxent are used to develop probabilistic map of species distribution (Martínez-meyer, 2005; Abade *et al.,* 2014; Morales *et al.,* 2017). They are used widely to predict the effects of various factors including climate change, identifying areas for new protected areas or migration routes of species such as elephants (Chłond *et al*., 2015). Maxent uses presence-only data to estimate in combination with environmental variables to estimate the species past and projected future distribution given any changes (Phillips *et al.*, 2006; Warren & Seifert, 2011).

The Selous ecosystem occupies most part of southeastern protected areas of Tanzania (Fitzherbert *et al.*, 2006; Marrocoli, 2011). However, there is inadequate information on small mammals (Denys *et al.*, 2011) including the current and projected distribution of small mammal species under different climate RCPs scenario. Overall, most of savannah ecosystems are understudied (Newbold, 2018). This is due to vastness of the areas and complex terrain which is not easily accessible like most wildlife protected areas and thus making it difficult to obtain adequate information (Zimmermann *et al.,* 2010; Abade *et al*., 2014). However, presence-only data collected opportunistically in the ecosystem can provide potential information for estimating current and future species distribution due to various scenario in particular climate change for informed conservation and management purposes including diseases (zoonotic) prevalence and sustainability (Phillips & Dudik, 2008; Abade *et al*., 2014; Young *et al*., 2017; Shamsabad *et al*., 2018). This study therefore aimed at evaluating the current and potential future distribution of small mammals in the Selous ecosystem using presence-only data collected from various locations within the ecosystem. We hypothesized that climate change will not disrupt the current distribution of small mammal in the ecosystem.

2.0 Materials and Methods

2.1 Location, size and climate

The Selous ecosystem covers an area of about 100 000 km^2 (Figure 1). The ecosystem includes various forms of Protected Areas which are national parks (Nyerere, Mikumi and Udzungwa), Game Reserves (Selous), Forest Reserves (Mkulazi, Magombera and Undendeule West) about eleven Wildlife Management Areas (WMAs) and Ramsar sites (Kilombero). It is located in southeastern Tanzania between 7°20'-10°30'S and 36°00'-38°40'E (MNRT, 2012).

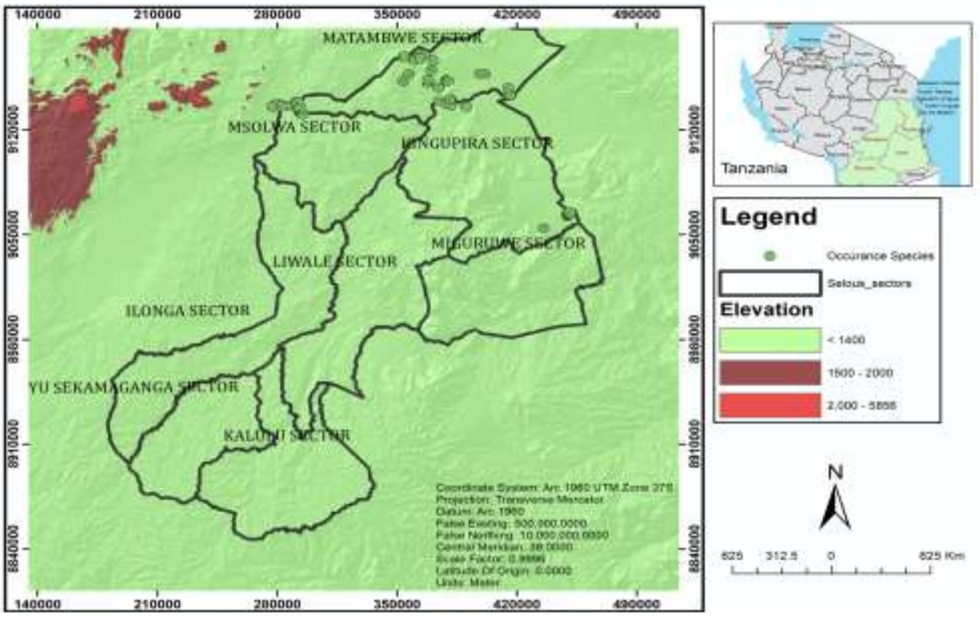

Figure 1: Selous ecosystem, Tanzania

The ecosystem falls within the unimodal rainfall belt of southern Tanzania and annual rainfall ranges from 750 mm in the east to about 1 300 mm in the west, falling mainly between mid-November and mid-May (Jihnson, 2003). The average annual temperature ranges from 13°C to 41°C (Jihnson, 2003). The reserve constitutes a globally important example of vegetation types that is between Somali-Masai and Zambezian regional centers of endemism and mostly on the later (URT, 2005). The area possesses a diverse flora with an estimated total of over 2 000 species with exceptionally high variety of habitats (McGinley, 2008). Dominant habitats include riverine forests/thickets along both seasonal and perennial rivers and woodlands mainly dominated by *Brachystegia spiciformi* Benth., *Julbernardia globiflora* (Benth.) Troupin and *Pterocarpus angolensis* - DC. (UNESCO-WHC, 2012). The area is also covered by forest along the valleys and mountain ranges and patches of grasslands including inundated grasslands. The ecosystem harbors significant populations of wildlife including vulnerable (African elephant *Loxodonta* *africana africana* Blumenbach, 1797), endangered (African hunting dog *Lycaon pictus* Temmick, 1820) and critically endangered (black rhinoceros *Diceros bicornis minor* Drummond, 1876) species among many others (UNEP-WCMC, 2011). There are about 450 species of birds among them endemic and rare, which makes the reserve among the few Important Bird Areas (IBA) in the region (Briggs, 2008).

2.2 Habitat and site selections

A total of 143 random sites were established in 9 different habitats and over laid in the Selous ecosystem using GIS ratio in relation to the size (in hectares) of each habitat. In each habitat a representative number of grids were set. The number of grids in each habitat ranged from 8 to 23. Two seasons were used for this study; December 2018 – May 2019 (wet season) and June – November 2019 (Dry season).

