Sokoine University of Agriculture

MSc Dissertation

Diversity and Temporal Fluctuations in Abundance of Rodents, Shrews and Their Flea-Ectoparasites in an Extensive Agricultural Landscape of Mgeta Division, Morogoro Region, Tanzania

Constance Chisala Chonde
May 2024

DIVERSITY AND TEMPORAL FLUCTUATIONS IN ABUNDANCE OF RODENTS, SHREWS AND THEIR FLEA-ECTOPARASITES IN AN EXTENSIVE AGRICULTURAL LANDSCAPE OF MGETA DIVISION, TANZANIA

Dissertation Submitted to Sokoine University
of Agriculture in Partial Fulfilment of the Requirements for the
Degree of Master of Science in Public Health Pest Management

By

Constance Chisala Chonde

Supervisors

Prof. A. A. S. Katakweba
Dr. B. Mubemba
Prof. A. W. Massawe

Deprtment of Veterinary Medicine and Public Health
College of Veterinary Medicine and Biomedical Sciences
Sokoine University of Agriculture, Morogoro, Tanzania

May 2024

EXTENDED ABSTRACT

Rodents and shrews play an important role in a variety of ecosystems including crop farming and the keeping of food animals. Increasing cultivation of crops and livestock keeping in Mgeta division, along the western slopes of Uluguru Mountain, is threatening the survival of rodents and shrews, and consequently, changes in the likelihood of these animals in their disease transmission patterns, which involves also their ectoparasites, particularly fleas, due to changes in their abundance and distribution in the ecosystem. This study was conducted from December 2021 to May 2022, and intended to investigate the diversity and temporal fluctuations in abundance of rodents, shrews and their flea-ectoparasites in Mgeta, an area with extensive agriculture in south-east Tanzania. Three habitats (forest, fallow and cultivated lands), each, were selected and defined as low (1,100 - 1,500 m a.s.l) and high (1,600 - 1,900 m a.s.l) elevations and subsequently sampled for rodents, shrews and their flea-ectoparasites. Removal trapping with baited live Sherman®, Harvahart® and locally made traps was carried out. A total of 192 rodents and 15 shrews were captured, and 199 fleas were collected. Identification of the rodents, shrews and fleas was done up to their species levels. Captured rodents included: *Rattus rattus* (1.45%), *Mastomys natalensis* (9.66%), *Beamys hindei* (1.45%), *Lophuromys flavopunctatus* (21.74%), *Lophuromys kilonzoi* (2.42%), *Praomys delectorum* (40.58%), *Grammomys ibeanus* (8.7%), *Graphiurus murinus (1.45%), Mus minutoides* (3.38%), *Mus musculus* (1.45%) and *Dasmys spp* (0.48%), whereas, the shrew species included: *Crocidura olivieri* (3.86%) and *Crocidura hirta* (3.38%). A Total number of 95 (45.89%) rodents and 6 (2.8%) shrews were infested by *Dinopsyllus lypusus, Nosopsyllus fasciatus* or *Ctenopthalmus calceatus*. The mean abundance of fleas presented a significant variation among the host species ($F_{(12, 194)} = 11.82$, $P < 0.001$), habitats ($F_{(2, 204)} = 9.935$, $P < 0.001$) and along the elevation gradient ($F_{(1, 205)} = 10.15$, $P = 0.02$). Similarly, the prevalence varied significantly between the hosts ($F_{(12, 194)} = 22.44$,

$P < 0.001$) and habitats ($F_{(2, 204)} = 4.837$, $P = 0.009$) but not with elevation ($F_{(1, 205)} = 0.291$, $P = 0.59$). The mean intensity of flea infestation, on the other hand, varied significantly among the hosts ($F_{(12, 194)} = 9.257$, $P < 0.001$) and along the elevation gradient ($F_{(1, 205)} = 47.91$, $P < 0.001$), but not habitats ($F_{(2, 204)} = 0.75$, $P = 0.474$). Furthermore, while rainfall intensity was strongly associated with mean abundance of fleas ($r = 0.054$, $P < 0.05$), neither temperature, elevation, nor humidity were correlated with either mean intensity or prevalence of fleas on the hosts. However, rainfall, temperature, and relative humidity had a significant effect on rodent and shrew abundance ($P< 0.05$). Given the discovery of *D. lypusus*, which is a well-known vector of the plague pathogen, *Yersinia pestis*, and a common ectoparasite of M. *natalensis* and *R. rattus*. Effective conservation strategies to preserve the remainder forest patches and community awareness programs regarding the existence of potential plague vectors and mitigation measures in the study area as well as avoidance mechanism should be implemented to ensure the health of the entire ecosystem.

IKISIRI KUU

Panya wanafanya kazi kubwa sana katika mazingira ikiwemo kusaidia ukuaji wa mazao shambani. Kuongezeka kwa shughuli za kilimo pamoja na ufugaji katika kata ya Mgeta pembezoni kabisamwa safu za milima ya Uluguru inaongeza hatari uwezekano wa kuishi miongoni mwa aina mbalimbali za panya na hatimaye kubadilisha muelekeo unaoweza kusababisha magonjwa kwa binadamu kupitia viroboto. Tafiti hii ilifanyika kati ya mwezi Disemba 2021 na Mei 2022 huku ikiwa imejikita katika kutambua mtawanyiko na utofauti wa muonekano wa panya pamoja na viroboto vyake katika eneo la kilimo katika kata ya mgeta, Tanzania. Aina tatu za maeneo zilichaguliwa na kutambuliwa kam situ, falo pamoja na eneo lililolimwa yote yakiwa katika muinuko mdogo (1,000 - 1,500 m a.s.l) na mkubwa (1,600 - 2,400 m a.s.l). Kwa kutumia njia ya kuondoa, iliweza kukamata panya 207 pamoja na viroboto 199. Aina za panya zilizokamatwa zilihusisha *Rattus rattus* (1.45%), *Mastomys natalensis* (9.66%), *Beamys hindei* (1.45%), *Lophuromys flavopunctatus* (21.74%), *Lophuromys kilonzoi* (2.42%), *Praomys delectorum* (40.58%), *Grammomys ibeanus* (8.7%), *Graphiurus murinus (1.45%), Mus minutoides* (3.38%), *Mus musculus* (1.45%), *Dasmys spp (*0.48%), *Crocidura olivieri* (3.86%) na *Crocidura hirta* (3.38%). Uwingi wa viroboto ulikuwa ni halisi miongoni mwa panya ($F_{(12, 194)} = 11.82$, $P < 0.001$), maeneo ($F_{(2, 204)} = 9.935$, $P < 0.001$) pamoja na katikati ya muinuko ($F_{(1, 205)} = 10.15$, $P = 0.02$). Uwingi wa viroboto miongoni mwa panya waliodhurika ulitofautiana kwa uhalisia kati ya mwinuko ($F_{(1, 205)} = 47.91$, $P < 0.001$), lakini haukutofautiana kati ya eneo moja na jingine ($F_{(2, 204)} = 0.75$, $P = 0.474$). Wakati Kiwango cha mvua kilijionesha kuwa na uhusiano mkubwa na uwingi wa viroboto miongoni mwa panya ($r = 0.054$, $P < 0.05$), sio joto, unyevunyevu wala muinuko ulioonesha kuwa na uhusiano wa moja kwa moja na uwingi wa viroboto.

Maneno muhimu: Panya, viroboto, muinuko, uwingi, mtawanyiko, Mgeta

DECLARATION

I, Constance Chisala Chonde, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted to any other institution for a degree award.

Constance C. Chonde **Date**
(Candidate-MSc. Public Health Pest Management)

The above declaration is confirmed by:

Prof. A. A. S. Katakweba **Date**
(Supervisor)

Dr. B. Mubemba **Date**
(Supervisor)

Prof. A. W. Massawe **Date**
(Supervisor)

COPYRIGHT

ACKNOWLEDGEMENT

My greatest gratitude goes to God for giving me the ability and strength to complete this work. Indeed, I can do all things through Christ Jesus who gives me strength.

I am highly grateful to my supervisors, Prof. A. A. S. Katakweba and Prof. A. Massawe of Institute of Pest Management, (IPM) Sokoine University of Agriculture in Tanzania and Dr. B. Mubemba of the Copperbelt University in Zambia, who tirelessly gave me support and guidance throughout this research.

I would like to recognize and express my gratitude to African Centre of Excellence for Innovative Rodent Pest Management and Biosensor Technology Development (ACE IRPM and BTD) through Project No 5799-TZ under IMP of the Sokoine University of Agriculture for funding this Master’s program thereby giving me a platform to grow in my career as without this scholarship I would not have reached this far.

Also, I would like to thank the management and administrative officials of Tanzania Forest Reserve (TFS) and Local Government for granting me permission to carry out this study in Mgeta. Many thanks go to Ginethon Mhamphi of IPM and the entire team from Mgeta who made my work lighter by helping me with sample collection and processing.

I would like to express my gratitude to my family especially my loving parents for their love, support and unwavering faith in me.

Special gratitude goes to the most loving, caring and supportive husband Buuya Siagwelele and my beautiful daughter Terresa L. Siagwelele for standing with me throughout the course of this study. Your immense contribution cannot be fully captured by words. I love you both.

Many other thanks go to my colleagues Faith Ngwewa, Jeremiah Lyatuu, Clara Majawa, Alphonce Echumba and Dr. J. Luvanga who helped me in various ways throughout my study.

DEDICATION

I dedicate this work to my beloved daughter, Teressa Lutangalo Siagwelele who was born during this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

%	Percent
°C	Degree Celsius
a.s.l	Above sea level
ACE-IRPM & BTD	Africa Centre of Excellence for Innovative Rodent Pest Management and Biosensor Technology Development
ANOVA	Analysis of Variance
df	Degree of freedom
GPS	Global positioning system
IPM	Institute of Pest management
Km	kilometer
km^2	Kilometer square
m	Metre
mm	Millimeters
P	Probability
SPSS	Statistical Package for Social Science
SUA	Sokoine University of Agriculture
TFS	Tanzania Forest service

STRUCTURE OF THE DISSERTATION

This dissertation consists of FOUR chapters. Chapter ONE describes background information on rodents, shrews and their associated fleas, as well as factors grounding their distribution pattern in different habitats. It also contains the problem statement and justification, research objectives, and the list of manuscripts. Chapter TWO elucidates the diversity and temporal fluctuations of rodents, shrews and their fleas in an extensive agricultural landscape of Mgeta, Morogoro Region-Tanzania. Chapter THREE highlights the investigations on the prevalence of fleas on rodents and shrews, and its potential for transmission of rodent vector-borne zoonoses in Mgeta, Morogoro-Tanzania. Chapter FOUR consists of the general discussion, conclusion and recommendations.

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Rodents and Shrews

Rodents and shrews account for a significant part of mammalian species diversity, and they are an essential component of a variety of habitats ranging from agricultural lands, forest and mountainous areas (Vaughan *et al*, 2000; Avenant and Cavallini, 2007). They have a significant ecological impact on the composition, structure and diversity of ecosystems (Mukherjee *et al*., 2004). For instance, they have a critical position in the food web in diverse ecosystems, as numerous predators such as snakes and owls depend on them as a source of food (Byron *et al*., 2015). Furthermore, based on species diversity, abundance, and assemblages; rodents' and shrews' use of different habitat types may indicate ecosystem changes (Ofori *et al*., 2016) or landscape integrity (Milstead *et al*., 2007; Avenant *et al*., 2011). Therefore, they are good ecological indicators of habitat disturbance and important contributors to biodiversity (Avenant and Cavallini, 2007). Along with their contribution to the ecosystem, rodents and shrews are hosts to a range of pathogen bearing ectoparasite arthropods such as ticks, bugs, mites, fleas and lice (Chae *et al.,* 2008; Kia *et al*., 2009; Changbunjong *et al*., 2010). As a result, they potentially mediate the transmission of diseases such as plague and murine typhus that are associated with these arthropods (Makundi *et al*., 2008; Vallée *et al*., 2010).

1.2 Fleas

Fleas are hematophagous and obligate ectoparasites infesting vertebrates, particularly rodents and shrew (McCauley *et al.,* 2008). They are distributed globally with more than 2500 species belonging to 17 families and 238 genera (Maleki-Ravasan *et al*., 2017). Despite primarily invading rodent and shrew (de Bellocq *et al*., 2006), they occasionally infest a wide range of animals, including birds (Kotti, 2015), large mammals (Clark *et al*., 2018) and humans (Miarinjara *et al*., 2021). They typically infest the host's skin, particularly the external orifices, such as hair root, nares, and orbits (Paramasvaran *et al*., 2009). They differ in terms of host specificity (Shenbrot *et al*., 2007), as some of them invade a wide range of hosts while others are host specific (Medvedev, 2002). For instance, *Nosopsyllus fasciatus, Ctenophthalmus apertus*, and *Leptopsylla taschenibergi* are reported to prefer infesting common voles (Herrero-Cofreces *et al*., 2021) while *Thrassis pandorae*, *Eumolpianus eumolp*i and *Oropsylla idoensis* infests wide range of hosts (Goldberg *et al*., 2020). Rodents and shrews, as good reservoirs of fleas, play a significant role in the epidemiology of zoonotic diseases such as plague, murine typhus and tularemia, transmitted by pathogens such as *Y. pestis*, *Rickettsia typhi* and *Francisella tularensis,* respectively (Mostafavi *et al*., 2017).

1.3 Abundance and Distribution of Rodents, Shrews and their Fleas

The distribution of rodents, shrews and their flea-ectoparasites is strongly affected by a range of biotic and abiotic factors (Yin *et al*., 2011; Lang *et al*., 2014; Gutiérrez *et al*., 2014). However, due to their high dependence on the hosts for feeding, the spatial distribution of fleas is sometimes thought to be dictated by the distribution and habitat of the host (Krasnov *et al.,* 2002; Sanchez *et al*., 2019; Fantozzi *et al*., 2022). With regards to rodents and shrews, habitats are associated with environmental variables such as climate (Magnusson *et al*., 2021, Wallace *et al*., 2021), altitude (Mulungu *et al*., 2008; Gebrezgiher *et al*., 2022), vegetation type and cover (Flores-Peredo and Vázquez-Domínguez, 2016; Thomas *et al*., 2022), anthropogenic activities (Guevara and Ball, 2018; Ssuuna *et al*., 2020) and other interactions such as parasitism, mutualism, competition, and predation (Xiao *et al*., 2005). Nevertheless, precipitation is the most important factor regulating demographic processes and population dynamics in tropical rodents because primary productivity is highly dependent on precipitation (Brown and

Ernest, 2002; Previtali *et al*., 2009). In addition, seasonal changes significantly affect small mammal abundance and habitat preferences (Pakdeenarong *et al*., 2014) via alteration of the availability of dietary components such as seeds, flowers and fruits (Xiao *et al*., 2005). On the other hand, solely or combination effect of hosts and environmental factors influence flea assemblages on their hosts (Yin *et al*., 2011). For instance, host species, sex and age might cause variation in flea assemblage as a result of differences in the host's home range and immunity, (Abu-Madi *et al*., 2005). Similarly, abiotic pressures such as humidity, temperature and rainfall cause variation in the growth of flea larva and reproduction (Metzger *et al*., 1999; Krasnov *et al*., 2001). Anthropogenic activities, particularly agriculture, also contributes to population dynamic of rodents, shews and their fleas through altering important habitats used by hosts (Young *et al*., 2017).

1.4 Problem Statement and Justification

1.4.1 Problem Statement

Mountainous landscapes are safe havens for a variety of small mammals such as rodents and shrews (Richard *et al*., 2022; Gebrezgiher *et al*., 2022; Thomas *et al*., 2022). However, increased disturbances, including human and natural causes, are very likely to compromise their endemism and, more importantly, alter the distribution of their ectoparasite vectors of zoonotic diseases, particularly plague (Friggens and Beier, 2010; Young *et al*., 2017). In the western slopes of Uluguru Mountains, which is part of the Eastern Arc Mountains (EAM) and an important area for conservation in Tanzania (Burgess *et al*., 2007), biodiversity is facing an alarming threat of anthropogenic disturbances such as transformation of natural landscape to agricultural land. This is as a result of the area being densely populated by smallholder farmers, with 84% of them practicing both crop or animal farming or both (John, 2012). These activities are significantly altering the diversity of rodent and shrews, and their ectoparasites, particularly fleas, thus increasing the likelihood of transmission of vector-borne zoonotic diseases such as plague. Therefore, this study aimed at exploring the diversity and temporal variations of rodents, shrews and their flea-ectoparasites, as well as investigating their potential for transmission of flea-borne pathogens in the human - altered landscape of Mgeta highlands.