2.3 Small mammals trapping

We used Capture-Mark-Recapture (CMR) in this study. In each habitat seleced we established 8 to 23 grids of 70 x 70 m with seven parallel lines at a distance of 10 m apart from each line. Each line had seven trapping stations and in total 49 stations per grid (Hoffmann *et al.*, 2010). Each trapping station was marked by coordinates using Global Positioning System (GPS) to help locate the traps because most of them were set under herbs/cover to protect them from direct sunlight and predators. Trapping was conducted at four weeks interval for three consecutive nights in each trapping session from July 2018 to June 2020. Each Sherman trap was baited using a mixture of peanut butter and maize bran and variety of vegetables including slices of sweet potatoes, ripe banana raw maize and carrots were used as bait in Havahart traps. All traps were checked before 10:00 hrs. Identification of captured species in the field followed available distribution maps as provided by Kingdon (1997, 2015) and species confirmation were through molecular (Cytochrome *b*) technique. Sex, reproductive condition and weight (to the nearest gram) were recorded. The animals were marked by toe clipping as it has been proved minimal impact to animals (Borremans *et al.*, 2015) and were released at the site and point of capture. The remaining samples of clipped toes are stored at 70% alcohol at Institute of Pest Management – Sokoine University of Agriculture, Morogoro, Tanzania.

2.4 Modeling climate change on distribution of small mammals

Species occurrence (presence data) data and habitat parameters including temperature and rainfall were recorded from the field to enable mapping suitable habitat for rodents in the ecosystem and their future distribution in Selous ecosystem. Additional data were obtained from WorldClim Dataset for bioclimatic data. Nineteen bioclimatic variables from WorldClim were downloaded in raster (ASCII) format. Habitat parameters such as elevation were recorded from the field to enable mapping suitable habitat for rodents in the ecosystem and their future distribution in Selous ecosystem. Topographical data were obtained from Digital Elevation Models (DEM).

2.6 Data Analysis

Species composition and relative abundance

Small mammals' species composition was estimated as the total number of different species and their percentage contribution in that community in different habitats. Species abundance was estimated as relative contribution of each species in the habitat. Data normality was tested using Shapiro.test function. Means were compared using Wilcox.test function in R version 3.4 (R Core Team, 2020) in the 9 habitats. Two-way ANOVA by employing lm and ddply functions in R version 3.4 (R Core Team, 2020) was used to detect variations between habitats across seasons.

Species diversity

The Shannon-Wiener Index, H’ was used to determine the diversity of species in different study sites and seasons in Selous ecosystem. The Shannon – Wiener diversity index (H′) will be calculated as follows;

$$H' = -\sum_{i=1}^{s} (p_{\mathrm{i}}) (\mathrm{In}p_{\mathrm{i}})$$

Where; H′ is information content of a sample, species diversity index, *s* is number of species, *P*i is the proportion of individuals of the i^th^ species or the abundance of the i^th^ species expressed as the proportion of the total individuals and In is natural log of individual proportion.

Community similarity

Community similarity was determined by Bray-Curtis dissimilarity index using the function ‘vegdist’ (package ‘vegan’) from R software version 3.4 (R Core Team, 2020). PerMANOVA was used to test for differences among groups (Clarke, 1993).

Forecasting suitable habitats for small mammals

We used Maxent algorithms to estimate the current and future distribution of small mammals in the Selous ecosystem (Phillips *et al.,* 2006). The Maxent was chosen over others because it has a potential to predict the distribution more accurately with few presence-only data (Abade *et al*., 2014; Chlond *et al.,* 2015).

Occurrence points and all 24 variables were used to build the model (table 1). We used randomly allocated 75% of the occurrence points for training and 25% were used for testing (Nenzen & Araujo, 2011; Shamsabad *et al*., 2018; Martynov *et al*., 2020). We used a jackknife test to determine the most influential variables that determine small mammal distribution.

To predict the future scenario, projected downscaled climate data (year 2050) were used from WorldClim for Representative Concentration Pathway (RCP) 8.5W/m^2 (table 1). Spatial interpolation procedure (IDW) was used to generate a 30, 30m resolution data set using previously converted elevation points from the original data.

Table 1: Variables used for modelling the potential current and future distribution of small mammals is Selous ecosystem, Tanzania

Environment variable	Variable Source	Resolution
19 Bioclim	WorldClim database [60], v. 1.04. http://www.worldclim.org/current	30 arc-seconds
Elevation	Shuttle Radar Topography Mission. http://www.landcover.org/data/srtm/	-
Aspect	Derived from digital elevation model	-
Slope	Derived from digital elevation model	-
NDVI	Derived from Landsat satellite image downloaded from USGS	30 m
Land use/cover	Landsat satellite image was used to derive land use/ cover type of study site	30 m

Environmental variables; topographic variables (e.g., slope and aspect) were processed from an ASTER DEM downloaded from the USGS website (table 1). Land use/cover and NDVI were processed from Landsat images. The digital elevation model (DEM) was used to generate slope and aspect (both in degrees). All environmental variables were made uniform in terms of cell size and extent and then resampled to 30, 30-meter spatial resolution (cell size) and set to have uniform extent. The coordinate reference system for all environmental variables was set to WGS 1984 datum. Enmevaluate package was used to determine the best setup of the model in R software version 3.4 (R Core Team, 2020).

Models performance was evaluated using Area Under the Receiver Operating Characteristics Curve (AUC) to determine the best of fit. Models with values from 0.7 are termed fair and above 0.9 are perfect fit (Phillips & Dudik, 2008; Wizs *et al*., 2008; Jiménez-Valverde, 2012; Abade *et al*., 2014). Therefore, we used AUCs above 0.75 as they are termed reasonable for use in conservation (Wizs *et al*., 2008). After model assessment and comparison, the results were converted into maps using QGIS v.3.10 (QGIS.org, 2019) which show the probability of current and future occurrence of species in the Selous ecosystem. The suitable habitats categories range between 0 and 1, with five classes values; where, <0.1 unsuitable habitat, 0.1 – 0.2 least suitable, 0.2 – 04 moderately suitable, 0.4 – 0.6 suitable habitat and > 0.6 highly suitable habitat.