1.4.2 Justification

Since rodents and shrews form an essential component of diverse ecosystems (Richard *et al*., 2022; Gebrezgiher *et al*., 2022) ranging from agricultural lands, forest and mountainous areas (Avenant and Cavallini, 2007), information on their abundance, diversity, temporal and habitat variations is useful in developing management and conservation measures. On the other hand, information on potentially dangerous fleas and how rodent population dynamics affect the flea populations is critical in understanding the dynamics of rodent-flea-borne disease transmission that may occur in the study area (Krasnov *et al*., 2002; Makundi *et al*., 2015). This will then assist relevant authorities in developing a surveillance system to monitor rodent and flea infestations in order to provide early warning of potential disease outbreaks, which will translate into prevention and control of rodent and flea-borne diseases in the study area.

1.5 Research Objectives

1.5.1 General Objective

To determine the diversity and temporal fluctuations of rodents, shrews and their flea- ectoparasites in an extensive agricultural mountainous landscape of Mgeta, Morogoro-Tanzania

1.5.2 Specific Objectives

i. To determine species diversity, abundance and temporal fluctuations of rodents, shrews and their flea-ectoparasites in Mgeta highlands
ii. To assess the variation of flea-ectoparasite infestation on rodent and shrew species and its potential for transmission of flea-borne pathogens

1.6 List of Manuscripts

Dissertation of this research is based on two manuscripts corresponding to research specific objectives:

1st Manuscript: DIVERSITY AND RELATIVE ABUNDANCE OF RODENTS, SHREWS AND THEIR FLEA-ECTOPARASITES IN DIFFERENT HABITATS AND ELEVATIONS IN MGETA, MOROGORO REGION-TANZANIA.

2nd Manuscript: PREVALENCE OF FLEAS ON RODENTS AND SHREWS, AND THEIR POTENTIAL FOR TRANSMISSION OF ZOONOSES IN MGETA, MOROGORO REGION- TANZANIA.

CHAPTER TWO

DIVERSITY AND RELATIVE ABUNDANCE OF RODENTS, SHREWS AND THEIR FLEA-ECTOPARASITES IN DIFFERENT HABITATS AND ELEVATIONS IN MGETA, MOROGORO REGION-TANZANIA

Constance C. Chonde[1,2,3], Abdul A. S. Katakweba[1,3], Benjamin Mubemba[4] and Apia W. Massawe[1,3]

[1] Department of Veterinary Medicine and Public Health, Sokoine University of Agriculture, Morogoro Tanzania P.O. Box 3021
[2]Institute of Pest Management, Sokoine University of Agriculture, P.O. Box 3110, Morogoro, Tanzania
[3]African Centre of Excellence for Innovative Rodent Pest Management and Biosensor Technology Development (ACE IRPM and BTD) Project, Sokoine University of Agriculture, P.O. Box 3110, Morogoro, Tanzania.
[4]Department of Zoological and Aquatic Sciences, Copperbelt University, P.O. Box 21692, Kitwe, Zambia

* Correspondence: constancechonde@gmail.com

Manuscript submitted and under review: Ecosphere Journal

ABSTRACT

Rodents and shrews account for a significant part of mammalian species diversity and are of significant importance in diverse ecosystems. This study investigated the diversity, abundance and temporal fluctuations of rodents, shrews and the associated flea-ectoparasites in habitats sampled between elevations along the extensive agricultural landscape of Mgeta highlands, Morogoro, Tanzania. Three habitats (forest, fallow and cultivated lands) were selected at low (1,100 - 1,500 m a.s.l) and high (1,600 - 1,900 m a.s.l) elevations and subsequently sampled. Five transect lines each 50 m were established per habitat type. Removal trapping using 50

Sherman® traps, two Havahart® traps, and five locally made traps was carried out. The trapping duration was in total 6048 trap nights in which 207 individuals were captured, comprising of 11 rodent and two shrew species. Individual animals' fur was carefully brushed to remove ectoparasites of which 199 were fleas of the species *Dinopsylus lypusus*, *Ctenophthalmus calceatus* and *Nosopsyllus fasciatus. Dinopsylus lypusus* was the most abundant flea species. A total of 292 mites (*Laelaps* spp) and six ticks (*Haemophisalis* spp) were also collected. The overall abundance of captured rodents and shrews varied significantly between habitats ($F_{(2,75)} = 6.22$, $P = 0.003$) and the time of trapping ($F_{(5,6)} = 7.97$, $P = 0.013$), but not between elevations ($F_{(1,10)} = 0.478$, $P = 505$). The number of rodents, shrews and corresponding flea-ectoparasites peaked in April and May, with the forest and low elevations showing the highest abundance and diversity of rodents and shrews. The relative humidity, temperature, and rainfall showed stronger association with the temporal variation in relative abundance of rodents and shrews ($p < 0.001$). Given the importance of rodent and shrew species in ecosystems, and the fact that most of them were collected within the forest, conservation strategies should be implemented; however, caution is required given the presence of vectors of public health importance particularly *D. lypusus*, known to be an efficient vector of *Y. pestis*, the causative pathogen of plague in East Africa.

Keywords: Abundance, Diversity, Fleas, Rodents, Shrews, Agricultural landscape, Mgeta, Tanzania

2.0 INTRODUCTION

Small mammals, particularly rodents and shrews are considered pests due to the significant economic impact they cause (Harris, 2009; St Clair, 2011). Apart from economic losses they cause in agriculture (Magige, 2012; Mulungu, 2017) and domestic or industrial settings via consumption of food and destruction of materials (Almeida *et al*., 2013), rodents are also potential reservoirs of several pathogens (Luis *et al*., 2013; Jahan *et al*., 2021). The spread of pathogens to other susceptible hosts is highly aided by vectors, such as fleas in the transmission of plague (Laudisoit *et al*., 2007; Makundi *et al*., 2008), mites in dermatitis (Battersby, 2015) or ticks and chiggers in transmission of lyme disease and scrub typhus, respectively (Shaw *et al*., 2003; Zhang *et al*., 2013). On the other hand, rodents and shrews perform key ecological roles by providing food for avians, reptiles and mammalian predators, and are also important primary consumers of seeds and herbage (Krebs, 2007; Mulungu *et al*., 2013). They also respond to resource availability and/or diversity, microhabitat structure, and are sensitive to landscape and environmental changes (Kajin and Grelle, 2012; Melo *et al*., 2017) and thus are good indicators of environmental quality and an ideal group of animal species to assess landscape, human-driven and climate change impacts on biodiversity (Bonvicino *et al*., 2002; Camargo *et al*., 2019).

Biodiversity, referred to as the variety and variability of life in a particular habitat is threatened by numerous forces in human-modified surroundings (Gardner *et al*., 2009; Crispo *et al*., 2011). As a result, there is an accelerated loss of biodiversity and a drastic alteration of processes and ecological configurations which, to a great extent, trace back to anthropogenic drivers (Savin and Nistreanu, 2009; Ruffino *et al*., 2013). For example, these landscape alterations in the tropics result mostly from the conversion of natural environments into agriculture and pasture (Françoso *et al*., 2015; Strassburg *et al*., 2017). These human-driven changes may affect the distribution pattern as well as the associated fleas on rodent and shrew (Hieronimo *et al*., 2014; McCauley *et al*., 2015). On the other hand, Livestock grazing causes mechanical disturbance, reduces plant biomass, and changes the composition of the vegetation, as well as encourage vegetation regrowth and nutrient enhancement (Vial *et al*., 2011), resulting in changes in rodent and flea populations (Van der Mescht *et al*., 2013; Young *et al.,* 2015).

Like many other animals, rodents, shrews and their ectoparasites form an important component in a variety of habitats including the Uluguru Mountains (Burgess *et al*., 2002; Kalumanga, 2007). This mountain is one of the most important blocks of the Eastern Arc Mountains (EAM) which is designated as one of the 20 “Global Biodiversity Hotspot” areas (Burgess *et al*., 2007; Mattee *et al*., 2020). Nonetheless, different species of fauna and flora, including rodents and shrews in this eco-region are under constant threat due to progressive damage of the landscape following the conversion of natural environments into crop cultivation settings as well as for livestock keeping (Burgess *et al*., 2002). This is an important conservation concern as these activities do not only modify small mammal community but also alters the distribution of associated vectors particularly fleas, which are responsible for the transmission of zoonotic diseases like plague (Kimaro *et al*., 2014; Hieronimo *et al*., 2014; Poland *et al*., 2019). This study therefore, examined the abundance, diversity and temporal fluctuations of rodents and shrews, and their flea-ectoparasites as well as the effect of climatic conditions (rainfall, temperature and humidity) on the temporal variation in relative abundance and diversity of rodents and shrews in an extensive agricultural landscape of Mgeta, Morogoro, Tanzania. This was with a view of providing baseline data for conservation of rodent and shrew species and surveillance for potential rodent -borne diseases in the area.

2.1 Methodology

2.1.1 Materials and methods

2.1.1.1 Study area

The study was conducted in Vinile village in Mgeta ward of Mvomero District located between 7^{o} 2’ 8’’ S and 37^{o} 33’55’’ E in Tanzania ((Fig. 2.1), from December 2021 to May 2022. The Ward lies about 60km South-West of Morogoro Region on the Western slopes of Uluguru Mountains at an altitude of 1100 to 1950 m above sea level (Nziku *et al*., 2016). Being part of the Eastern Arc Mountains, Uluguru Mountains are considered as a hotspot and important area for the conservation of biodiversity in Tanzania (Burgess *et al*., 2001). The area experiences a bimodal rainfall pattern, with a short rainy season between October and January, and long rainy season between March and May (Chidodo *et al*., 2020). Annual precipitation ranges from 700 to 2,300 mm, with lowest amounts being found at low elevations, and average temperatures of 30^{o} C in the warmer months and 18^{o} C in the cooler season. The soils are moderately deep, reddish, well-drained, yellowish sandy clay loams and sandy clays (Burgless *et al.,* 2007). The area is characterized by heterogeneous kind of vegetation and landforms along the altitudinal gradient particularly, piedmonts, peneplains and steep mountains (Chidodo *et al*., 2020).

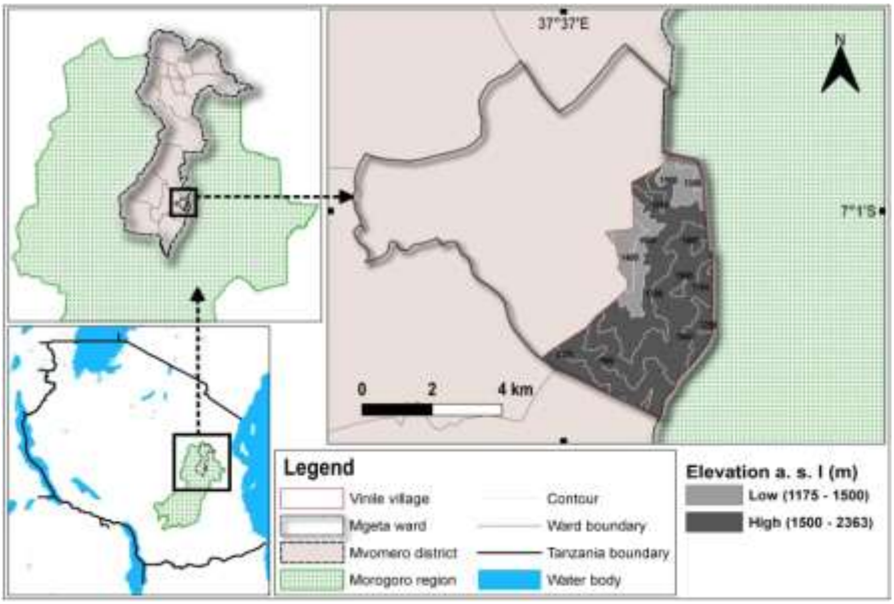


Figure 2.1: Map of Mgeta ward showing study sites in different elevations. The map was generated in QGIS Version 3.24 Tisler' retrieved on 31 August 2022

2.1.1.2 Sampling Design

The study area was stratified into two altitude ranges (1 600 to 1 900 m a.s.l and 1 100 to 1 500 m a.s.l), which were referred to as the high (H) and low (L) elevations respectively. Elevations were sampled using Global Positioning System (GPS) and three different habitats (forest, fallow and cultivated land) were identified for trapping in each elevation. Forest habitat was defined as a continuous strand of trees with no evidence of farming or settlements, the fallow was identified as a discontinuous strand of trees with evidence of farming activities, settlement, and/or recurrent wildfire; while the cultivated portions were attributed to mono and mixed cropping methods and were identified as land that was used for farming for at least eight months in each year (Chidodo *et al*., 2020).

2.1.1.3 Study design and trapping of rodent and shrew

The study employed a repeated cross-sectional design. Trapping was done for three days consecutively at intervals of four weeks for a period of six months from December, 2021 to May, 2022 and comprised six trapping sessions. Trapping of the rodents and shrews was done in three habitat types (forest, fallow and cultivated lands) at two different elevation gradients (Low and High). Removal method was employed in which five line transects of 50 m were established in each habitat. On each transect, ten Sherman® live traps (23 × 9 × 8 cm; H.B. Sherman Traps, Inc., Tallahassee, Florida) were placed 10 m apart. To increase the capture success of small mammal species, two Havahart® traps (60 x 15 x 170 cm) and five local traps were also placed randomly within each of the three habitats, making a total of 57 traps per habitat type in the lower and high elevations, and 342 traps across the whole study area. The setting of traps was done simultaneously in the three (3) habitats and in both low and high elevations. Traps were baited with peanut butter and maize flour, green maize, avocado and ripe bananas (Andrzejewski*,* 2002; Nyirenda *et al.,* 2020), and set in the evening at 6pm and inspected the next day in the morning at 7am (East African Time).

2.1.1.4 Identification of rodents and shrews

Identification of captured rodents and shrews was made to species level, and for each individual body parameters were recorded, including: weight, sex and maturity/breeding status. Identification was done using keys and illustrations developed by Happold (2015).

2.1.1.5 Collection of Fleas from captured rodents and shrews

Collection of fleas from rodents and shrews was done after anaesthetizing the animals with 90% Diethyl Ether (C4H100) EMPLURA^R (Katakweba *et al.,* 2013). The fur of the captured animals was then brushed thoroughly with a hard toothbrush to disengage the ectoparasites in a basin lined with a white plain cloth (Eads and Biggins, 2019). Thereafter, fleas and other ectoparasites were gently picked from the basin, using a fine camel hair brush into vials containing 70% ethanol for preservation (Nyirenda *et al.,* 2018). These were then transported to the Laboratory of the Institute of Pest Management (IPM) at Sokoine University of Agriculture (SUA) for further processing and identification.

2.1.1.6 Processing and identification of Fleas

From the vials containing preservation medium (70% alcohol), fleas were removed and boiled in 10 % KOH (Potassium hydroxide) for 10 minutes, after which they were transferred into acidified water and then rinsed in distilled water. Later, they were put in 50 % ethanol for 1h and then replaced into 70 % ethanol for another 1h and replaced again into 95 % ethanol for 1h. Thereafter, they were placed into absolute ethanol for another hour then placed in clove oil overnight to clear them. Mounting was then done by DPX solution, after which they were examined under a compound microscope (Bahmanyar and Cavanaugh, 1976). Fleas were identified and sexed using their main distinguishing morphological features, which included genal combs, pronotal combs, reproductive organs (spermathecae in females and penis plates in males) and the shape of the head (Nyirenda *et al.,* 2018). Identification of the fleas was done using keys and steps developed by Kohl (1957). For the Mites and Ticks, they were heated into the KOH (potassium hydroxide), then after a curved slide was prepared and a drop of Hoyer's medium was placed at the centre of the slide. The mites and ticks were singularly placed into the drop of Hoyer's medium in each slide; the orientation was either dorsoventrally or laterally then a cover slip was placed on top of it. The slides were then placed into the oven at 45-50 degrees for 24 hours, then the slides were removed from the oven and more Hoyer's medium was added and left for the slides to cool and then they were placed under microscope for identification (Krantz, 1971).

2.1.2 Data analysis

Data entry and coding was done in Microsoft excel and analysis was done using Statistical Package for the Social Sciences (SPSS) version 26 (IBM Corporation, Armonk, NY, USA). Computation of abundance and diversity of rodents was based on the relative abundance and Shannon-Wiener diversity index (Mulungu *et al*., 2008). The index was also used to compute the diversity of fleas among habitats, between elevations and among trapping months. Relative abundance (RA) of rodent and shrew species in each habitat was calculated as the ratio between the number of species found in each habitat and the total number of species recorded in the study area.

i.e $$R.A = \frac{\text{number of species} \qquad\qquad\qquad \times 100}{\text{Total number of all individual species}}$$

The Shannon-Wiener diversity index was defined as:

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

Where *H'* is the diversity index and *pi* is the proportion of the total sample belonging to each species *i*. where P_i is the proportion of captured rodents in the samples of a particular number, i, of individuals per habitat type, $\ln P_i$ is the natural logarithm of the proportion of captured rodents while S is the number of sampling units. The success rate of capture was referred to as trap success and calculated by dividing the number of individuals captured by the trap nights and multiplying it by 100.

i.e. Trap success = $$\frac{N*100}{\text{Trap night } (Nt * Nd)}$$

Where *N* = total number of rodents or shrews of species X captured, *Nt* = number of traps used and *Nd* = total trap nights. A “trap night” is one trap set for one full night (Shilereyo *et al*., 2019). Trap success has been recommended as a good measure of spatial and temporal variations in relative abundance (Cavia *et al*., 2012). Pearson coefficient was used to check the correlation between weather parameters (relative humidity, temperature, rainfall) and habitats on the abundance of rodents and shrews. Analysis of Variance (ANOVA) was used to compare the abundance of rodents and shrew among habitats, trapping months and along the elevation gradient. Estimation of flea abundance among habitats, months and between elevations was based on the mean abundance, which was calculated as the number of fleas infesting particular hosts to the total hosts examined. Prevalence was estimated as the total number of hosts infested with a particular flea to the total number of hosts examined.

2.2 Results

2.2.1 Rodent and shrew species composition and population abundance

A total of 207 rodents and shrews were captured in 6048 trap nights from all habitats sampled between elevations. Eleven (11) rodent species (*Rattus. rattus, Mastomys natalensis, Beamys hindei, Lophuromys flavopunctatus, Lophuromys kilonzoi, Praomys delectorum, Grammomys ibeanus, Graphiurus murinus, Mus minutoides, Mus musculus, and Dasmys* spp) and two shrew species (*Crocidura olivieri* and *Crocidura hirta*) (Table 2.1). *Praomys delectorum* (40.59%) comprised the largest percentage of all captured rodent species, followed by *Lophuromys flavopunctatus* (21.74%), *Mastomys natalensis* (9.66%) and *Grammomys ibeanus* (8.7%). Of the least frequently captured species were: *Crocidura olivieri,* (3.86%)*, Crocidura hirta* (3.38%), *Mus minutoides* (3.38%), *Lophuromys kilonzoi* (2.42%), *Rattus rattus* (1.45%), *Beamys hindei*

(1.45%), *Graphiurus murinus* (1.45%), *Mus musculus* (1.45%) and *Dasmys* spp (0.48%) (Table 2.1). The overall abundance of captured rodents and shrews varied significantly among habitats ($F_{(2,\ 75)} = 6.22$, $P = 0.003$) and months ($F_{(5,6)} = 7.97$, $P = 0.013$), but not between elevations ($F_{(1,\ 10)} = 0.478$, $P = 505$). However, the individuals captured in the low elevation had a higher relative abundance than the ones caught in the high elevation ($F_{(1,\ 10)} = 0.654$, $P = 0002$), and the abundance of rodent species within the forests, fallows and cultivated habitats differed significantly along the elevation gradient ($F_{(12,13)} = 11.99$, $P < 0.001$, ($F_{(12,13)} = 2.617$, $P = 0.049$ and ($F_{(12,13)} = 33.87$, $P < 0.001$, respectively).

Table 2.1: Number of Rodents and shrews and their percentage relative abundance (in parentheses) in different habitats and elevations in the agricultural landscape

	Low Elevation			**High Elevation**			
Rodent species	**(F_L)**	**(FA_L)**	**(C_L)**	**(F_H)**	**(FA_H)**	**(C_H)**	**Total**
L.flavopunctatus	25 (27.17)	4 (36.36)	1 (7.69)	12 (16.22)	1 (20)	2 (16.67)	45 (21.74)
L.kilonzoi	3 (3.26)	-	-	2 (2.7)	-	-	5(2.42)
M.minutoides	-	2 (18.18)	2 (15.38)	1 (1.35)	-	2 (16.67)	7 (3.38)
M.musculus	-	-	2 (15.38)	-	-	1 (8.33)	3 (1.45)
M.natalensis	-	4 (36.36)	7 (53.38)	1 (1.35)	2 (40)	6 (50)	20 (9.66)
Dasmys spp	-	1 (9.09)	-	-	-	-	1 (0.48)
G.ibeanus	6 (6.52)	-	-	11 (14.86)	-	1 (8.33)	18 (8.7)
P.delectorum	43 (46.74)	-	1 (7.69)	40 (54.05)	-	-	84 (40.58)
B.hindei	3 (3.26)	-	-	-	-	-	3 (1.45)
G.murinus	3 (3.26)	-	-	-	-	-	3 (1.45)
R.rattus	2 (2.17)	-	-	-	1 (20)	-	3 (1.45)
Shrew species							
C.olivieri	2 (2.17)	-	-	5 (6.76)	1 (20)	-	8 (3.86)
C.hirta	5 (5.43)	-	-	2 (2.7)	-	-	7 (3.38)
Total Captures	92 (100)	11 (100)	13 (100)	74 (100)	5 (100)	12 (100)	207 (100)
Trap nights	1008	1008	1008	1008	1008	1008	6048
Trap success	0.091	0.011	0.013	0.073	0.004	0.011	0.03

KEY: FL – Forest low, FAL – Fallow low, CL – Cultivated low, FH – Forest High, FAH – Fallow high, CH – Cultivated high

2.2.2 Diversity of rodent and shrew species

Species diversity of rodents and shrews varied significantly with habitat type, along the elevation (Table 2.2) and on monthly basis ($P < 0.001$). Forest low (F_L) showed the highest diversity of rodents and shrews, respectively, than the other habitats and elevations. Species richness and evenness also varied among habitats and elevations, however, the apparent differences were not significant (P = 0.86).

Table 2.2: **Rodent and shrew species diversity, richness and evenness in the agricultural landscape of Mgeta**

	Low Elevation			High Elevation		
	F_L	**FA_L**	**C_L**	**F_H**	**FA_H**	**C_H**
Richness	9	4	5	8	4	5
Individuals	92	11	13	74	5	12
Shannon index	1.547	1.264	1.304	1.404	1.332	1.358
Evenness	0.522	0.8846	0.7367	0.5092	0.9473	0.7777

KEY: F_L – Forest low, FA_L – Fallow low, C_L – Cultivated low, F_H – Forest High, FA_H – Fallow high, C_H – Cultivated high

2.2.3 Influence of climatic variables and elevation on rodent and shrew variation

Rainfall, temperature and humidity showed significant influence on the abundance of rodents and shrews in the three habitat types in both elevations as evidenced by the same value of *p* (0.01). Meanwhile, elevation showed no influence on rodent and shrew abundance (*p* =0.677). However, low elevation presented a higher number of individuals than high elevation (Table 2.1).

Table 2.3: Pearson correlation results showing the association between climatic variables (Humidity, temperature, rainfall) and abundance of rodents and shrews.

Variable	**R**	**P**
Relative humidity	0.6	< 0.05
Temperature	0.5	< 0.05
Rainfall	0.8	< 0.05

2.2.4 Abundance and prevalence of fleas

A total of 497 ectoparasites including 199 fleas (40.04%), 292 (58.75%) mites and six ticks (1.2%) belonging to the order Siphonaptera, Mesostigmata and Ixodida, respectively, were collected from the rodents and shrews. The flea species included *D. lypusus*, *C. calceatus and N. fasciatus*, whereas mites included *Laelaps* spp while ticks were *Haemaphysalis* spp. Overall, a total number of 95(45.89%) rodents and 6 (2.9%) shrews were at least infested by one of the flea species. The abundance and diversity of fleas varied among trapping habitats, between elevations, and among trapping months with April showing higher diversity than others (Table 2.4), however, the difference was not significant F ($_{5, 30}$) =0.984, P = 0.444).

Table 2.4: Monthly variation of flea abundance and mean abundance (in parentheses)

	December	**January**	**February**	**March**	**April**	**May**
N(hosts)	**20**	**16**	**19**	**35**	**53**	**63**
D. lypusus	26 (1.3)	11(0.69)	19(1)	26(0.74)	29(0.55)	42(0.67)
N. fasciatus	3(0.15)	1(0.06)	0(0)	4 (0.11)	2(0.04)	6 (0.1)
C. calceatus	3(0.15)	1(0.06)	2(0.11)	3(0.09)	19(0.36)	5(0.08)
TOTAL	**32 (1.6)**	**13 (0.81)**	**21 (1.11)**	**33 (0.94)**	**50 (0.94)**	**53 (0.84)**

Table 2.5: Species diversity, richness and evenness of fleas in the agricultural landscape

	LOW ELEVATION			**HIGH ELEVATION**		
	F_L	**FA_L**	**C_L**	**F_H**	**FA_H**	**C_H**
Richness	3	3	1	3	2	2
Individuals	61	18	12	85	7	20
Shannon Index	0.714	0.66	0	0.805	0.41	0.199
Evenness	0.681	0.642	1	0.745	0.753	0.763

KEY: F_L – Forest low, FA_L – Fallow low, C_L – Cultivated low, F_H – Forest High, FA_H – Fallow high, C_H – Cultivated high

2.2.5 Hosts sex, age and flea biased parasitism

Although females made up the majority of total captures (53.6%), male rodents and shrews were more infested by fleas ($F_{(1,24)} = 11.2$, $P = 0.04$) than females. Also, adult males were more preferred by fleas than juveniles ($F_{(1,24)} = 40.97$, $P < 0.001$)

2.3 Discussion

To our knowledge, this is the first study reporting on the diversity and relative abundance of rodents and shrews and their flea-ectoparasites in different habitats and elevations in Mgeta. Nearly all the rodent and shrew species as well as their ectoparasite-vectors, particularly *D*. *lypusus*, recorded in this study have been previously identified in Northern Tanzania (Meliyo *et al*., 2014; Makundi *et al*., 2015) as well as in neighbouring countries of Kenya (Oguge *et al*., 2009) and Uganda (Bai *et al*., 2017). Some of the rodent species, like *R. rattus* as well as their associated ectoparasites, are regarded as reservoirs and vectors of various pathogens, respectively.

As expected, species diversity and richness of rodents and shrews, with their flea ectoparasites were higher in forest habitats. This demonstrates the importance of protection in maintaining habitat and, species diversity and richness in the ecosystem. The recorded a high abundance of rodents than shrews by this study was anticipated because of rodents' high adaptability and colonization potential across diverse habitats (Fabre *et al*., 2012).

Praomys delectorum was the most abundant, with over 46 % and 54 % contribution in F_L and F_H respectively, whereas *L. flavopunctatus* ranked second. The high abundance of *P. delectorum* was expected since the species is known to be primarily a forest specialist that usually occur in intact or tropical high forests that have undergone minimal levels of human disturbance (Isabirye-Basuta and Kasene, 1987; Makundi *et al* 2007; Gebrezgiher *et al*., 2022). Similar results were obtained from Kilimanjaro Mountain (Mulungu *et al*., 2008) and the Usambara Mountain, Tanzania (Hieronimo *et al*., 2014; Ralaizafisoloarivony *et al*., 2014).

L. flavopunctatus inhabits a wide range of forested habitats including primary and secondary forests (Monadjem *et al*., 2015), characterized by cool moist environments (Clausnitzer and Kityo, 2001; Happold, 2013). This species was captured mostly at lower elevations near a river. It was previously observed that *Lophuromys* spp are highly adapted to different environmental settings, and they tend to colonize disturbed habitats (Massawe *et al*., 2005) similar to our findings in the three habitat types in the current study.

This study also confirmed that *G. murinus* is a forest-specialist species (Kryštufek *et al*., 2004), as it was the only individual that was captured in the forest, although Mulungu *et al*. (2008) on Mount Kilimanjaro in Tanzania, and Rowe-Rowe and Meester (1982) in Natal Drakensberg in Southern Africa, reported the occurrence of this species in the woodlands and rocks, respectively.

Fallows and cultivated land mostly, in both elevations were significantly dominated by *M. natalensis* which supports that this is a generalist rodent species with the widest distribution than any other African rodent (Mulungu *et al*., 2013; Mayamba *et al*., 2019). It is usually associated with agricultural fields and peri-domestic environments but can also be found in natural savannah and grasslands, and easily increase in abundance after any kind of disturbance (Monadjem *et al*., 2015). Apart from being exclusively spotted in disturbed habitats, the species has, nonetheless, been reported to occur even in undisturbed habitats (Makundi *et al*., 2010).

Rodents and shrew abundance in this study was highest in the low elevations. In contrast, however, some species such as *G. ibeanus and C. olivieri* showed a different trend of abundance along the elevations, which decreased with increasing elevation. This affirms the notion that different small mammal groups have different requirements and tolerance along the elevation gradient. This further confirms the results of Mulungu *et al*. (2008) on Mount Kilimanjaro, and Clausnitizer and Kityo (2001) on Mount Elgon in Tanzania and Uganda respectively, who reported on habitat preference by several rodent species, like *Rhabdomys pumilio*, for moorlands, grassland and sub-alpine zones on high altitudes.

The overall habitat settings of the current study revealed that proximity of forests to households and farmlands, may have facilitated the free movement of species from one habitat type to another in search for food. This could explain the presence of commensal rodent species such as *R. rattus, M. natalensis*, *M. minutoides* and *M. musculus* in the forest and cultivated lands, respectively. These results are in agreement with the findings of Bowland and Perrin (1993), who reported that rodents tend to move short distances, with ranging distances being influenced by food scarcity. However, Goodman (1995) in Madagascar further reported the ability of the *R. rattus* to compete for resources with native rodent species (subfamily Nesomyinae) and ultimately to inhabit different habitats.

Despite having limited distribution in east Africa, *Grammomys ibeanus* and *Crocidur*a spp were caught in all elevations, however, more in forest habitats. The phenomenon that could link the former with the genus'- overall character of inhabiting moist zones (Kingdon, 1997). Other species of the same genus (*G. macmillan, G. dolichurus* and *G. cometes*, however, have been reported to exist in woodlands, and thickets all over sub-Saharan Africa (Kryštufek *et al*., 2008; Bryja *et al.,* 2017). The higher occurrence of *Crocidura* spp in the forest agrees with Kadjo *et al*. (2013) in Banco National Park, Ivory Coast and may be related with their preference for dense herb layer in search of food sources particularly insects.

In line with Horváth *et al*. (2001), and Kasangaki *et al*. (2003), the diversity and trap success of rodents and shrews was highest in the forest habitats, compared to fallow and cultivated habitats along the elevation gradient. Pickett (1994) elucidated that in the forest-kind of vegetation such as ecotones, there are generally heterogeneous distribution of food sources as well as moderate climatic conditions which greatly attract a diversity of rodents. Nevertheless, greater size of boarder zones in the forest might have negative effects such as massive change of climatic conditions as well as vegetation pattern (Saunders *et al*., 1991 Bierregaard *et al*., 1992).

In aggregate, December presented with the highest diversity of rodent and shrew species, compared to other months, despite showing the least number of individuals for both species. This could be related to prevailing short rainfall over the entire month. This finding agrees with that of Brown (1973) in eastern California, Nevada and Western Utah, reporting on the high increase of rodent and shrew diversity due to persisting precipitation. In addition, the peaked diversity of rodents and shrews in December could also be related to the pre-harvesting period in cultivated lands. This also agrees with Dubale and Ejigu (2015) in Aquatimo forest patches in Ethiopia, relating the increase in availability of food sources.

Climatic factors also influence the abundance of rodents and shrews. Similar to the observation made by Galiano *et al*. (2013) in Araucaria Forest of Southern Brazil, this study showed that rainfall, temperature and relative humidity have greater influence on the abundance of rodents. Climatic variables rather than landscape structure are highly considered due to their ecological support in terms of food, survival and reproduction, which are ultimately the determinants of a functional diversity and abundance for small vertebrates (Lima *et al*., 2002). However, rainfall has other ways thought to give it potential ahead of other factors. This finding confirms several other reports in many areas of tropical Africa where the amount of rainfall has been shown to strongly affect the abundance of rodents and shrews (Fleming and Loveridge 2003). For example, Makundi *et al*. (2007) in Magamba forest reserve along the western Usambara Mountains in northern Tanzania reported a strong influence of rainfall on the reproduction and the overall population dynamics of rodents and shrews.

Female rodents and shrews outnumbered males in this study which conforms with findings elsewhere (Santra and Manna (2008), and

Takele *et al.* (2022). This could be due to inter-seasonal dynamics, gender disparities in behavior, and seasonal fluctuations in habitat availability, all of which have a substantial effect on population structure, species composition, and sex disparities in mobility, among others (Mmetwaly *et al*., 2009; Mushtaq *et al*., 2014). However, only a more intensive and longer sampling could explain this ambiguity. Additionally, the reactions of rodent and shrew populations to various types of environmental disturbances may also involve changes in the sex ratio (Xianguo and Tijun, 2001; Koskela *et al*., 2009). A biased sex ratio could be a sign of population stress caused by habitat degradation (Banks *et al*., 2011; Shilereyo *et al*., 2022). In an undisturbed forest, for instance a 1:1 sex ratio is predicted, assuming parents invested equally in offsprings of either sex (Leturque and Rouset, 2003; Fontúrbel, 2012). However, our results deviated slightly from this assumption in the forest habitat in both elevations which may be due to elevation and environmental variations.