3.0 Results

3.1 Relative abundance, diversity and community similarity

A total of 674 individuals belonging to 22 species were captured in Selous ecosystem between December 2018 and November 2019. Overall trap success was 4.71% while forested areas had the highest trap success with 15% and the least was recorded in closed woodland and wooded grasslands with 1% (table 2). African spiny mice *Acomys ngurui* had the highest relative abundance while only one individual was captured for three species namely marsh mongoose *Atilax paludinosus* F. Cuvier 1826, bush squirrel *Paraxerus* sp., and tiny fat mouse *Steatomys parvus* Rhoads, 1896 (table 2).

Acomys ngurui was the most widely distributed species occurring in all habitats (table 2). Thicket rat *Grammomys selouis* Denys et al. 2011, *S. parvus*, *Paraxerus* sp., and *A. paludinosus* were restricted to one habitat (table 2). Abundance varied significantly with habitat (F = 3.414, df = 8, p = 0.001) being higher in montane (MTN) habitat. Seasonality had no effect on species abundance ($F_{(1,\ 386)}$ = 0.474, p = 0.492).

Species richness was higher (16) in Seasonal riverine forest (SRF) and low (2) in woodland (WL) (table 2). Diversity was higher in perennial riverine forest/thickets (RRF) (H’ = 2.319) and low in Seasonal inundated areas (H’ = 0.202).

Communities showed a great variation between habitats and were significantly different (F = 2.586 df = 8, p = 0.001). All sites showed high similarity (above 60%) except WGL which varied from other habitats with less than 50% similarity (table 3). RRF had high dissimilarity (24%) with SRF compared to other habitats (table 3).

Table 2: Small mammal species relative abundance in different habitats in Selous ecosystem, Tanzania (WL = Woodland; MTN = Montane woodland CLW = Close woodland SEI= Seasonal inundated grassland/shrubland, FRT=Forest, WGL = Wooded grassland, GSL = Grassland, RRF = Perennial riverine forest/thickets and SRF = Seasonal riverine forest.)

	Species	Habitats/Relative abundance									
		WL	MTN	CLW	SEI	FRT	WGL	GSL	RRF	SRF	Total
1	*Acomys ngurui* Verheyen *et al.,* 2011*	70%	23%	32%	12%	33%	8%	25%	33%	42%	195(28.9)
2	*Aethomys chrysophilus* de Winton, 1897*	30%	41%	4%	0%	4%	8%	0%	18%	5%	176(26.1)
3	*Mastomys natalensis* Smith, 1834*	0%	18%	0%	41%	15%	38%	25%	0%	9%	98(14.54)
4	*Lemniscomys rosalia* Thomas, 1904*	0%	12%	28%	6%	0%	0%	25%	18%	4%	70(10.39)
5	*Paraxerus flavovittis* (Peters, 1852)	0%	1%	4%	35%	0%	15%	0%	4%	10%	25(3.71)
6	*Crocidura hitra* Peters, 1852	0%	2%	0%	6%	6%	8%	8%	0%	4%	17(2.52)
7	*Mus minutoides* Smith, 1834	0%	3%	4%	0%	4%	0%	8%	0%	0%	14(2.08)
8	*Cricetomys ansorgei* Thomas 1904	0%	0%	0%	0%	0%	0%	0%	0%	10%	11(1.63)
9	*Grammomys surdaster* Thomas and Wroughton 1908	0%	1%	0%	0%	13%	0%	0%	2%	1%	11(1.63)
10	*Petrodromus tetradactylus* (Peters, 1846)	0%	1%	0%	0%	13%	0%	0%	2%	1%	11(1.63)
11	*Rattus rattus* Linnaeus, 1758	0%	0%	0%	0%	0%	0%	0%	6%	6%	10(1.48)
12	*Paraxerus palliatus* (Peters, 1852)	0%	0%	4%	0%	2%	15%	0%	2%	4%	9(1.34)
13	*Gerbilliscus leucogaster* (Peters, 1852)	0%	0%	24%	0%	0%	0%	0%	4%	0%	8(1.19)
14	*Genetta genetta* (Linnaeus, 1758)	0%	0%	0%	0%	2%	0%	0%	8%	1%	6(0.89)
15	*Helogale pervula* Sundevall 1847	0%	0%	0%	0%	2%	0%	0%	2%	1%	3(0.45)
16	*Otolemur garnetti* (E. Geoffroy 1812)	0%	0%	0%	0%	4%	0%	0%	0%	1%	3(0.45)
17	*Grammomys selousi* Denys *et al.,* 2011	0%	0%	0%	0%	2%	0%	0%	0%	0%	2(0.3)
18	*Atilax paludinosus* F. Cuvier 1826	0%	0%	0%	0%	0%	0%	0%	0%	1%	1(0.15)
19	*Arvicanthis niloticus* (E. Geoffroy, 1803)	0%	0%	0%	0%	0%	0%	8%	0%	0%	1(0.15)
20	*Beamys hindei* Thomas, 1909	0%	0%	0%	0%	0%	0%	0%	0%	1%	1(0.15)
21	*Paraxerus* sp.	0%	0%	0%	0%	0%	0%	0%	0%	1%	1(0.15)
22	*Steatomys parvus* Rhoads, 1896	0%	0%	0%	0%	0%	8%	0%	0%	0%	1(0.15)
	Total (N)	**23**	**370**	**25**	**17**	**52**	**13**	**12**	**49**	**113**	**674**
	Richness	**2**	**10**	**7**	**5**	**13**	**7**	**6**	**8**	**16**	**22**
	Trap success (%)	**1.02**	**26.9**	**1.28**	**2.17**	**3.54**	**0.78**	**1.22**	**2.27**	**6.78**	**4.71**
	Number of sites	**23**	**14**	**20**	**8**	**15**	**17**	**10**	**22**	**17**	**146**
	Trap nights	**2,255**	**1,373**	**1,961**	**784**	**1,471**	**1,667**	**980**	**2,157**	**1,667**	**14,308**
	Shannon Diversity	**0.61**	**0.86**	**1.57**	**0.202**	**2.03**	**0.48**	**1.73**	**2.31**	**2.07**	

Table 3: Community similarity between habitats obtained from Bray-Curtis dissimilarity index in Selous ecosystem.

	WL	MTN	CLW	SEI	FRT	WGL	GLS	RRF	SRF
WL	1								
MTN	0.7576	1							
CLW	0.9167	0.8462	1						
SEI	0.7419	0.6000	0.8182	1					
FRT	0.8400	0.8571	0.6000	0.8333	1				
WGL	0.6000	0.8636	1.0000	0.7619	0.9444	1			
GLS	0.8824	0.7391	1.0000	0.7143	1.0000	0.5556	1		
RRF	0.6591	0.7403	0.9412	0.8133	0.9420	0.5556	0.8462	1	
SRF	0.6286	0.6610	0.9200	0.7544	0.9216	0.4568	0.8000	0.2456	1

*Habitat comparisons >0.70 shows strong similarity. See Table 1 for abbreviation of terms.

3.2 Species current and projected distribution

Overall small mammals current and projected distribution in Selous ecosystem

Overall, all models obtained using the maxent algorithm had higher AUC in both current and future distributions of small mammals (table 4). Small mammal current distribution is influenced by isothermality which defines their distribution by 30.42% while mean temperature of the driest quarter contributes 19.12% (table 5). The mean temperature of the warmest quarter defined small mammal habitats by 37.62% (table 5).

Acomys ngurui

Suitable habitat (>60%) for *A. ngurui* is currently located in the northern parts and parts of Msolwa sector in the Selous ecosystem (figure 2). Current distribution is mostly determined by precipitation of the driest quarter (58.83%) and precipitation of the warmest month (10.72%) (table 5). The future distribution of this species will mostly be determined by mean diurnal range (54.41%) and precipitation seasonality (19.95%) (table 6).

Table 4: Maxent training and testing AUC used to forecast the current (2019) and future (2050) distribution of small mammals in Selous ecosystem, Tanzania

Species	Training AUC	Testing AUC
Current distribution		
Acomys ngurui	0.9816	0.9784
Aethomys chrysophilus	0.9761	0.9638
Mastomys natalensis	0.9932	0.987
Lemniscomys rosalia	0.9719	0.9674
Nested	0.9489	0.9231
Future distribution (RCP 8.5)		
Acomys ngurui	0.8765	0.7151
Aethomys chrysophilus	0.9363	0.912
Mastomys natalensis	0.9904	0.9911
Lemniscomys rosalia	0.8262	0.7584
Nested	0.9725	0.9607

Note: we considered all models with AUC >0.7 as significant.

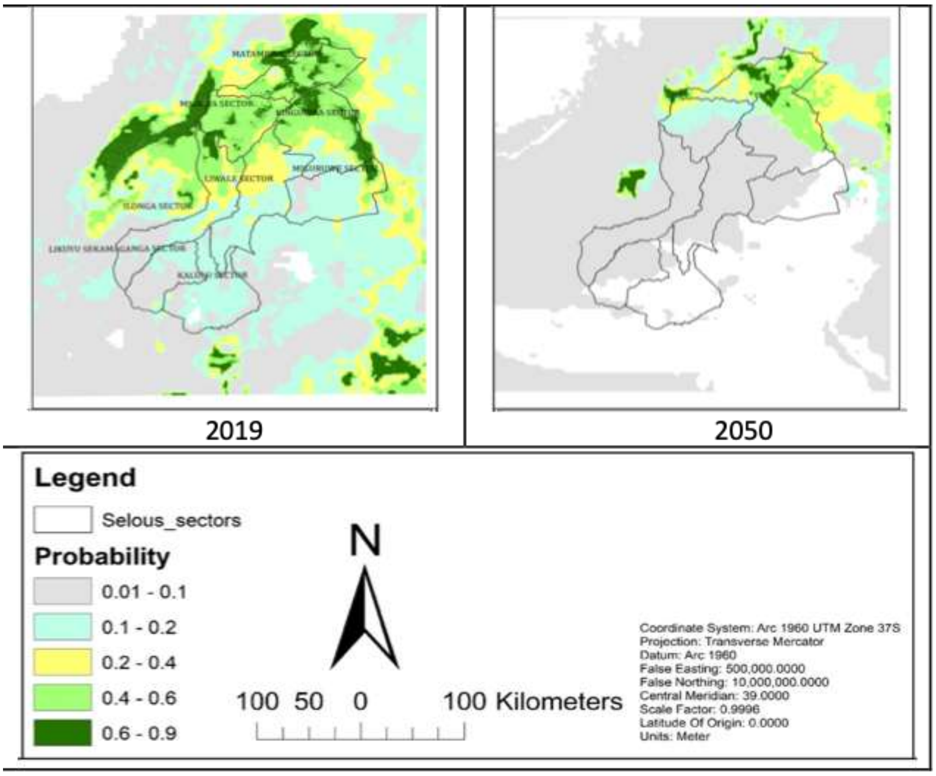

Figure 2: Current (2019) and projected (2050) distribution of small mammals under RCP 8.5 W/m^2 in Selous ecosystem, Tanzania. (Total area = 172,383.92 km^2). The range of habitat suitability is categorized between 0 and 1, values <0.1 unsuitable habitat, 0.1 – 0.2 least suitable, 0.2 – 04 moderately suitable, 0.4 – 0.6 suitable habitat and > 0.6 highly suitable habitat.