In line with Khanam *et al*. (2017), Dadi *et al*. (2020) and Takele *et al*. (2022), this study presented the overall highest number of adult rodents than juveniles. This is a common trend in small mammal populations, and could be due to exploratory behavior and body weight inequalities. Adults have a more developed exploratory behavior and are heavier, which are critical features for either finding the bait or triggering the door-closing mechanism of Sherman® traps (Parra-Vargas *et al*., 2020). Another explanation could be due to the existence of vast adult home ranges, which reduces the cost of competing with juveniles (Gebresilassie *et al*., 2006).

The dominance of *D. lypusus* (Hystrichopsyllidae) in this study has also been reported by previous studies as being the most common species of rodents, widespread in East Africa (Kilonzo and Mhina, 1983; Makundi *et al*., 2003; Laudisoit *et al*., 2007) and, an important and efficient vector of *Y. pestis* - plague (Zimba *et al*., 2012; McCauley *et al*., 2015). Furthermore, temperatures ranging from

10°C and 30°C promote the reproduction of this flea species. (Bahmanyar and Cavanaugh, 1976), which was the temperature range in our study area. Notably, *C. calceatus* ranked second and *N. fasciatus* was the least in abundance of all fleas collected. However, unlike *D. lypusus* both species are regarded as non-efficient vectors of plague (Devignat, 1946).

Despite being considered passive vectors of plague in East Africa, the unique distribution of *C. calceatus* and the relatively low abundance of *N. fasciatus* on the rodents and shrews may be related to differences in host specificity. Unlike *C. calceatus,* whose host species vary among rodent and shrews, humans are among hosts associated with *N. fasciatus* (Zajac *et al*., 2020), thus their low abundance may probably have been due to absence of humans as hosts in this study.

In consideration of the variation in rodents and flea distribution; regardless of species, the abundance of rodents, shrews, and associated fleas was highest in April and May, while it was lowest in January and February. Unlike the latter months, April and May were near the end of the long rainy season in the study area. Hence, the impact of rainfall may have similarly dictated their distribution (Pavey and Nano, 2013; Meheretu *et al*., 2015; Thibaut *et al*., 2010). Following the average rainfall, there is expectedly growth and overall increase in reproduction in plants. As a result, abundant food sources and ultimately high rodent and flea population (Gubler *et al*., 2001; Brown and Ernest, 2002).

The results of this study further showed that the diversity of rodents and shrews decreased with elevation and that flea turnover was independent of host turnover. Flea diversity index was higher on high elevation than on lower elevation, with the opposite being true with rodents and shrews. This did not reflect the expectation that a broader host community will have, also, a greater number of parasites (Krasnov, 2008). These shifts were presumably as a result of observed variations in the composition and structure of vegetation in different habitats and elevations associated with land-use conversion (McCauley *et al.,* 2015).

Sex and age biased flea parasitism is crucial in the selection processes with males usually having a higher parasite prevalence and load relative to females across different habitats and altitudes (Krasnov, 2005). The larger body size of male rodents in comparison to females leads to heavier flea infestation (Herrero-Cofreces *et al*., 2021). This was demonstrated in the current study as fleas showed a male-biased infestation pattern which is in contrast with other studies in bats, that flea parasitism is mostly female-biased (Kiffer *et al*., 2013). However, the proportions of infested males and females did not differ substantially. On the other hand, the difference in type and sometimes hormone levels, particularly during reproductive period, is thought to cause the variation of flea infestation with males showing stronger biased parasitism than female hosts (Kiffner *et al*., 2014).

Results of this study further reaffirms the remarkable phenomenon of adult small mammal hosts having the highest flea infestation compared to juveniles (Krasnov *et al.*, 2006). This scenario is perceived to be caused, indirectly, due to foraging behavior (Hawlena *et al*., 2005). Unlike adults, the bodies of juvenile hosts are constantly under high energy demand for maintenance, growth maturation, and consolidation of the immune system, as a result they become less exposed than adults. Smit *et al.* (1962), linked continuous adult biased parasitism to home range as they can occasionally leave their nests and become infested elsewhere.

2.4 Conclusion and Recommendations

This study revealed variation in the abundance, evenness and diversity of rodents and fleas across habitats and along an elevation gradient. The fact that the abundance, species diversity and richness of rodents, shrews and fleas was highest in the forest habitats. This implies a greater habitat heterogeneity and complexity as well as less human activities in the forest supports species survival. Cultivated land supports abundant and more diverse rodent and shrew species than fallow land due to greater food availability, especially post-harvest. This aggregates that small mammal species' population dynamics in the environment can be affected as a result of changes in the quantity and quality of resources related to cultivation (Massawe *et al*., 2005). All the climatic variables (temperature, rainfall and relative humidity) tested in this study showed a significant influence on the abundance of rodents and shrews, which implicates the significant role of seasonal changes in determining the abundance and distribution of species along an elevation gradient.

In the face of current extensive farming and transformation of natural landscape into farmlands in Mgeta, it is essential to generate more effective conservation policies focused on managing the remaining forest patches and small mammal. Furthermore, the discovery of ectoparasites of public health importance (i.e *D. lypusus)* calls for implementation of preventive strategies and awareness among the local communities. This is reinforced by the notion that agricultural transformation has the potential to increase rodent borne infection especially *Y. pestis* - plague (Makundi *et al*., 2005). We, therefore, recommend that future studies should further investigate population dynamics of rodents, shrews and fleas across seasons to monitor and better understand species temporal variations over time.

REFERENCES

Almeida, A., Corrigan, R. and Sarno, R. (2013). The economic impact of commensal rodents on small businesses in Manhattan’s Chinatown: trends and possible causes. *Suburban Sustainability*, *1*(1), 2.

Andrzejewski, R. (2002). The home-range concept in rodents revised. *Acta Theriologica* 47: 81-101.

Bahmanyar, M., and D. C. Cavanaugh. 1976. Plague manual, pp. 76Ð89. World Health Organization, Geneva, Switzerland.

Bai, Y, Osikowicz, L.M., Kosoy, M.Y., Eisen, R.J, Atiku, L.A., Mpanga, J.T and Gage, K.L., (2017).Comparison of zoonotic bacterial agents in fleas collected from small mammals or host seeking fleas from a Ugandan region where plague is endemic. Msphere, 2(6), 00402- 17

Banks, S. C., Dujardin, M., McBurney, L., Blair, D., Barker, M. and Lindenmayer, D. B. (2011). Starting points for small mammal population recovery after wildfire: recolonisation or residual populations? *Oikos*, *120*(1), 26-37.

Battersby, S. A (2015). Rodents as carriers of disease.” Rodent pests and their control, 81 - 100

Bierregaard Jr, R. O., Lovejoy, T. E., Kapos, V., dos Santos, A. A. and Hutchings, R. W. (1992). The biological dynamics of tropical rainforest fragments. *BioScience*, 859-866.

Bonvicino, C. R., Lindbergh, S. M. and Maroja, L. S. (2002). Small non-flying mammals from conserved and altered areas of Atlantic Forest and Cerrado: comments on their potencial use for monitoring environment. *Brazilian Journal of Biology*, *62*, 765-774.

Bowland, J. M. and Perrin, M. R. (1993). Wetlands as reservoirs of small-mammal populations in the Natal Drakensberg. *South African Journal of Wildlife Research-24-month delayed open access*, *23*(2), 39-43.

Brown, J. H. (1973). Species diversity of seed-eating desert rodents in sand dune habitats. *Ecology*, *54*(4), 775-787.

Brown, J. H. and Ernest, S. M. (2002). Rain and rodents: complex dynamics of desert consumers: although water is the primary limiting resource in desert ecosystems, the relationship between rodent population dynamics and precipitation is complex and nonlinear. *BioScience*, *52*(11), 979-987.

Bryja, J., Šumbera, R., Kerbis Peterhans, J. C., Aghová, T., Bryjová, A., Mikula, O. and Verheyen, E. (2017). Evolutionary history of the thicket rats (genus Grammomys) mirrors the evolution of African forests since late Miocene. *Journal of Biogeography*, *44*(1), 182-194

Burgess, N., Butynski, T. M., Cordeiro, N. J., Doggart, N. H., Fjeldså, J., Howell, K. M. and Stuart, S. N. (2007). The biological importance of the Eastern Arc Mountains of Tanzania and Kenya. *Biological conservation*, *134*(2), 209-231.

Burgess, N., Doggart, N. and Lovett, J. C. (2002). The Uluguru Mountains of eastern Tanzania: the effect of forest loss on biodiversity. *Oryx*, *36*(2), 140-152.

Burgess, N.D., Lovett, J.C., and Muhagama, S. (2001). *Biodiversity Conservation and Sustainable Forest management in the Eastern Arc Mountains.* Unpublished report prepared for GEF/PDFB Eastern Arc Strategy Process.

Camargo, N. F., Machado, L. F., Mendonça, A. F. and Vieira, E. M. (2019). Cranial shape predicts arboreal activity of Sigmodontinae rodents. *Journal of Zoology*, *308*(2), 128-138.

Cameron, N., Del Corpo, A., Diorio, J., McAllister, K., Sharma, S. and Meaney, M. J. (2008). Maternal programming of sexual behavior and hypothalamic-pituitary-gonadal function in the female rat. *PloS one*, *3*(5), e2210.

Cavia, R., Cueto, G. R. and Suárez, O. V. (2012). Techniques to estimate abundance and monitoring rodent pests in urban environments. *Integrated pest management and pest control—current and future tactics*, 147-172.

Chesson, P., Gebauer, R. L., Schwinning, S., Huntly, N., Wiegand, K., Ernest, M. S. and Weltzin, J. F. (2004). Resource pulses, species interactions, and diversity maintenance in arid and semi-arid environments. *Oecologia*, *141*, 236-253.

Chidodo, S., Kilawe, C. J., Mnyone, L. L., Broecke, B. V. and Mulungu, L. S. (2020). Factors affecting the composition of rodent assemblages in the North Uluguru Mountains, Tanzania. *Journal of Vertebrate Biology*, *69*(2), 20047-1.

Clausnitzer, V. and Kityo, R. (2001). Altitudinal distribution of rodents (Muridae and Gliridae) on Mt Elgon, Uganda. *Tropical Zoology*, *14*(1), 95-118.

Crispo, E., Moore, J. S., Lee-Yaw, J. A., Gray, S. M. and Haller, B. C. (2011). Broken barriers: Human-induced changes to gene flow and introgression in animals: An examination of the ways in which humans increase genetic exchange among populations and species and the consequences for biodiversity. *BioEssays*, *33*(7), 508-518.

Dadi, M. N., Mammo, D. Y., Teferedegn, G. D. and Zelelew, G. G. (2020). Species Composition, Relative Abundance and Distribution of Rodents in Wof-Washa Natural State Forest, North Shewa, Amhara, Ethiopia.

Devignat, R. (1946). *Aspects de l'épidémiologie de la peste au Lac Albert*. Goemaere.

Dubale, M. and Ejigu, D. (2015). Diversity, relative abundance and habitat association of rodents in Aquatimo forest patches and adjacent farmland, East Gojjam, Ethiopia. *Ethiopian Journal of Biological Sciences*, *14*(2), 201-216.

Eads, D. A. and Biggins, D. E. (2019). Plague management of prairie dog colonies: degree and duration of deltamethrin flea control. *Journal of Vector Ecology*, *44*(1), 40-47.

Fabre, PH., Hautier, L., Dimitrov, D. et al. A glimpse on the pattern of rodent diversification: a phylogenetic approach. BMC Evol Biol 12, 88 (2012). https://doi.org/10.1186/1471-2148-12-88

Fleming, P. A. and Loveridge, J. P. (2003). Miombo woodland termite mounds: resource islands for small vertebrates? *Journal of Zoology*, *259*(2), 161-168.

Fontúrbel, F. E. (2012). Does habitat degradation cause changes in the composition of arboreal small mammals? A small-scale assessment in Patagonian temperate rainforest fragments. *Journal of Conservation*, (2-3), 68-72.

Françoso, R. D., Brandão, R., Nogueira, C. C., Salmona, Y. B., Machado, R. B. and Colli, G. R. (2015). Habitat loss and the effectiveness of protected areas in the Cerrado Biodiversity Hotspot. *Natureza & conservação*, *13*(1), 35-40.

Galiano, D., Kubiak, B. B., Marinho, J. R. and de Freitas, T. R. O. (2013). Population dynamics of Akodon montensis and Oligoryzomys nigripes in an Araucaria forest of Southern Brazil. *Mammalia*, *77*(2), 173-179.

Gardner, T. A., Barlow, J., Chazdon, R., Ewers, R. M., Harvey, C. A., Peres, C. A. and Sodhi, N. S. (2009). Prospects for tropical forest biodiversity in a human-modified world. *Ecology letters*, *12*(6), 561-582.

Gebresilassie, W., Bekele, A., Belay, G. and Balakrishnan, M. (2006). Home range and reproduction of rodents in Maynugus irrigation field, northern Ethiopia. *SINET: Ethiopian Journal of Science*, *29*(1), 57-62.

Gebrezgiher, G. B., Makundi, R. H., Meheretu, Y., Mulungu, L. S. and Katakweba, A. A. (2022). A Decade-Long Change in the Elevational Distribution of Non-Volant Small Mammals on Mount Meru, Tanzania. *Diversity* 14(6): 454.

Goodman, S.M. (1995). Rattus on Madagascar and the dilemma of protecting the endemic rodent fauna Conservation biology 9(2), 450 -453

Gubler, D. J., Reiter, P., Ebi, K. L., Yap, W., Nasci, R. and Patz, J. A. (2001). Climate variability and change in the United States: potential impacts on vector-and rodent-borne diseases. *Environmental Health Perspectives*, *109*(suppl 2), 223-233.

Happold DCD. 2013. *Mammals of Africa. Volume III: Rodents, Hares and Rabbits*, 1st edn. Bloomsbury Publishing, London, UK.

Harris, D. B. (2009). Review of negative effects of introduced rodents on small mammals on islands. *Biological Invasions*, *11*, 1611-1630.

Hawlena, H., Abramsky, Z. and Krasnov, B. R. (2005). Age-biased parasitism and density-dependent distribution of fleas (Siphonaptera) on a desert rodent. *Oecologia*, *146*, 200-208.

Herrero-Cófreces, S., Flechoso, M. F., Rodríguez-Pastor, R., Luque-Larena, J. J. and Mougeot, F. (2021). Patterns of flea infestation in rodents and insectivores from intensified agro-ecosystems, Northwest Spain. *Parasites & Vectors*, *14*(1), 1-13.

Hieronimo, P., Gulinck, H., Kimaro, D. N., Mulungu, L. S., Kihupi, N. I., Msanya, B. M. and Deckers, J. A. (2014). Human activity spaces and plague risks in three contrasting landscapes in Lushoto District, Tanzania. *Tanzania Journal of Health Research*, *16*(3).

Hieronimo, P., Kihupi, N. I., Kimaro, D. N., Gulinck, H., Msanya, B. M., Leirs, H. and Deckers, J. A. (2014). Contribution of land use to rodent flea load distribution in the plague endemic area of Lushoto District, Tanzania. *Tanzania Journal of Health Research*, *16*(3).

Horváth, A., March, I. J. and Wolf, J. H. (2001). Rodent diversity and land use in Montebello, Chiapas, Mexico. *Studies on Neotropical Fauna and Environment*, *36*(3), 169-176.

Isabirye-Basuta, G. and Kasenene, J. M. (1987). Small rodent populations in selectively felled and mature tracts of Kibale Forest, Uganda. *Biotropica*, 260-266.

Jacob, J. (2008). Response of small rodents to manipulations of vegetation height in agro-ecosystems. *Integrative Zoology*, *3*(1), 3-10.

Jahan, N. A., Lindsey, L. L. and Larsen, P. A. (2021). The role of peridomestic rodents as reservoirs for zoonotic foodborne pathogens. *Vector-Borne and Zoonotic Diseases*, *21*(3), 133-148.

Kajin, M. and Grelle, C. E. V. (2012). Microhabitat selection when detection is imperfect: the case of an endemic Atlantic forest mammal. *Ecological research*, *27*, 1005-1013.

Kajo B., Kouadjo, R. Y., Vogel. V., Dubey. S, and Vogel, P. (2013). Assesment of terrestrial small mammals and a record of the critically endangered shrew Crocidura wimmeri in Banco National Park (Cote d vore) *Mammalia* 77 (4); 439 – 446

Kalumanga, E. (2007). *Abundance and diversity of small Mammals in disturbed and undisturbed forests in the Uluguru Mountains, Tanzania* (Doctoral dissertation, University of Dar es Salaam).