Table 5: Contribution of Environmental and Bioclim variables in the current (2019) distribution of small mammals in the Selous Ecosystem, Tanzania

Species	Variables	% contribution
Acomys nguri	BIO17 = Precipitation of Driest Quarter	58.8337
	BIO18 = Precipitation of Warmest Quarter	10.7207
	BIO15 = Precipitation Seasonality (Coefficient of Variation)	5.9023
	BIO10 = Mean Temperature of Warmest Quarter	5.6802
	BIO5 = Max Temperature of Warmest Month	5.2712
	BIO6 = Min Temperature of Coldest Month	3.8201
	BIO9 = Mean Temperature of Driest Quarter	3.4877
	BIO1 = Annual Mean Temperature	1.3961
	BIO7 = Temperature Annual Range (BIO5-BIO6)	1.3043
	BIO8 = Mean Temperature of Wettest Quarter	1.0831
	BIO3 = Isothermality (BIO2/BIO7) (×100)	1.0572
Aethomys chrysophilus	Land cover/use	63.3042
	BIO4 = Temperature Seasonality (STD ×100)	22.0508
	BIO9 = Mean Temperature of Driest Quarter	10.45
	BIO18 = Precipitation of Warmest Quarter	1.133
	BIO3 = Isothermality (BIO2/BIO7) (×100)	1.0204
Mastomys natalensis	BIO5 = Max Temperature of Warmest Month	53.7847
	Land cover/use	15.7559
	BIO15 = Precipitation Seasonality (Coefficient of Variation)	15.2029
	BIO11 = Mean Temperature of Coldest Quarter	2.8151
	BIO13 = Precipitation of Wettest Month	2.6194
	BIO1 = Annual Mean Temperature	2.4054
	BIO9 = Mean Temperature of Driest Quarter	1.7057
	BIO10 = Mean Temperature of Warmest Quarter	1.4896
	Aspect	1.1679
Lemniscomys rosalia	BIO17 = Precipitation of Driest Quarter	66.9239
	BIO8 = Mean Temperature of Wettest Quarter	19.9733
	BIO18 = Precipitation of Warmest Quarter	6.6553
	BIO9 = Mean Temperature of Driest Quarter	5.1028
Pulled	BIO3 = Isothermality (BIO2/BIO7) (×100)	30.4242
	BIO9 = Mean Temperature of Driest Quarter	19.1282
	Land cover/use	15.0621
	Slope	13.2521
	BIO4 = Temperature Seasonality (standard deviation ×100)	9.4579
	BIO1 = Annual Mean Temperature	3.446
	BIO7 = Temperature Annual Range (BIO5-BIO6)	2.646
	Aspect	2.3644
	BIO13 = Precipitation of Wettest Month	1.7843
	BIO18 = Precipitation of Warmest Quarter	1.367

Note: Contributions are based on Jackknife test. We considered all the variables with values 1 and above as significant contributors to species distribution.

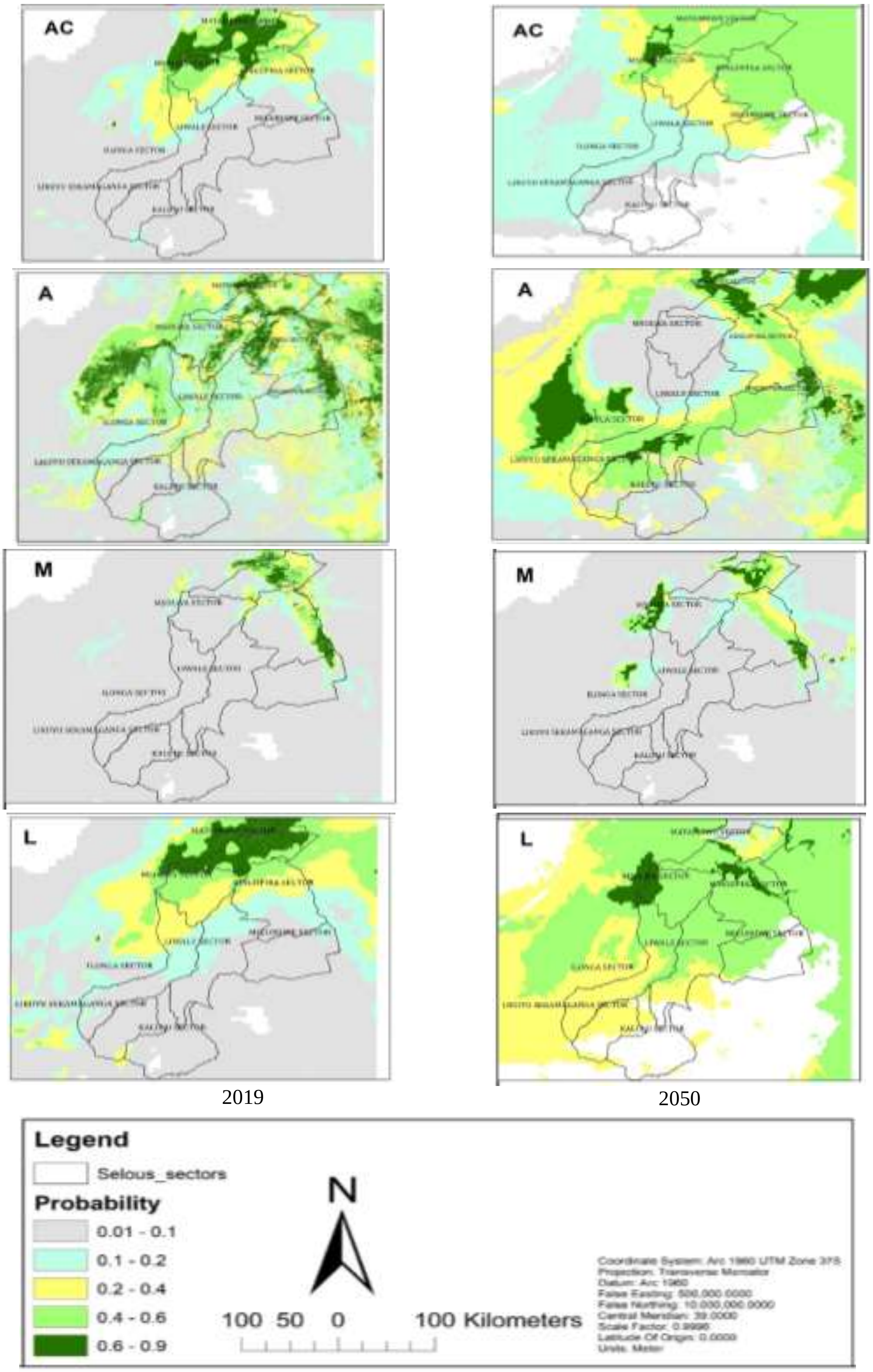

Figure 3: Current (2019) and projected (2050) distribution of small mammals under RCP 8.5 W/m^2 in Selous ecosystem, Tanzania. AC=*Acomy ngurui*; A=*Aethomys chrysophilus*; M=*Mastomys natalensis*; L=*Lemniscomys rosalia.* The range of habitat suitability is categorized between 0 and 1, values <0.1 unsuitable habitat, 0.1 – 0.2 least suitable, 0.2 – 04 moderately suitable, 0.4 – 0.6 suitable habitat and > 0.6 highly suitable habitat.

Aethomys chrysophilus

Highly suitable habitat (>60%) for *A. chrysophilus* is currently in the wider area of the central northern part of the ecosystem and within the KGCA (figure 3). Current distribution is mostly determined by land cover/use (63.3%) and temperature seasonality (22.05%) (table 5, figure 3). According to the model prediction, the future distribution of this species will be determined by mean diurnal range (43.9%) and mean temperature of the coldest quarter (42.15%) and will occur in few areas (table 6, figure 3). The probability of their distribution in the areas which they are currently present especially in the Msolwa sector is low (<10%) (figure 3).

Mastomys natalensis

Currently, highly suitable habitat (>60%) for *M. natalensis* is in the northern and northeastern parts of the ecosystem (figure 3). The current distribution is mostly determined by maximum temperature of the warmest month (53.78%), land cover/use (15.75%) and precipitation seasonality (15.2%) (table 5). The model predicted its future distribution will be determined by annual mean temperature (38.85%) and mean temperature of the warmest quarter (14.63%). (table 6) and will be distributed in KGCA and far North of the ecosystem (figure 3).

Lemniscomys rosalia

The distribution of *L. rosalia* is currently concentrated in the northern part of the ecosystem with the highly suitable habitat (>60%) in this area (figure 3). Its current distribution is mostly determined by precipitation of the driest month (66.92%) and mean temperature of the wettest quarter (19.97%) (table 5). The future distribution will be determined by mean temperature of the wettest quarter (77.45%) and mean diurnal range (15.42%) (table 6) with a shift from central northern parts to southern Mikumi National Park (MINAPA) (figure 3). The probability for their presence in the areas which they are currently present especially in the northern parts will decrease from highly suitable to suitable habitats (figure 3).

Table 6: Contribution of Bioclim variables in the future (2050) distribution of small mammals under RCP 8.5 W/m^2 in the Selous Ecosystem, Tanzania

Species	Variables	% contribution
Acomys ngurui	BIO2 = Mean Diurnal Range	54.4171
	BIO4 = Temperature Seasonality (Std ×100)	19.9352
	BIO15 = Precipitation Seasonality (Coefficient of Variation)	14.8347
	BIO8 = Mean Temperature of Wettest Quarter	10.813
Aethomys chrysophilus	BIO2 = Mean Diurnal Range	43.0989
	BIO11 = Mean Temperature of Coldest Quarter	42.1516
	BIO10 = Mean Temperature of Warmest Quarter	12.3187
	BIO4 = Temperature Seasonality (std ×100)	1.4832
Mastomys natalensis	BIO1 = Annual Mean Temperature	38.851
	BIO10 = Mean Temperature of Warmest Quarter	14.638
	BIO18 = Precipitation of Warmest Quarter	11.8699
	BIO2 = Mean Diurnal Range (Mean of monthly)	10.5468
	BIO3 = Isothermality (BIO2/BIO7) (×100)	5.9574
	BIO14 = Precipitation of Driest Month	5.535
	BIO11 = Mean Temperature of Coldest Quarter	3.578
	BIO8 = Mean Temperature of Wettest Quarter	2.7525
	BIO15 = Precipitation Seasonality (Coefficient of Variation)	2.0524
	BIO12 = Annual Precipitation	1.3642
Lemniscomys rosalia	BIO8 = Mean Temperature of Wettest Quarter	77.45
	BIO2 = Mean Diurnal Range (Mean of monthly)	15.4247
	BIO11 = Mean Temperature of Coldest Quarter	2.9717
	BIO1 = Annual Mean Temperature	2.8427
Pulled	BIO10 = Mean Temperature of Warmest Quarter	37.6272
	BIO4 = Temperature Seasonality (std ×100)	13.8263
	BIO2 = Mean Diurnal Range (Mean of monthly)	13.4937
	BIO15 = Precipitation Seasonality (Coefficient of Variation)	13.4023
	BIO11 = Mean Temperature of Coldest Quarter	11.2485
	BIO18 = Precipitation of Warmest Quarter	5.573
	BIO13 = Precipitation of Wettest Month	2.5224
	BIO7 = Temperature Annual Range (BIO5-BIO6)	1.2953

Note: Contributions are based on Jackknife test. We considered all the variables with values 1 and above as significant contributors to species distribution.

4.0 Discussion

4.1 Relative abundance, diversity and community similarities

The current study has demonstrated that small mammals in the Selous ecosystem prefer high areas with a montane like vegetation. This might be associated with availability of food and shelter as compared to lower areas which are frequented by large herbivores particularly herds of buffaloes. Large mammals might pose some degree of disturbances through grazing which is not conducive for small mammal habitation (Hoffmann & Zeller, 2005). Higher areas are reliable for small mammal habitation due to stable cover and food as compared to lower areas. The occurrence of *A. ngurui* in all habitats in the Selous ecosystem conforms to Kingdon (2015) assertion that, it is found in all habitats in tropical Africa. Species like *G. selouis, S. parvus, Paraxerus* sp., and *A. paludinosus* were restricted by habitat types which might be a sign of specialist species. Although, abundance was higher in montane areas, species richness was greater in seasonal riverine habitats which suggests that, diverse habitat do support more species. High species diversity has been attributed to habitat complexity (MacArthur & MacArthur, 1961; Tews *et al.*, 2004; Stein *et al.*, 2014). The diverse habitats areas are characterized by closed vegetation with both horizontal and vertical stratification including patches of grassland, bushlands and thick forest with tree higher than four meters.