Katakweba, A. A. S., Kipanyula, M. J., Durnez, L., Mhamphi, G., Luziga, C., Mgode, G. F. and Machang'u, R. S. (2013). Rodents and shrews as vectors of zoonotic spirochetes and trypanosomes in Tanzania

Khanam, S., Mushtaq, M., Nadeem, M. S. and Kayani, A. R. (2017). Population ecology of the house mouse (Mus musculus) in rural human habitations of Pothwar, Pakistan. *Zoology and Ecology*, *27*(2), 106-113.

Kiffner, C., Stanko, M., Morand, S., Khokhlova, I. S., Shenbrot, G. I., Laudisoit, A. and Krasnov, B. R. (2013). Sex-biased parasitism is not universal: evidence from rodent–flea associations from three biomes. *Oecologia*, *173*, 1009-1022.

Kiffner, C., Stanko. M, Morand. S., Khokhlova, I. S., Shenbrot. G. I., Laudisoit, A. and Krasnov, B. R. (2014). Variable effects of host characteristics on species richness of flea infracommunities in rodents from three continents. *Parasitology Research*, 113; 2777 - 2788

Kilonzo, B. S. and Mhina, J. I. (1983). Observations on the current status of plague endemicity in the Western Usambara mountains, north-east Tanzania. *Acta Tropica*, *40*(4), 365-373.

Kimaro, D. N., Msanya, B. M., Meliyo, J., Hieronimo, P., Mwango, S., Kihupi, N. I. and Deckers, J. A. (2014). Anthropogenic soils and land use patterns in relation to small mammal and flea abundance in plague endemic area of Western Usambara Mountains, Tanzania. *Tanzania Journal of Health Research*, *16*(3).

Kingdon, J. (1997) *The Kingdon Guide to African Mammals*. Academic Press Ltd, London.

Kohl, G.M. Tick (Ixodoidae) of Borneo and Malaya. (1957). *Student Instute for Medical Research* 28: 65-94.

Koskela, E., Mappes, T., Niskanen, T. and Rutkowska, J. (2009). Maternal investment in relation to sex ratio and offspring number in a small mammal–a case for Trivers and Willard theory?. *Journal of Animal Ecology*, *78*(5), 1007-1014.

Krasnov, B. R. (2008). *Functional and Evolutionary Ecology of Fleas: a model for ecological parasitology*. Cambridge University Press.

Krasnov, B. R., Morand, S., Hawlena, H., Khokhlova, I. S. and Shenbrot, G. I. (2005). Sex-biased parasitism, seasonality and sexual size dimorphism in desert rodents. *Oecologia*, *146*, 209-217.

Krasnov, B. R., Stanko, M. and Morand, S. (2006). Age-dependent flea (Siphonaptera) parasitism in rodents: a host's life history matters. *Journal of Parasitology*, *92*(2), 242-248.

Krebs, C. J., Lambin, X. and Wolff, J. O. (2007). Social behavior and self-regulation in murid rodents. *Rodent Societies: An Ecological and Evolutionary Perspective*, 173-181.

Kryštufek, B., Baxter, R. M., Haberl, W., Zima, J. and Bužan, E. V. (2008). Systematics and biogeography of the Mozambique thicket rat, Grammomys cometes, in eastern Cape province, South Africa. *Journal of Mammalogy*, *89*(2), 325-335.

Kryštufek, B., Haberl, W., Baxter, R. M. and Zima, J. (2004). Morphology and karyology of two populations of the woodland dormouse Graphiurus murinus in the Eastern Cape, South Africa. *Folia Zoologica*, *53*(4), 339.

Laudisoit, A., Leirs, H., Makundi, R. H., Van Dongen, S., Davis, S., Neerinckx, S. and Libois, R. (2007). Plague and the human flea, Tanzania. *Emerging Infectious Diseases*, *13*(5), 687.

Leturque, H. and Rousset, F. (2003). Joint evolution of sex ratio and dispersal: conditions for higher dispersal rates from good habitats. *Evolutionary Ecology*, *17*(1), 67-84.

Lima, M., Stenseth, N. C. and Jaksic, F. M. (2002). Food web structure and climate effects on the dynamics of small mammals and owls in semi-arid Chile. *Ecology letters*, *5*(2), 273-284.

Lövy, M., Boratyński, Z., Okrouhlík, J., Svačinová, L., Meheretu, Y. and Šumbera, R. (2022). Alternative highland adaptations: organ masses and fur insulation in Afroalpine rodents. *Journal of Zoology*. *5*, 1-12.

Luis, A. D., Hayman, D. T., O'Shea, T. J., Cryan, P. M., Gilbert, A. T., Pulliam, J. R. and Webb, C. T. (2013). A comparison of bats and rodents as reservoirs of zoonotic viruses: are bats special? *Proceedings of the Royal Society B: Biological Sciences*, *280*(1756), 20122753.

Magige, F. J. (2012). Human-wildlife interaction in Serengeti and Ngorongoro districts of Tanzania: a case study on small mammals. *Tanzania Journal of Science*, *38*(1), 95-103.

Makundi, R. H., Massawe, A. W. and Mulungu, L. S. (2007). Breeding seasonality and population dynamics of three rodent species in the Magamba Forest Reserve, Western Usambara Mountains, north-east Tanzania. *African Journal of Ecology* 45(1): 17-21.

Makundi, R. H., Massawe, A. W., Mulungu, L. S. and Katakweba, A. (2010). Species diversity and population dynamics of rodents in a farm-fallow field mosaic system in Central Tanzania African Journal of Ecology, 48(2), 313 -320

Makundi, R. H., Massawe, A. W., Mulungu, L. S., Katakweba, A., Mbise, T. J. and Mgode, G. (2008). Potential mammalian reservoirs in a bubonic plague outbreak focus in Mbulu District, northern Tanzania, in 2007.

Makundi, R. S., Kilonzo, B. S. and Massawe, A. W. (2003). Interaction between rodent species in agro-forestry habitats in the western Usambara Mountains, north-eastern

Tanzania, and its potential for plague transmission to humans.

Massawe, A. W., Rwamugira, W., Leirs, H., Makundi, R. H. and Mulungu, L. (2005). Influence of land preparation methods and vegetation cover on population abundance of Mastomys natalensis in Morogoro, Tanzania.

Mattee, A. Z., Busindeli, I. M. and Malisa, E. T. N. (2020). Promoting sustainable agriculture and natural resource management through the process approach: experience from UMADEP project of Sokoine University of Agriculture, Tanzania. *Tanzania Journal of Agricultural Sciences*, *19*(1), 44-52.

Mayamba, A., Byamungu, R. M., Makundi, R. H., Kimaro, D. N., Isabirye, M., Massawe, A. W. and Mulungu, L. S. (2019). Species composition and community structure of small pest rodents (Muridae) in cultivated and fallow fields in maize growing areas in Mayuge district, Eastern Uganda. *Ecology and evolution*, *9*(13), 7849-7860.

McCauley, D. J., Salkeld, D. J., Young, H. S., Makundi, R., Dirzo, R., Eckerlin, R. P. and Helgen, K. M. (2015). Effects of land use on plague (Yersinia pestis) activity in rodents in Tanzania.

McCauley, L. A., Anteau, M. J., van der Burg, M. P. and Wiltermuth, M. T. (2015). Land use and wetland drainage affect water levels and dynamics of remaining wetlands. *Ecosphere*, *6*(6), 1-22.

Meheretu, Y., Welegerima, K., Sluydts, V., Bauer, H., Gebrehiwot, K., Deckers, J. and Leirs, H. (2015). Reproduction and survival of rodents in crop fields: the effects of rainfall, crop stage and stone-bund density. *Wildlife Research*, *42*(2), 158-164.

Melo, L. T., Duailibe, M. A. B., Pessoa, L. M., da Costa, F. N., Vieira-Neto, A. E., de Vasconcellos Abdon, A. P. and Campos, A. R. (2017). (−)-α-Bisabolol reduces orofacial nociceptive behavior in rodents. *Naunyn-Schmiedeberg's Archives of Pharmacology*, *390*, 187-195.

Mmetwaly, A. M., Montasser, S. A. and Al-Gendy, A. A. R. (2009). Survey of rodent species and damage assessment caused by Meriones shawi isis (Thomas) in some field crops at Bustan area. *Journal of Applied Sciences Research*, *5*(1), 40-45.

Monadjem, A., Taylor, P. J., Denys, C. and Cotterill, F. P. (2015). *Rodents of sub-Saharan Africa: a biogeographic and taxonomic synthesis*. Walter de Gruyter GmbH & Co KG.

Mulungu, L. S. (2017). Control of rodent pests in maize cultivation: the case of Africa. *Achieving Sustainable Maize Cultivation*, *2*, 318-337.

Mulungu, L. S., Makundi, R. H., Massawe, A. W., Machang'u, R. S. and Mbije, N. E. (2008). Diversity and distribution of rodent and shrew species associated with variations in altitude on Mount Kilimanjaro, Tanzania. *Mammalia 72*: 178-185.

Mulungu, L. S., Ngowo, V., Mdangi, M., Katakweba, A. S., Tesha, P., Mrosso, F. P and Kilonzo, B. S. (2013). Population dynamics and breeding patterns of multimammate mouse, Mastomys natalensis (Smith 1834), in irrigated rice fields in eastern Tanzania. *Pest Management Science*, *69*(3), 371-377.

Mulungu, L. S., Ngowo, V., Mdangi, M., Katakweba, A. S., Tesha, P., Mrosso, F. P. and Kilonzo, B. S. (2013). Population dynamics and breeding patterns of multimammate mouse, Mastomys natalensis (Smith 1834), in irrigated rice fields in eastern Tanzania. *Pest Management Science* 69(3): 371-377.

Mushtaq, M., Kayani, A. R., Nadeem, M. S. and Beg, M. A. (2014). Distribution pattern of commensal rodents in shops of urban Rawalpindi, Pakistan. *Pakistan Journal of Zoology*, *46*(6).

Nyirenda, S. S., Hang’ombe, B. M., Mulenga, E., Machang’u, R. S., Kilonzo, B. S., Sianzinda, E. and Chanda, P. (2020). Biodiversity and distribution of flea (Siphonaptera), rodent (Rodefntia), and Crocidura (Insectivora) species associated with plague epidemiology in eastern Zambia. *Journal of Zoonotic Diseases*, *4*(4), 21-35.

Nyirenda, S. S., Simulundu, E., Mulenga, E., Moonga, L., Misinzo, G. and Kilonzo, B. S. (2018). Molecular epidemiological investigations of plague in Eastern Province of Zambia. *BMC Microbiology*, *18*(1), 1-7.

Nyirenda, V. R., Namukonde, N., Simwanda, M., Phiri, D., Murayama, Y., Ranagalage, M. and Milimo, K. (2020). Rodent assemblages in the mosaic of habitat types in the Zambezian Bioregion. *Diversity*, *12*(10), 365.

Nziku, Z. C., Asheim, L. J., Eik, L. O., Mwaseba, D. and Kifaro, G. C. (2016). Climate change adaptation in vulnerable crop and livestock production systems in Mgeta, Tanzania. *African Journal of Food, Agriculture, Nutrition and Development*, *16*(2), 10853-10865.

Oguge, N.O., Durden, L.A, Keirans, J.E., Balami, H.D. and Schwan, T (2009). Ectoparasites (sucking lice, fleas and ticks) of small mammals in southeastern Kenya. *Medical and Veterinary Entomology,* 23(4); 387;392

Parra-Vargas, M., Ramon-Krauel, M., Lerin, C. and Jimenez-Chillaron, J. C. (2020). Size does matter: Litter size strongly determines adult metabolism in rodents. *Cell Metabolism*, *32*(3), 334-340.

Pavey, C. R. and Nano, C. E. (2013). Changes in richness and abundance of rodents and native predators in response to extreme rainfall in arid A Australia. *Austral Ecology*, *38*(7), 777-785.

Pickett STA (1994): Mosaics and patch dynamics. In: Meffe, G.K., Carroll, C.R., eds., *Principles of conservation biology.*

Poland, J. D., Quan, T. J. and Barnes, A. M. (2019). Plague. In *Handbook of zoonoses* (pp. 93-112). CRC Press.

Ponte, S. (2001). Trapped in decline? Reassessing agrarian change and economic diversification on the Uluguru Mountains, Tanzania. *The Journal of Modern African Studies*, *39*(1), 81-100.

Ralaizafisoloarivony N.A., Didas N.K., Kihupi N.I. and Mulungu L.S. (2014). Vegetation habitats and small mammals in a plagus endemic area in Western Usambara Mountains, Tanzania. *Tanzania Journal of Health Resources*, *16*, 1-12.

Richard, U., Byamungu, R. M., Magige, F. and Makonda, F. B. (2022). Microhabitat, altitude and seasonal influence on the abundance of non-volant small mammals in Mount Rungwe forest nature reserve. *Global Ecology and Conservation*, *35*, e02069.

Rowe-Rowe, D. T. and Meester, J. (1982). Habitat preferences and abundance relations of small mammals in the Natal Drakensberg. *African Zoology*, *17*(4), 202-209.

Ruffino, L., Russell, J. and Vidal, E. (2013). Anthropogenic subsidies mitigate environmental variability for insular rodents. *Oecologia*, *172*, 737-749.

Santra, L. B. and Manna, C. K. (2008). Studies of some aspects of rodent ecology in the four districts of the gangetic plain of West Bengal, India. *University Journal of Zoology, Rajshahi University*, *27*, 85-90.

Saunders, D. A., Hobbs, R. J. and Margules, C. R. (1991). Biological consequences of ecosystem fragmentation: a review. *Conservation biology*, *5*(1), 18-32.

Savin, A. and Nistreanu, V. (2009). Structural–functional transformations of rodent communities in ecosystems of Moldova on the background of anthropogenic and climatic changes. *Oltenia-studii si comunicari stiintele naturii*, (25), 275-280.

Shaw, M.T., Keesing, F, McGrail, R., and Ostfeld, R, S. Factors influencing the distribution of larval blacklegged ticks on rodent hosts. *The American Journal of Tropical Medicine and Hygiene*, 68(4), 447-452

Shilereyo, M. T., Magige, F. J., Ogutu, J. O. and Røskaft, E. (2019). Spatial and temporal variation in small mammal abundance and diversity under protection, pastoralism and agriculture in the Serengeti Ecosystem, Tanzania. *bioRxiv*, 727206.

Shilereyo, M., Magige, F. J. and Ogutu, J. O. (2020). Small mammal community demography and reproductive seasonality under protection, pastoralism and agriculture in the Serengeti Ecosystem, Tanzania. *International Journal of Biodiversity and Conservation*, *12*(4), 253-269.

Smit, F. G. A. M. (1962). Siphonaptera collected from moles and their nests at Wilp, Netherlands, by Jhr. WC van Heurn. *Tijdschr Entomol*, *105*, 29-44.

St Clair, J. J. (2011). The impacts of invasive rodents on island invertebrates. *Biological Conservation*, *144*(1), 68-81.

Stanley, W. T. and Hutterer, R. (2007). Differences in abundance and species richness between shrews and rodents along an elevational gradient in the Udzungwa Mountains, Tanzania. *Acta Theriologica*, *52*(3), 261-275.

Strassburg, B. B., Brooks, T., Feltran-Barbieri, R., Iribarrem, A., Crouzeilles, R., Loyola, R. and Balmford, A. (2017). Moment of truth for the Cerrado hotspot. *Nature Ecology & Evolution*, *1*(4), 0099.

Takele, B., Yihune, M. and Bekele, A. (2022). Composition, abundance and distribution of rodent species in Alemsaga Priority State Forest and farmlands, northwestern Ethiopia. *African Journal of Ecology*, *60*(3), 447-455.

Thibault, K. M., Ernest, S. M., White, E. P., Brown, J. H. and Goheen, J. R. (2010). Long-term insights into the influence of precipitation on community dynamics in desert rodents. *Journal of Mammalogy*, *91*(4), 787-797.

Thomas, S. M., Soka, G. E. and Mulungu, L. S. (2022). Influence of vegetation structure, seasonality, and soil properties on rodent diversity and community assemblages in west Mount Kilimanjaro, Tanzania. *Ecology and Evolution*, *12*(9), e9211.

Van der Mescht, L., Le Roux, P. C. and Matthee, S. (2013). Remnant fragments within an agricultural matrix enhance conditions for a rodent host and its fleas. *Parasitology*, *140*(3), 368-377.

Vaughan, J., Ryan, J. and Czaplewsiki, N. (2000). Mammalogy, 4th ed. Saunders College Publishing, Toronto.

Vial, F., Macdonald, D. W. and Haydon, D. T. (2011). Response of endemic afro-alpine rodents to the removal of livestock grazing pressure. *Current Zoology*, *57*(6), 741-750.