The high similarity observed in most habitats in the Selous ecosystem might be attributing to floristic similarity (Venance, 2009). High dissimilarity observed was between perennial riverine forest/thicket and seasonal riverine forest which might be a result of variation in large mammal activities, prescribed burning and sporadic runoffs in perennial riverine areas which affected small mammal survival.

4.2 Small mammal current and projected distribution in Selous ecosystem

The spatial distribution modelling showed the current (2019) and projected (2050) distribution of small mammals in Selous ecosystem under RCP 8.5 climate change scenario. The model indicated a current wide distribution of small mammal in the ecosystem. However, the projected highly suitable (>60%) areas of future distribution will shrink by 2050 and small mammals will be concentrated in few patches particularly KGCA, northern parts of the ecosystem, and area surrounding the ecosystem. Most of the areas which the model predicted as the currently suitable distribution for small mammals will not support them in future since most of the central parts of the ecosystem will become less suitable (<10%). This suggest that future climate effects will diminish small mammal distribution in the ecosystem. Small mammals are expected to be concentrated in the KGCA in the future considering the worst emission scenario (RCP 8.5 W/m^2) (Newbold, 2018). Considering the future small mammal distribution outside the Selous ecosystem, diseases prevalence might increase as asserted by Young *et al*. (2017).

All species will be affected differently by climate change if the RCP 8.5W/m^2 will be attained. The *A. ngurui* is a small murid species which occur in most of tropical Africa in mainly arid and semiarid areas (Kingdon, 2015; Haughton *et al*., 2016). The species portrays various traits such as communal breeding and precocial development which are important for survival in various condition including deserts (Haughton *et al*., 2013). The species is widely distributed in almost all habitats in Selous ecosystem. Highly suitable habitat for this species is currently concentrated in the northern parts and southern part of Mikumi National Park. The future distribution of this species will shrink and will be found in a small area of the western NNP. This shift however is not a threat to this species as it can tolerate variety of habitats in the ecosystem.

Aethomys chrysophilus is widely distributed in Africa from south Kenya to northern South Africa and is a habitat generalist and omnivorous species of the savannah, endemic to Africa (Linzey *et al.*, 2016). The model estimates that, the species highly suitable habitat is currently contiguous in the wide part of the central northern part of the ecosystem and within the KGCA. However, the projected distribution of this species will be patchy with few strong holds including KGCA, South central parts of the ecosystem, central northern parts and far North of the ecosystem. Most of these areas especially those north of the ecosystem are agriculture fields. The probability for their presence in the areas which they are currently present especially in the southern MINAPA will decrease. However, considering its current status in the IUCN Red List, the species is not under threat and it can occur in disturbed areas like agricultural landscapes (Linzey *et al.*, 2016). Being a habitat generalist reduces the chances of significant effect of climate or other environmental changes.

Mastomys natalensis is widely distributed in all habitats in Africa except deserts, higher areas and contiguous forests and is most common pest species and reservoir of zoonotic diseases in Sub-Saharan Africa (Mulungu *et al.*, 2013; Martynov *et al.*, 2020). They also occur in unstable habitats and have large litter size, high reproductive effort, population fluctuations and good colonizing ability (Willan & Meester, 1989). The species current highly suitable habitat in the Selous ecosystem is in the northern and northeastern parts. Its projected distribution will not shift from the current distribution, instead its probability will increase on the few patches within the same areas of the ecosystem including KGCA, northern parts and far North. Considering its ability to occupy unstable habitats, high reproduction efforts (Willan & Meester, 1989), the chance that this species will survive the worst climate scenario is possible. As observed in this study, its highly suitable areas will not shift significantly.

Lemniscomys rosalia occurs in most of the African savannahs (Monadjem *et al*., 2016). This species can tolerate a wide range of habitats and can even tolerate modified habitats (Driver *et al*., 2011; Monadjem *et al*., 2016). The model predicts its current distribution to be concentrated in the northern part of Selous ecosystem. These areas are mostly dominated by grassland patches which are ideal for the species. Its anticipated distribution due to climate change effect will shift from the northern parts of the ecosystem to southern MINAPA and on few patches especially in the KGCA, central northern parts and far North of the ecosystem. The probability for its occurrence in areas which they are currently present especially in the northern parts will decrease but should not be a matter of serious concerns due to their ability to tolerate the modified habitats.

Species are expected to lose around 28.8% of their current distribution by 2070 and 20% net loss of species are expected in particular the local biodiversity under RCP 8.5W/m^2 (Newbold, 2018). The situation will be worse for restricted species in dispersal capabilities (Newbold, 2018). This can be attributed to restriction on species movement and possible extinction especially for species which are endemic or rare/endangered (Danielsen *et al*., 2009). Another possible consequence is species spreading to new areas and increasing the prevalence of diseases in humans (McKelvey *et al*., 2013). The expected shrinkage of highly suitable habitats in this study to apparent which suggests loss of habitat under RCP 8.5W/m^2 if the scenario of greenhouse gases emission will not be controlled. Species distribution is expected to shift poleward and altitudinally as an adaptation to climate change, suggesting species in the lower altitudes will be affected the most (Baltensperger & Huettmann, 2014; Shamsabad *et al*., 2018). Considering the observed effects, climate change should be considered among the important factors influencing conservation priorities (Jetz *et al.*, 2007).

Climate change has been projected to affect future distribution of species because of the changes in the habitat dynamic (HilleRisLambers *et al*., 2013; Holyoak & Heath, 2015). Therefore, there is a possibility that the biotic interactions/habitat dynamics may accelerate or impede climate change effects (HilleRisLambers *et al*., 2013; Ettinger & HilleRisLambers, 2013; Holyoak & Heath, 2015). Climate in combination with factors such as land use/cover changes will determine species distribution depending on connectivity between habitat patches (Guo *et al.,* 2018). The assumption here is that the ability of the ecosystems to respon d and auto-mitigate the climate induced impact is not yet fully known. Such knowledge is especially necessary for species in the conservation areas which are not directly affected by anthropogenic activities.