Xianguo, G. U. O. and Tijun, Q. I. A. N. (2001). Sex ratio and age structure of gamasid mites from small mammals in western Yunnan, China. *Insect Science*, *8*(2), 166-174.

Young, H. S., Dirzo, R., McCauley, D. J., Agwanda, B., Cattaneo, L., Dittmar, K. and Helgen, K. M. (2015). Drivers of intensity and prevalence of flea parasitism on small mammals in East African savanna ecosystems. *The Journal of Parasitology*, *101*(3), 327-335.

Zając, Z., Kulisz, J. and Woźniak, A. (2020). Flea communities on small rodents in Eastern Poland. *Insects*, *11*(12), 894.

Zhang, W. Y, Wang, L.Y, Ding, F., Hu, W.B, Soares Magalhaes, R.J, Sun, H.L., and Li, C.Y. Scrub typhus in mainland China, 2006 – 2012: the need for targeted public health interventions. *PLOS Neglected Tropical Diseases,* 7, no 12 (2013), e24933

Zimba M, Loveridge J, Davies DM, Mukaratirwa S, 2012. Seasonal abundance and epidemiologial indices of potential plague vectors Dinopysyllus lypusus (Siphonaptera: Hystrichopsyllidae) and Ctenophthalmus calceatus (Siphonaptera: Ctenophthalmidae) on rodents captured from three habitat types of Hatcliffe and Dzivarasekwa suburbs of Harare, Zimbabwe*. J Med Ent.,* 49, 1453–1459.

CHAPTER THREE

PREVALENCE OF FLEAS ON RODENTS AND SHREWS: POTENTIAL FOR TRANSMISSION OF RODENT AND SHREW ECTOPARASITE (VECTOR)-BORNE ZOONOSES IN MGETA, TANZANIA

Constance C. Chonde[1,2,3], Abdul A. S. Katakweba[1,3], Benjamin Mubemba[4] and Apia W. Massawe[1,3]

[1] Department of Veterinary Medicine and Public Health, Sokoine University of Agriculture, P.O. Box 3021, Morogoro, Tanzania.
[2]Institute of Pest Management, Sokoine University of Agriculture, P.O. Box 3110, Morogoro, Tanzania.
[3]African Centre of Excellence for Innovative Rodent Pest Management and Biosensor Technology Development (ACE IRPM and BTD) Project, Sokoine University of Agriculture, P.O. Box 3110, Morogoro, Tanzania.
[4]Department of Zoological and Aquatic Sciences, Copperbelt University, P.O. Box 21692, Kitwe, Zambia.
* Correspondence: constancechonde@gmail.com

ABSTRACT

Fleas are of great epidemiological importance because they transmit disease pathogens from animals to humans. This study aimed to assess fleas on rodents and shrews in habitats sampled between altitudinal elevations in an extensive agricultural landscape of Mgeta from December 2021 to May 2022. Three three habitats of forest, fallow and cultivated lands, in selected high and low elevations, were sampled for rodent prevalence. Removal rodent trapping method was employed in which five line transects of 50m were drawn in each habitat from which a total of 199 fleas were collected from 207 rodents and shrews captured. A total of 95 (45.89%) rodent and 6 (2.8%)shrew species were infested with either *Dinopsyllus lypusus,* *Nosopsyllus fasciatus* or *Ctenopthalmus calceatus* flea species. Overall, *Rattus rattus, Mastomys natalensis* and *Lophuromys flavopunctatus* presented highest flea infestations among the rodent hosts. The mean abundance of fleas presented a significant variation among host species ($F_{(12, 194)} = 11.82$, $P < 0.001$), habitats ($F_{(2, 204)} = 9.935$, $P < 0.001$) and along the elevation gradient ($F_{(1, 205)} = 10.15$, $P = 0.02$). Similarly, prevalence varied significantly among hosts ($F_{(12, 194)} = 22.44$, $P < 0.001$) and habitats ($F_{(2, 204)} = 4.837$, $P = 0.009$) but not in elevation ($F_{(1, 205)} = 0.291$, $P = 0.59$). The mean intensity varied significantly among hosts ($F_{(12, 194)} = 9.257$, $P < 0.001$) and along the elevation- gradient ($F_{(1, 205)} = 47.91$, $P < 0.001$) but not among habitats ($F_{(2, 204)} = 0.75$, $P = 0.474$). Rainfall was strongly associated with mean abundance of fleas ($r = 0.054$, $P < 0.05$), but temperature, elevation and humidity were correlated with either mean intensity or prevalence of fleas on the rodent hosts. Given the presence of several flea species, among which *Dinopsyllus lypusus* the efficient vector of *Yersinia Pestis* in East Africa, effective and combative strategies should be implemented to ensure public health is strengthened in the entire ecosystem.

Keywords: Elevation**,** Flea, Habitat, Rodent, Shrew, Prevalence Mgeta, Tanzania, Zoonoses.

3.0 INTRODUCTION

Fleas are common ectoparasites of a wide variety of living organisms, including rodents and shrews (Linardi and Krasnov, 2013). They are hematophagous and greatly specialized as vectors of pathogens (Smith *et al*., 2021). While some species of fleas are restricted or specialized to particular hosts, others have a wide host range (Maleki-Ravasan *et al.*, 2017) Mammalian but blood is the only meal option for the fleas, and they readily invade other animals in the absence of their usual hosts (Amatre *et al*., 2009). Fleas are of great epidemiological importance in the transmission of disease pathogens from animals to humans (Durden and Hinkle, 2019). They have often been regarded as the primary agents for the transmission of the plague causing pathogen, *Y. pestis* (Kilonzo *et al.,* 1997; Laudisoit *et al*., 2007: Makundi *et al*., 2008: Hinnebusch *et al.,* 2016) as well as other diseases like murine typhus (Eremeeva *et al.,* 2008), Rickettsioses (Tay *et al.,* 2014), and tungiasis (Feldmeier *et al.,* 2013). Surprisingly, there are considerations of the possible involvement of fleas in the transmission of diarrhea, dysentery and tularemia pathogens (Hinnebusch *et al.,* 2016) but indisputably, fleas are a nuisance/annoyance as they cause severe itching on its victims skin (Jones, 1987; Bitam *et al*., 2010).

The prevalence and spatial distribution of fleas on rodents and shrews, are presumed to be affected by co-association, or independent cause of abiotic and biotic factors (Laudisoit *et al.,* 2009; Pontifes *et al*., 2022; López-Pérez *et al.,* 2022). However, due to temporal inhabitation on the hosts' bodies, the overall distribution of some flea species is strongly related to environmental factors such as relative humidity, temperature, geographical range, seasonal variation and human activities (Metzger and Rust, 1999: Gutiérrez *et al*., 2014) than biotic factors such as skin covering, age, sex, reproductive status, host species and density (Krasnov *et al*., 2004; Hammond *et al*., 2019). Anthropogenic activities, particularly agriculture, are considered the most determinant of flea species distribution among hosts and between different geographical ranges

(Van der Mescht *et al*., 2013; McCauley *et al*., 2019). This is further validated by either indirect effect, in which land manipulation tends to alter host's distribution first, and associated fleas later or directly, when the same disturbance in later growth stages of the flea larvae (Krasnov *et al.,* 2001; Herrero-Cófreces *et al*., 2021).

Landforms, including mountains, provide rodents, shrews and their ectoparasite - fleas with safe havens for survival and nourishment (Laudisoit *et al*., 2009; Kowalski *et al*., 2014). Their distribution has been related with overall habitat change as a result of human and natural disturbance (Paramasvaran *et al*., 2009; Van der Mescht, 2011; Hamidi and Moravvej, 2015). Considering the ongoing anthropogenic activities, particularly crop cultivation and livestock rearing, and the fact that there is no information on potential zoonotic disease vectors associated with rodents and shrews in Mgeta, compared to other districts, e.g. Lushoto and Hanang districts, which present with similar environmental landscapes and microclimate. There is, therefore, reason to investigate the potential of rodent ectoparasites in transmitting diseases, such as plague, for the interest of public health protection.

Plague is a vector-borne disease caused by the gram negative, non-motile and non-spore forming coccobacillus bacterium, *Y. pestis* which infects diverse mammals. Rodents are considered the natural reservoirs once they survive the initial infection (Nyirenda *et al*., 2018). The prevalence of plague in small mammal populations is generally overlooked until outbreaks in human populations, particularly in zoonotic foci. In Tanzania, much of the plague surveillance apparatus has evolved in an *ad hoc* manner, with most treatment/preventions being done only after human cases are recorded, rather than on substantiation of the disease among natural reservoirs. This is a gap in disease control effectiveness of this often fatal disese and, therefore, the need for continuous surveillance and rapid intervention when need arises (Haikukutu *et al*., 2022).

This study aimed, therefore, to investigate various flea species on rodents and shrews, as well as to examine their potential in causing diseases, especially *Y. pestis* plague. Furthermore, it investigated the effect of climatic and physical variables (temperature, relative humidity, rainfall and altitude) on the abundance of fleas on rodent and shrew populations taking Mgeta highlands as a reference.

3.1 Methodology

3.1.1 Materials and methods

3.1.1.1 Study area

The study was conducted from December 2021 to May 2022 in Mgeta ward, Mvomero District, specifically in Vinile village located 7^{o} 2' 8'' S and 37^{o} 33'55'' E in Tanzania (Fig 3.1). The Ward lies about 60km South-East of Morogoro Region in the Western slopes of Uluguru Mountains at an altitude of 1100 to 1950m above sea level (Nziku *et al*., 2016). The Uluguru Mountains are part of the Eastern Arc Mountain range which is a hotspot for diversity and an important area for the conservation of biodiversity in Tanzania (Burgess *et al*., 2001). The area is characterized by bimodal rainfall pattern, with a long rainy season between March and May, and a short rainy season between October and January each year (Chidodo *et al*., 2020). Annual precipitation ranges from 700 to 2,300mm, with higher amounts being found at higher elevations. Average temperatures range from 18 ^{o} C, in the cooler season to 30 ^{o} C in the warmer months of the year. The soils are well-drained, moderately deep, reddish to yellowish sandy clay loams, and sandy clays (Burgless *et al.,* 2007).

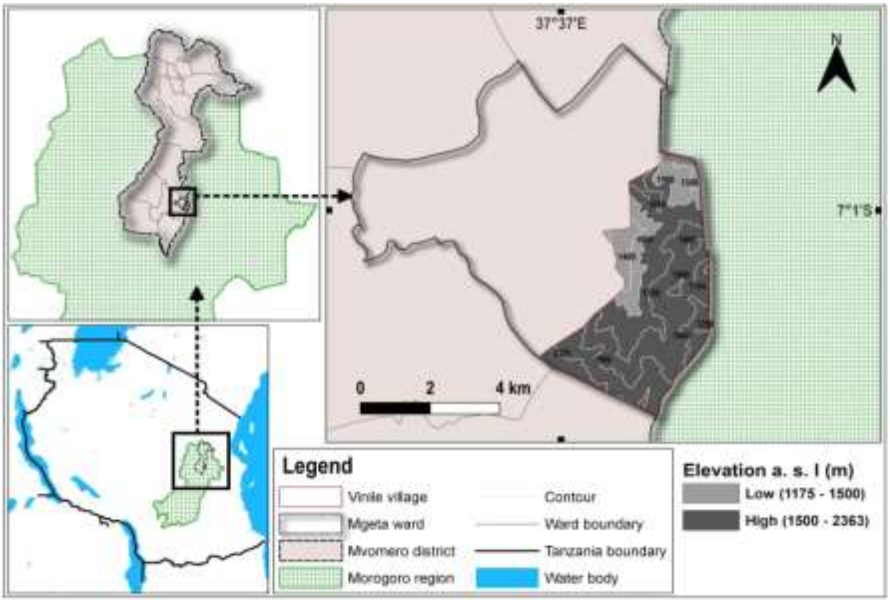


Figure 3.1: Map of Mgeta ward showing study sites of different habitats and elevations. Source: QGIS Version 3.24 Tisler' retrieved on 31 August 2022

The study area was stratified into two elevation ranges (1 100 to 1 500 m a.s.l and 1 600 to 1 900 m.a.s.l), which were referred to as low and high elevations, respectively. In each stratum, three different habitats (i.e. forest, fallow, and cultivated land) were selected. As each stratum contained similar habitats, forest, fallow, and cultivated land in high and low elevation were denoted as F_H, FA_H, C_H and F_L, FA_L, C_L, respectively.

3.1.1.2 Study design and trapping of rodent and shrew

Study design

The study was of repeated cross sectional one and trapping was done for three days consecutively, at intervals of four weeks and for a total period of six months from December, 2021 to May, 2022. Trapping of the rodent and shrew was done in three habitat types (forest, fallow, and cultivated) at the low and the high elevation gradients Removal trapping method was employed in which five line transects of 50m were established in each habitat. On each transect, ten Sherman® live traps (23 × 9 × 8 cm; H.B. Sherman Traps, Inc., Tallahassee, Florida) were laid 10m apart. Two Havahart ® traps (60 x 15 x 170 cm) and five local traps were also laid randomly within each of the three habitats types, making a total of 57 traps per habitat type in the lower and high elevations, and a total of 342 traps across the whole study area. The setting of the traps was done simultaneously in the three habitat types both in low and high elevations. To increase the likelihood of trapping a wide diversity of the rodent and shrew, traps were baited with peanut butter and maize flour, green maize, avocado and ripe bananas (Andrzejewski*,* 2002; Nyirenda *et al.,* 2020). Traps were set in the evening at 18.00h and inspected next day in the morning at 7.00h.

3.1.1.2 Identification of rodent and shrew

Identification of the captured rodent and shrew was done to species level using keys and illustrations developed previously (Happold 2015). This was aided by further recording other body parameters including weight, sex and maturity/breeding condition.

3.1.1.3 Collection of fleas

Collection of fleas was done after anaesthetizing the rodents and shrews with 90% Diethyl Ether (C4H100) EMPLURA® (Katakweba *et al.,* 2013). The fur of the animals was then brushed thoroughly with a hard toothbrush to disengage the ectoparasites into a flat basin lined with a white plain cloth (Eads and Biggins, 2019). Thereafter, fleas and other ectoparasites were gently picked, using a fine camel brush into vials containing 70% ethanol for preservation (Nyirenda *et al.,* 2018) and then transported to the Laboratory at the Institute of Pest Management (IPM) at Sokoine University of Agriculture (SUA) for further processing and identification.

3.1.1.4 Processing and identification of fleas

The fleas were removed from the vials, boiled in 10% KOH for 10mn and then transferred into acidified water and subsequently rinsed in distilled water. After rising were put in 50% ethanol for 1h then into 70% ethanol for another 1 hour and into 95% of ethanol for an hour to clear them and subsequently, in clove oil overnight. Mounting was done using DPX solution followed by examination under a compound microscope (Bahmanyar and Cavanaugh, 1976). Fleas were identified based on their main features which include genal combs, pronotal combs, reproductive organs (spermathecae in females and penis plates in males), and the shape of their heads (Nyirenda *et al.,* 2018), for species confirmation according to Kohl (1957).

3.1.2 Data analysis

Raw data were entered and coded in Microsoft excel and data analysis was done using Statistical Package for the Social Sciences (SPSS) version 26 (IBM Corporation, Armonk, NY, USA). Estimation of flea infestation on the examined hosts was based on prevalence, mean abundance and mean intensity. Prevalence was estimated as the total number of individuals infested with at least one flea species over the total number of hosts examined multiplied by 100. Mean intensity was estimated as the total number of fleas that infested a particular host species to the total number of hosts infested with the parasite. Mean abundance of fleas was estimated as the total number of fleas that infested a particular host species to the total number of hosts examined. Likewise, computation of potential zoonotic fleas was estimated using the Specific Flea Index (SFI) as the total number of zoonotic-associated flea species on a particular host species to the total number of host species examined (Chotelersak *et al*., 2015).

$$\text{Specific flea index (SFI)} = \frac{\text{Number of flea species collected from host species } Z}{\text{Number of individual species } Z \text{ examined}}$$

Analysis of Variance (ANOVA) was used to compare prevalence, mean abundance and mean intensity of fleas among host species, habitats, elevation gradient, host, age and sex. Pearson’s correlation coefficient test was used to establish the association of elevation and weather parameters (humidity, temperature and rainfall) on the mean abundance, mean intensity and prevalence of fleas on hosts examined.

3.2 Results

3.2.1 Prevalence and abundance of fleas

A total of 199 fleas belonging to three species were collected from 207 rodents examined which were *Dinopsyllus lypusus*, with highest prevalence of 38.65%, followed by *Ctenopthalmus calceatus* (8.21%) and *Nosopsyllus fasciatus* (4.83%). A total of 101 (48.79 %) hosts comprised of rodents (*Rattus rattus, Mastomys natalensis, Beamys hindei, Lophuromys flavopunctatus, Lophuromys kilonzoi, Praomys delectorum, Grammomys ibeanus, Graphiurus murinus, Mus minutoides, Mus musculus, Dasmys spp*), while the rest were shrew species (*Crocidura olivieri* and *C. hirta*) species (Table 3.1). The mean abundance of fleas (Table 3.2) varied significantly among host species ($F_{(12, 194)} = 11.82$, $P < 0.001$), $P < 0.001$), between elevations ($F_{(1, 205)} = 10.15$, $P = 0.02$) and among habitats ($F_{(2, 204)} = 9.935$, $P < 0.001$). Prevalence (Table 3.3) varied significantly among hosts ($F_{(12, 194)} = 22.44$, $P < 0.001$) and habitats ($F_{(2, 204)} = 4.837$, $P = 0.009$) but not along the elevation gradient ($F_{(1, 205)} = 0.291$, $P = 0.59$). Whereas the mean intensity (Table 3.4) varied significantly along the elevation gradient ($F_{(1, 205)} = 47.91$, $P < 0.001$) and among hosts ($F_{(12, 194)} = 9.257$, $P < 0.001$) but not habitats ($F_{(2, 204)} = 0.75$, $P = 0.473$).

Table 3.1: Overall prevalence of flea species on rodents and shrews

		Number of hosts infested (Prevalence, %)		
Host species	**n (host)**	***Ctenopththalmus calceatus***	***Dinopsyllus lypusus***	***Nosopsyllus fasciatus***
L. flavopunctatus	45	11(5.31)	17 (8.21)	3(1.45)
L. kilonzoi	5	1(0.49)	3(1.45)	-
M. minutoides	7	-	3(1.45)	-
M. musculus	3	-	1(0.49)	-
M. natalensis	20	1(0.49)	14(0.07)	-
Dasmys spp	1	-	-	1(0.49)
G. ibeanus	18	1(0.49)	5(0.02)	-
P. delectorum	84	3(1.45)	29(14)	1(0.49)
B. hindei	3	-	1(0.49)	1(0.49)
G. murinus	3	-	-	-
R. rattus	3	-	1(0.49)	-
C. olivieri	8	-	2(1)	-
C. hirta	7	-	4(1.9)	-
Total	207	N= 17 (8.21%)	N=76 (36.71%)	N=6(2.9%)

Table 3.2: Mean abundance of fleas on rodents and shrews among habitats and between elevations

		Number of fleas (Mean Abundance)						
		Low Elevation			**High Elevation**			
Host species	**n(hosts)**	**F_L**	**FA_L**	**C_L**	**F_H**	**FA_H**	**C_H**	**Total**
L flavopunctatus	45	24 (0.12)	13 (0.06)	-	15 (0.07)	3 (0.01)	1 (0.004)	56 (0.27)
L. kilonzoi	5	1(0.004)	-	-	7(0.03)	-	-	8(0.04)
M.minutoides	7	-	-	-	1(0.004)	-	4(0.02)	5(0.02)
M.musculus	3	-	-	1(0.004)	-	-	-	1(0.004)
M.natalensis	20	-	4(0.02)	8(0.04)	1(0.004)	4(0.02)	10(0.05)	27(0.13)
Dasmys spp	1	-	1(0.004)	-	-	-	-	1(0.004)
G.ibeanus	18	2(0.01)	-	-	9(0.04)	-	-	11(0.05)
P. delectorum	84	19(0.1)	-	-	28(0.14)	-	-	47(0.23)
B.hindei	3	1(0.004)	-	-	-	-	-	1(0.004)
G.murinus	3	-	-	-	-	-	-	-
R.rattus	3	6(0.03)	-	-	-	-	3(0.01)	9(0.04)
C.olivieri	8	-	-	-	4(0.02)	-	-	4(0.02)
C. hirta	7	4(0.02)	-	-	2(0.01)	-	-	6(0.03)
Total	**207**	**57(0.28)**	**18(0.09)**	**9(0.04)**	**67(0.32)**	**7(0.03)**	**18(0.09)**	**176(0.85)**

KEY: **F_L** – Forest low, **FA_L** – Fallow low, **C_L** – Cultivated low, **F_H** – Forest High, **FA_H** – Fallow high, **C_H** – Cultivated high

Table 3.3: Prevalence of fleas on rodents and shrews among habitats and between elevations

		Number of hosts infested (PREVALENCE, %)						
		Low Elevation			High Elevation			
Host species	**n(host)**	**F_L**	**FA_L**	**C_L**	**F_H**	**FA_H**	**C_H**	**Total**
L flavopunctatus	45	16(7.7)	4(1.9)	-	6(2.9)	1(0.49)	1(0.49)	28(13.5)
L. kilonzoi	5	1(0.49)	-	-	2(0.97)	-	-	3(1.45)
M. minutoides	7	-	-	-	1(0.49)	-	2(0.97)	3(1.45)
M. musculus	3	-	-	3(1.45)	-	-	-	3(1.45)
M. natalensis	20	-	3(1.45%)	5(2.42)	1(0.49)	1(0.49)	4(1.93)	14(6.76)
Dasmys spp	1	-	1(0.49)	-	-	-	-	1(0.49)
G. ibeanus	18	2(0.97)	-	-	5(2.42)	-	-	7(3.4)
P. delectorum	84	19(9.2)	-	-	43(20.77)	-	-	62(29.95)
B. hindei	3	2(0.97)	-	-	-	-	-	2(0.97)
G. murinus	3	-	-	-	-	-	-	-
R. rattus	3	2(0.97)	-	-	-	-	1(0.49)	3(1.45)
C. olivieri	8	-	-	-	2(0.97)	-	-	2(0.97)
C. hirta	7	3(1.45)	-	-	1(0.49)	-	-	4(1.93)
Total	**207**	**45(21.74)**	**8(3.86)**	**8(3.86)**	**61(29.47)**	**2(0.97)**	**8(3.86)**	**132(67.77)**

KEY: F_L – Forest low, **FA_L** – Fallow low, **C_L** – Cultivated low, **F_H** – Forest High, **FA_H** – Fallow high, **C_H** – Cultivated high

Table 3.4: Mean intensity of fleas on rodents and shrews among habitats and between elevations

		Number of fleas (Mean Intensity)						
		Low Elevation			High Elevation			
Host species	**n(host)**	**F_L**	**FA_L**	**C_L**	**F_H**	**FA_H**	**C_H**	**Total**
L flavopunctatus	28	24(0.24)	13(0.13)	-	15(0.15)	3(0.03)	1(0.01)	56(0.55)
L. kilonzoi	3	1(0.01)	-	-	7(0.07)	-	-	8(0.08)
M.minutoides	3	-	-	-	1(0.01)	-	4(0.04)	5(0.05)
M.musculus	1	-	-	1(0.01)	-	-	-	1(0.01)
M.natalensis	15	-	4(0.04)	8(0.08)	1(0.01)	4(0.04)	10(0.1)	27(26.73)
Dasmys spp	1	-	1(0.01)	-	-	-	-	1(0.01)
G.ibeanus	7	2(0.02)	-	-	9(0.09)	-	-	11(0.11)
P. delectorum	32	19(0.19)	-	-	28(0.28)	-	-	47(0.47)
B.hindei	2	1(0.01)	-	-	-	-	-	1(0.01)
G.murinus	-	-	-	-	-	-	-	-
R.rattus	3	6(0.06)	-	-	-	-	3(0.03)	9(0.09)
C.olivieri	2	-	-	-	4(0.04)	-	-	4(0.04)
C. hirta	4	4(0.44)	-	-	2(0.22)	-	-	6(0.06)
Total	**101**	**(57)0.56**	**18(0.18)**	**9(0.09)**	**67(0.66)**	**7(0.07)**	**18(0.18)**	**177(1.75)**

KEY: **F_L** – Forest low, **FA_L** – Fallow low, **C_L** – Cultivated low, **F_H** – Forest High, **FA_H** – Fallow high, **C_H** – Cultivated high

3.2.2 Host sex, age and weather parameters vs flea assemblage

Overall, adults ($F_{(1,24)} = 32.78$, $P < 0.001$) and male hosts ($F_{(1,24)} = 11.2$, $P = 0.04$) presented with the highest prevalence of fleas than females. However, neither rainfall, temperature nor humidity were correlated with mean flea intensity ({r= -0.074, P = 0.29}, {r = -0.046, P=0.509}, {r = 0.075, P = 0.28}) and prevalence ({r=0.04, P = 0.53}, {r= 0.01, P= 0.88}, {r= 0.03, P= 0.6}), respectively. With regards to the mean abundance, rainfall (r = 0.054, P = 0.044) presented a stronger association than temperature (r = 0.012, P = 0.867) and humidity (r= 0.0, P= 1).

3.2.3 Zoonotic potential of flea species

The Specific Flea Index (SFI) varied among habitats, hosts and along the elevation gradient (Table 3.5), with *D. lypusus* taking precedence over other species.

Table 3.5: Specific flea index (SFI) of *Dinopsyllus lypusus* on rodents and shrews among habitats and between elevations

		Number of fleas (Specific Flea Index -SFI)						
		Low Elevation			High Elevation			
Host species	**N(Host)**	**F_L**	**FA_L**	**C_L**	**F_H**	**FA_H**	**C_H**	**Total**
L.flavopunctatus	45	16(0.08)	9(0.04)	-	5(0.02)	1(0.004)	1(0.004)	32(0.15)
L. kilonzoi	5	1(0.004)	-	-	6(0.03)	-	-	7(0.03)
M. minutoides	7	-	-	-	2(0.01)	-	4(0.02)	6(0.03)
M. musculus	3	-	-	1(0.004)	-	-	-	1(0.004)
M. natalensis	20	-	5(0.02)	4(0.02)	1(0.004)	5(0.02)	9(0.04)	24(0.12)
Dasmys spp	1	-	1(0.004)	-	-	-	-	1(0.004)
G.ibeanus	18	1(0.004)	-	-	6(0.03)	-	-	7(0.03)
P.delectorum	84	17(0.08)	-	-	33(0.16)	-	-	50(0.24)
B.hindei	3	2(0.01)	-	-	-	-	-	2(0.01)
G. murinus	3	-	-	-	-	-	-	-
R.rattus	3	6(0.03)	-	-	-	-	3(0.01)	9(0.04)
C.olivieri	8	-	-	-	8(0.04)	-	-	8(0.04)
C.hirta	7	4(0.02)	-	-	2(0.01)	-	-	6(0.03)
Subtotal	**207**	**47(0.23)**	**15(0.07)**	**5(0.02)**	**63(0.3)**	**6(0.03)**	**17(0.08)**	
Total			**67(0.32)**			**86(0.42)**		**0.74**

KEY: F_L – Forest low, **FA_L** – Fallow low, **C_L** – Cultivated low, **F_H** – Forest High, **FA_H** – Fallow high, **C_H** – Cultivated high

3.3 Discussion

Three species of fleas (*Dinopsyllus lypusus, Ctenopthalmus calceatus* and *Nosopsyllus fasciatus*) were recorded. These flea species have been previously reported in northern Tanzania (Makundi *et al*., 2008; Ziwa *et al*., 2013; McCauley *et al*., 2015) Uganda (Bai *et al*., 2017) and Kenya (Oguge *et al*., 2009). Some of the flea species particularly *D. lypusus*, are regarded as vectors of pathogens such as *Yersinia pestis,* the causative agent of plague. Thus, great care and avoidance strategies should be observed in the landscape.

Co-infestation reflects the assemblage of fleas where different species occurs on the same host (Khokhlova *et al*., 2015). In line with previous surveys (Haule *et al*.,2013; McCauley *et al.*,2015; Msangi, 2019) conducted in northern Tanzania, this study has presented co-infestation of flea species on various hosts such as *P. delectorum* and *L. kilonzoi*. This phenomenon is likely to be triggered by facilitation through suppression of the immune system of hosts harboring them. As different flea species are known to be infected by the same pathogen (Rodríguez-Pastor *et al*., 2019), several other pathogens can be harbored by the same hosts (Han *et al*., 2015). Therefore, simultaneous infestation by different flea species could increase the danger of transmission of zoonotic diseases from the rodents.

Dinopsyllus lypusus, which has previously been identified as an important and efficient vector of plague-causing pathogen, *Y. pestis*, in east Africa (Kilonzo and Mhina, 1983; Makundi *et al.,* 2003; Shihepo *et al*., 2008) was more abundant and prevalent than any other flea species on the rodent and shrew hosts studied. This scenario can be attributed to the prevailing favorable climatic conditions in the study area. Bahmanyar and Cavanaugh (1976) reported that the propagation of *D. lypusus* is dependent on to temperature changes ranging from 10 ºC to 30 ºC, which was the temperature range in the study area. *Nosopsyllus fasciatus* and *C.*

calceatus, the other fleas recorded, were also prevalent on various hosts. However, they are regarded as non-efficient vectors of the *Y. pestis* (Devignat, 1946).

Unlike wild rodent and shrew species, most of the other species (eg. *M natalensis, R. rattus* and *M. minutoides*) inhabiting domestic and peri-domestic settings, were exclusively infested with *D. lypusus.* Some surveys on zoonotic diseases, especially plague (Msangi, 1969; Kilonzo and Mhina, 1982; Njunwa *et al*., 1989), have reported on the potential role of *D. lypusus* and *Xenopsylla brasiliensis* as the most efficient vectors of plague, together with *R. rattus* and *M. natalensis* as the main reservoirs of *Y. pestis* in Tanzania. However, the findings of this study suggest that zoonotic threats are likely to be caused by the respective hosts, given the presence of fleas on them and especially that they they live near human dwellings (Feng and Himsworth, 2014; Torres-Castro *et al*., 2016; Nyirenda *et al*., 2020).

Praomys delectorum, an arguably forest dwelling species (Carleton and Stanley, 2012), was most abundant across all elevations. Surprisingly, it was neither the most prevalent nor was it heavily infested with fleas. This could otherwise be attributed to the role of frequent precipitation in the humid montane and sub montane forest habitats (Willig and Presley, 2016). This assumption has been supported by Heanel and Regalado (1998), who reported that high level of precipitation may cause massive detachment of flea species from the host body, thus causing low ectoparasite count.

Unlike other host species, *M. natalensis* and *L. flavopunctatus* were exceptional, in that their associated fleas were found in nearly all the habitats studied along the two elevation gradients. This is presumably due to their wide distribution over the entire study site. According to Shenbrot *et al*. (2007), the geographical range of the respective hosts can strongly influence the abundance and prevalence of ectoparasites. Regarding host distribution; Mulungu *et* *al.* (2015), also reported a wide distribution of *M. natalensis* in lowland cultivated and fallow fields across Sub-Saharan Africa, as well as *L. flavopunctatus* being more abundant in moist, afforested zones, and bushes (Lavrenchenko *et al.,* 1998; Verheyen *et al*., 2002).

In contrast to cultivated and fallow lands, forest habitats in both elevations displayed the highest abundance and prevalence of fleas on different rodents and shrews. This may have been as a result of the highest number of hosts inhabiting that habitat type. Krasnov *et al.,* (2002), linked an increase in flea abundance to the density of respective hosts. Additionally, density of hosts increases the possibility of intra and interspecific interactions, that lead a high spread of fleas from one host to another.

The findings of this study have shown that adult rodent and shrew hosts had the highest flea infestation compared to juveniles, which is consistent with Krasnov *et al.* (2006) and was likely caused indirectly by foraging behavior (Hawlena *et al*., 2005). Smit *et al.* (1962), linked continuous adult-biased parasitism to home range as they occasionally leave their nests and become infested elsewhere in search of food.

With respect to the host's sex towards flea infestation, the high ectoparasite infestation observed in male hosts in our study concurs with the findings of Krasnov *et al.,* (2005); Bucholz and Dick, (2017) and Rynkiewicz *et al*., (2013). However, possible reasons for this include a great home range, differences in immune susceptibility, the pattern of social interactions, grooming behavior, and large body sizes. All of which together make the male hosts more prone of exposure to flea infestations (Perez-Orella and Schulte-Hostedde, 2005; Kiffner *et al.,* 2013).

Despite the fact that rainfall, temperature, and relative humidity are all important factors in determining flea assemblage in various small mammals (Silverman and Rust, 1983; Thomas and Blanford, 2003; Kreppel *et al*., 2016), only rainfall had a positive and stronger correlation with the mean abundance of fleas. This is consistent with Young *et al*. (2015), and may be related to the fact that the optimum increase of rainfall helps to increase abundance and quality of vegetation characters, thereby, increasing rodent abundance and diversities, and in turn, increases the population of fleas that relies on the hosts for survival and reproduction. Additionally, rainfall may directly increase flea reproduction as well as it moisturizes the soils lining the rodent's nests (Parmenter *et al*., 1999). Nonetheless, excessive precipitation may flood host nests, resulting in the extinction of major flea species. Our findings indicated that temperature and relative humidity did not correlate with either mean abundance, mean intensity, or prevalence which was in line with the findings of Krasnov *et al*. (2010) in Western Cape, Province South Africa, and Hawlena *et al*. (2005) in Western Negev Sand dunes in Israel, respectively. This may be as a result of limited exposure in the mid growth stage of fleas as environmental factors are thought to affect their survival more than adults.