5.0 Conclusions and Recommendations

This study has shown that, the small mammal species prefer montane like areas within the Selous ecosystem. The study has also demonstrated the expected climate change effects that will shift the small mammal distribution in Selous ecosystem both positively and negatively. The model suggests that most of the current highly suitable range will be affected and species will be forced to concentrate in few areas of the ecosystem. It is important however to consider that, although the model predicted the observed distribution, there is a chance that, this will depend on the species capacity to adapt to the changing environment and time expected for these changes to occur. The study suggest that all species are able to adapt to dynamic habitats and can tolerate the disturbed area. The study recommends a robust mechanism in regulating the greenhouse gases emissions. In addition, climate change should form a key component in developing a general management plans (GMP) that should include intensified patrol to curb encroachment of any form and extension services related to conservation of natural resources in the surrounding villages. In addition, areas with low protection status such as Kilombero Game Controlled Area should be upgraded to Game Reserve standard to protect the important areas for species including small mammal future strong holds.

Acknowledgement

We are grateful for the financial support and sponsorship of Aenea Saanya for a PhD program by the African Center of Excellence for Innovative Rodent Pest Management and Biosensor Technology Development (ACE-II) - Sokoine University of Agriculture (SUA). We are grateful to Tanzania Wildlife Management Authority (TAWA) and Tanzania National Parks (TANAPA) for granting us permission to work in Selous Game Reserve/Nyerere National Park. We are indebted to our field team Khalid Kibwana and Ramadhani Kigunguli of Institute of Pest Management – SUA, Joseph John, Maulidi Msomolo, Musa Hassan, Fikiri Nzegema and Paulo Pangani of Kisaki village – Morogoro and Selous ecologists - Singira Ngoishie and Charles Tarimo for security and guidance. We thank Michael Kimaro and Simon Chidodo of SUA for assisting in the analysis of data and Prof. Josef Bryja for species confirmation using molecular technique.

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CHAPTER SIX

6.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The finding of this study has provided first-hand information on the diversity and distribution of small mammals in the Selous ecosystem. This is important information for updating the current small mammal distribution maps as most of the small mammal species are reported for the first time from this area with molecular confirmation. Further, *Grammomys selousi* is reported for the first time in the northern part of Rufiji River and South of Ruaha River. Overall, the findings of this study show that small mammal species abundance, richness, and diversity are largely influenced by habitat complexity and seasonal variations in climate and activities of large herbivores such as grazing in the Selous ecosystem.

Prescribed burning as a management tool favors high abundance, richness, and diversity of herbivore-murids than other groups of small mammals in the Selous ecosystem. While for individual species prescribed burning has shown varying effects both positive and negative. *Acomys ngurui* and *M. natalesis* have shown variations in the effect of prescribed burning on various demographic characteristics, suggesting that, although they share the same habitat, prescribed burning affects them differently.

Small mammal species' home ranges are influenced by habitats and seasons in the Selous ecosystem. In relatively stable habitats with infrequent large herds of herbivores, home ranges have shown to be larger than areas without large herds of herbivores, particularly buffaloes. Murid species have shown a high overlap within closed woodland which is associated with some degree of disturbances (prescribed burning and large herds of buffaloes) which suggests shared resources with a possible separation of time, i.e. crepuscular (*L. rosalia*) and nocturnal (*A. ngurui* and *M. natalensis*) and feeding behaviors with others being generalist such as *M. natalensis* and omnivorous (*A. ngurui*). Most small mammals were associated with seasonal riverine forests suggesting that areas with limited activities of large mammals and management practices such as prescribed burning species are more relaxed and niche separation is possible.

The study has also demonstrated that the expected climate change effects especially from the ‘business as usual scenario’ (RCP 8.5) will affect the distribution of small mammals in the Selous ecosystem. The model suggests that most of the current highly suitable range will be affected and species will be forced to concentrate in a few areas of the ecosystem. It is important however to consider that, although the model predicted the observed distribution, there is a chance that this will depend on the species' capacity in adapting to the changing environment and the time-lapse needed for the expected changes to occur.

6.2 Recommendations

To address the gaps identified by the findings of this study, the following recommendations are made;

i. The results from this study call for an update of various management plans including General Management Plans (GMPs) and Prescribed Burning Plan to include the distribution of small mammals in the ecosystem in particular Nyerere National Park and Selous Game Reserve.

ii. Conservation managers are advised to maintain the current cycle of prescribed burning since any alteration might affect the survival and population structures of herbivore-murid species in the ecosystem.

iii. Considering the projected climate change impacts on the ecosystem, I recommend upgrading the Kilombero Game Controlled Area (KGCA) to become a Game Reserve/National park as it will be among the strongholds of small mammal habitat. This will ensure maximum protection of the habitats for both small mammals and other ecosystem components.

iv. Climate change should form a key component in the development of specific protected areas General Management Plans (GMPs) with a specific chapter highlighting the climate change projected impacts and strategies, especially on the resilience and adaption of its impacts. To start with, it is particularly important to intensify patrols aimed at reducing/avoiding encroachment of any form from livestock herders and agriculture. In addition, community-based conservation services related to the conservation of natural resources in the surrounding villages should be intensified.

v. Further studies are recommended in the ecosystem to enable the prediction of species distribution in different climate scenarios (RCP 2.5, 4.5, and 6.5) in combination with other drivers such as development activities in the ecosystem including proposed infrastructures development, oil exploration, and expansion of agriculture (irrigation and livestock) upstream and adjacent to the ecosystem.

vi. Also, studies are recommended on the ecology of small mammal species in the wide part of the ecosystem including population dynamics concerning various management practices including development projects in the area to enable establishing their status in the ecosystem. Also, the area seems to be rich in small mammal fauna and this is especially in genera *Grammomys* and *Acomys* which might be more than the species/sub-species identified in this study.

APPENDICES

Appendix 1: Small mammal species diversity and distribution in selous ecosystem, Tanzania