Regardless of the difference in threshold level for plague transmission, this study strongly agrees with Njunwa *et al*. (1989), and Makundi *et al*. (2008) in their studies conducted in the Western Usambara Mountains, to investigate which categories of host species were infested by fleas. They reported infestation of potential plague vectors in wild rodents including: *L. flavopunctatus, L Kilonzoi* and *P delectorum,* whereas for commensal rodents were included species, such as *R. rattus, M. minuitoides* and *M. musculus*. Simultaneous infestation with more than one plague vectors on the hosts suggests enhanced risks in respective of habitats.

Regarding the zoonotic potential of fleas, notably *D. lypusus*, which is arguably one of the prominent vectors of plague in East Africa (Makundi *et al*., 2003; Shihepo *et al*., 2008), this flea did not reach the threshold level for the transmission of plague. This is based on the Specific Flea Index (SFI) as the value greater than 1.5 is thought to indicate high risk of plague occurrence (Chotelersak *et al*., 2015). Therefore, this implies that, for the study period at least, there was no immediate threat associated with *D. lypusus* to transmit Y.*pestis* plague.

Forest habitats in both elevations displayed highest prevalence of fleas on rodents and shrews compared to the fallows and cultivated lands. This could possibly be related to the highest number of hosts captured in the forest habitat compared to other habitats because high host density tends to increase chances of interaction among flea species and consequently high flea assemblage. This agrees with Krasnov *et al*. (2002) in Israel and Stanko *et al*. (2002) in Slovakia.

3.4 Conclusion and Recommendations

Habitat type and rainfall exhibited an influence in dictating flea assemblage along the elevation gradient than relative humidity and temperature. Additionally, the study revealed different flea species infesting rodents and shrews, some of which are efficient and important vectors of plague, suggesting the likelihood of the presence of *Y. pestis* pathogen in the study area. Nonetheless, this analysis alone does not suffice to establish the existence of *Y. pestis* in small mammal reservoirs in the study area. Hence, the need for further studies to detect the pathogen, including using molecular techniques, to help predict outbreak, as plague monitoring and surveillance is helpful only in identifying sylvatic cases and epizootics and steps to control and avoid spillover into human populations (Haikukutu *et al*., 2022).

Even though the Specific Flea Index (SFI) was below the threshold level defined for disease transmission to occur, continuous epidemiological surveillance in small mammal populations is crucial. Moreover, the fact that the study was conducted within a limited timeframe and that laboratory confirmation of the pathogen did not occur, further studies of flea surveillance on various small mammals and humans in different seasons should be conducted. This will facilitate a thorough understanding of the seasonal fluctuations of fleas as well as their zoonotic potential.

REFERENCES

Amatre, G., Babi, N., Enscore, R. E., Ogen-Odoi, A., Atiku, L. A., Akol, A. and Eisen, R. J. (2009). Flea diversity and infestation prevalence on rodents in a plague-endemic region of Uganda. *The American Journal of Tropical Medicine* 81(4): 718 - 724

Andrzejewski, R. (2002). The home-range concept in rodents revised. *Acta Theriologica 47*: 81-101.

Bahmanyar, M., and D. C. Cavanaugh. 1976. Plague manual, pp. 76Ð89. World Health Organization, Geneva, Switzerland.

Bai, Y, Osikowicz, L.M., Kosoy, M.Y., Eisen, R.J, Atiku, L.A., Mpanga, J.T and Gage, K.L., (2017).Comparison of zoonotic bacterial agents in fleas collected from small mammals or host seeking fleas from a Ugandan region where plague is endemic. *Msphere,* 2(6), 00402- 17

Bitam, I., Dittmar, K., Parola, P., Whiting, M. F. and Raoult, D. (2010). Fleas and flea-borne diseases. *International Journal of Infectious Diseases*, *14*(8), e667-e676.

Buchholz, M. J. and Dick, C. W. (2017). Ecology of rodent—ectoparasite associations in South-Central Kentucky. *Northeastern Naturalist* 24(2): 97 - 109.

Burgess, N., Butynski, T. M., Cordeiro, N. J., Doggart, N. H., Fjeldså, J., Howell, K. M. and Stuart, S. N. (2007). The biological importance of the Eastern Arc Mountains of Tanzania and Kenya. *Biological Conservation 134*(2): 209 - 231.

Burgess, N.D., Lovett, J.C., and Muhagama, S. (2001). *Biodiversity Conservation and Sustainable Forest management in the Eastern Arc Mountains.* Unpublished report prepared for GEF/PDFB Eastern Arc Strategy Process.

Carleton, M. D. and Stanley, W. T. (2012). Species limits within the Praomys delectorum group (Rodentia: Muridae: Murinae) of East Africa: a morphometric reassessment and biogeographical implications. *Zoological Journal of the Linnean Society*, *165*(2), 420-469.

Chidodo, S., Kilawe, C. J., Mnyone, L. L., Broecke, B. V. and Mulungu, L. S. (2020). Factors affecting the composition of rodent assemblages in the North Uluguru Mountains, Tanzania. *Journal of Vertebrate Biology*, *69*(2), 20047-1.

Chotelersak, K., Apiwathnasorn, C., Sungvornyothin, S., Panasoponkul, C., Samung, Y. and Ruangsittichai, J. (2015). Correlation of host specificity, environmental factors and oriental rat flea abundance. *Southeast Asian Journal of Tropical Medicine and Public Health*, *46*(2), 198.

Devignat, R. (1946). *Aspects de l'épidémiologie de la peste au Lac Albert*. Goemaere.

Durden, L. A. and Hinkle, N. C. (2019). Fleas (siphonaptera). In *Medical and veterinary entomology* (pp. 145-169). Academic Press.

Eads, D. A. and Biggins, D. E. (2019). Plague management of prairie dog colonies: degree and duration of deltamethrin flea control. *Journal of Vector Ecology*, *44*(1), 40-47.

Eremeeva, M. E., Warashina, W. R., Sturgeon, M. M., Buchholz, A. E., Olmsted, G. K., Park, S. Y. and Karpathy, S. E. (2008). Rickettsia typhi and R. felis in rat fleas (Xenopsylla cheopis), Oahu, Hawaii. *Emerging Infectious Diseases*, *14*(10), 1613.

Feldmeier, H., Sentongo, E. and Krantz, I. (2013). Tungiasis (sand flea disease): a parasitic disease with particular challenges for public health. *European Journal of Clinical Microbiology & Infectious Diseases*, *32*, 19-26.

Feng, A. Y. and Himsworth, C. G. (2014). The secret life of the city rat: a review of the ecology of urban Norway and black rats (Rattus norvegicus and Rattus rattus). *Urban Ecosystems*, *17*, 149-162.

Gutiérrez, R., Morick, D., Cohen, C., Hawlena, H. and Harrus, S. (2014). The effect of ecological and temporal factors on the composition of Bartonella infection in rodents and their fleas. *The ISME Journal*, *8*(8), 1598-1608.

Haikukutu, L., Lyaku, J.R., Lyimo, C., Kasanga, C.J., Kandusi, E.S., Rahelinirina, S., Rasoamalala, F., Rajerison, M. and

Makundi, R. (2022). Plague in Tanzania: first report of sylvatic plague in Morogoro region, persistence in Mbulu focus, and ongoing quiescence in Lushoto and Iringa foci, *IJID Regions,Volume 4*.

Hamidi, K., Nourani, L. and Moravvej, G. (2015). The relationship of ectoparasite prevalence to the capturing season, locality and species of the murin rodent hosts in Iran. *Persian Journal of Acarology*, *4*(4).

Hammond, T. T., Hendrickson, C. I., Maxwell, T. L., Petrosky, A. L., Palme, R., Pigage, J. C. and Pigage, H. K. (2019). Host biology and environmental variables differentially predict flea abundances for two rodent hosts in a plague-relevant system. *International Journal for Parasitology: Parasites and Wildlife*, *9*, 174-183.

Han, B. A., Schmidt, J. P., Bowden, S. E. and Drake, J. M. (2015). Rodent reservoirs of future zoonotic diseases. *Proceedings of the National Academy of Sciences*, *112*(22), 7039-7044.

Happold DCD. 2013. *Mammals of Africa. Volume III: Rodents, Hares and Rabbits*, 1st edn. Bloomsbury Publishing, London, UK.

Haule, M., Lyamuya, E. E., Hang'ombe, B. M. and Matee, M. I. (2013). Investigation of fleas as vectors in the transmission of plague during a quiescent period in North-Eastern, Tanzania.

Hawlena, H., Abramsky, Z. and Krasnov, B. R. (2005). Age-biased parasitism and density-dependent distribution of fleas (Siphonaptera) on a desert rodent. *Oecologia*, *146*, 200-208.

Heaney, L. R. and Regalado Jr, J. C. (1998). *Vanishing treasures of the Philippine rain forest*. The Field Museum.

Herrero-Cófreces, S., Flechoso, M. F., Rodríguez-Pastor, R., Luque-Larena, J. J. and Mougeot, F. (2021). Patterns of flea infestation in rodents and insectivores from intensified agro-ecosystems, Northwest Spain. *Parasites & Vectors*, *14*(1), 1-13.

Hinnebusch, B. J., Chouikha, I. and Sun, Y. C. (2016). Ecological opportunity, evolution, and the emergence of flea-borne plague. *Infection and immunity*, *84*(7), 1932-1940.

Jones, F. G. (1987). Fleas.

Katakweba, A. A. S., Kipanyula, M. J., Durnez, L., Mhamphi, G., Luziga, C., Mgode, G. F. and Machang'u, R. S. (2013). Rodents and shrews as vectors of zoonotic spirochetes and trypanosomes in Tanzania.

Kiffner, C., Stanko, M., Morand, S., Khokhlova, I. S., Shenbrot, G. I., Laudisoit, A. and Krasnov, B. R. (2013). Sex-biased parasitism is not universal: evidence from rodent–flea associations from three biomes. *Oecologia*, *173*, 1009-1022.

Kilonzo, B. S. and Mhina, J. I. (1983). Observations on the current status of plague endemicity in the Western Usambara mountains, north-east Tanzania. *Acta Tropica*, *40*(4), 365-373.

Kilonzo, B. S. and Mhina, J. I. K. (1982). The first outbreak of human plague in Lushoto District, north-east Tanzania. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *76*(2), 172-177.

Kilonzo, B. S., Mvena, Z. S. K., Machangu, R. S. and Mbise, T. J. (1997). Preliminary observations on factors responsible for long persistence and continued outbreaks of plague in Lushoto district, Tanzania. *Acta tropica*, *68*(2), 215-227.

Kohl, G.M. Tick (Ixodoidae) of Borneo and Malaya. (1957). *Student Instute for Medical Research* 28: 65-94.

Kowalski, K., Eichert, U., Bogdziewicz, M. and Rychlik, L. (2014). Differentiation of flea communities infesting small mammals across selected habitats of the Baltic coast, central lowlands, and southern mountains of Poland. *Parasitology Research*, *113*, 1725-1734.

Krasnov, B. R. and Matthee, S. (2010). Spatial variation in gender-biased parasitism: host-related, parasite-related and environment-related effects. *Parasitology*, *137*(10), 1527-1536.

Krasnov, B. R., Khokhlova, I. S., Fielden, L. J. and Burdelova, N. V. (2001). Effect of air temperature and humidity on the survival of pre-imaginal stages of two flea species (Siphonaptera: Pulicidae). *Journal of Medical Entomology*, *38*(5), 629-637.

Krasnov, B. R., Morand, S., Hawlena, H., Khokhlova, I. S. and Shenbrot, G. I. (2005). Sex-biased parasitism, seasonality and sexual size dimorphism in desert rodents. *Oecologia* 146(2), 209-217.

Krasnov, B. R., Stanko, M. and Morand, S. (2006). Age-dependent flea (Siphonaptera) parasitism in rodents: a host's life history matters. *Journal of Parasitology*, *92*(2), 242-248.

Krasnov, B., Khokhlova, I. and Shenbrot, G. (2002). The effect of host density on ectoparasite distribution: an example of a rodent parasitized by fleas. *Ecology*, *83*(1), 164-175.

Krasnov, B., Khokhlova, I. and Shenbrot, G. (2002). The effect of host density on ectoparasite distribution: an example of a rodent parasitized by fleas. *Ecology*, *83*(1), 164-175.

Kreppel, K. S., Telfer, S., Rajerison, M., Morse, A. and Baylis, M. (2016). Effect of temperature and relative humidity on the development times and survival of Synopsyllus fonquerniei and Xenopsylla cheopis, the flea vectors of plague in Madagascar. *Parasites & Vectors*, *9*, 1-10.

Laudisoit, A., Leirs, H., Makundi, R. and Krasnov, B. R. (2009). Seasonal and habitat dependence of fleas parasitic on small mammals in Tanzania. *Integrative Zoology*, *4*(2), 196-212.

Laudisoit, A., Leirs, H., Makundi, R. H., Van Dongen, S., Davis, S., Neerinckx, S. and Libois, R. (2007). Plague and the human flea, Tanzania. *Emerging infectious diseases*, *13*(5), 687.

Lavrenchenko, L. A., Verheyen, W. N. and Hulselmans, J. (1998). Systematic and distributional notes on the Lophuromys flavopunctatus Thomas, 1888 species-complex in Ethiopia (Muridae–Rodentia). *Bull. Konink. Belg. Inst. Natuur*, *68*, 199-214.

Linardi, P. M. and Krasnov, B. R. (2013). Patterns of diversity and abundance of fleas and mites in the Neotropics: host related, parasite related and environment-related factors. *Medical and Veterinary Entomology*, *27*(1), 49-58.

López-Pérez, A. M., Pesapane, R., Clifford, D. L., Backus, L., Foley, P., Voll, A. and Foley, J. (2022). Host species and environment drivers of ectoparasite community of rodents in a Mojave Desert wetlands. *PloS one*, *17*(6), e0269160.

Makundi, R. H., Massawe, A. W., Mulungu, L. S., Katakweba, A., Mbise, T. J. and Mgode, G. (2008). Potential mammalian reservoirs in a bubonic plague outbreak focus in Mbulu District, northern Tanzania, in 2007.

Makundi, R. S., Kilonzo, B. S. and Massawe, A. W. (2003). Interaction between rodent species in agro-forestry habitats in the western Usambara Mountains, north-eastern Tanzania, and its potential for plague transmission to humans.

Maleki-Ravasan, N., Solhjouy-Fard, S., Beaucournu, J. C., Laudisoit, A. and Mostafavi, E. (2017). The fleas (Siphonaptera) in Iran: diversity, host range, and medical importance. *PLoS neglected tropical diseases*, *11*(1), e0005260.

Mattee, R. S. and Za, C. Indigenous knowledge system (IKS) and biodiversity conservation in South Nguru Mountain Forest Reserve, Tanzania: Often neglected partner for sustainable. *in Sub-Saharan Africa*, 65.

McCauley, D. J., Salkeld, D. J., Young, H. S., Makundi, R., Dirzo, R., Eckerlin, R. P. and Helgen, K. M. (2015). Effects of land use on plague (Yersinia pestis) activity in rodents in Tanzania. *The American Journal of Tropical Medicine and Hygiene*, *92*(4), 776-783.

Metzger, M. E. and Rust, M. K. (1999, July). Abiotic factors affecting the development of fleas (Siphonaptera) of California ground squirrels (Rodentia: Sciuridae) in southern California, USA. In *Proceedings of the 3rd International Conference on Urban Pests* (pp. 235-239).

Msangi, A. S. (1969). Entomological observations after the 1968 plague outbreak in Mbulu District, Tanzania. *East African Medical Journal*, *46*(8), 465-70.

Msangi, S. (2019). The surveillance of rodent populations in East Africa in relation to plague endemicity. *Tanzania Journal of Science*, *1*(1), 8-20.

Mulungu, L. S., Sixbert, V., Ngowo, V., Mdangi, M., Katakweba, A. S., Tesha, P. and Belmain, S. R. (2015). Spatio-temporal patterns in the distribution of the multi-mammate mouse, Mastomys natalensis, in rice crop and fallow land habitats in Tanzania. *Mammalia*, *79*(2), 177-184.

Njunwa, K. J., Mwaiko, G. L., Kilonzo, B. S. and Mhina, J. I. K. (1989). Seasonal patterns of rodents, fleas and plague status in the Western Usambara Mountains, Tanzania. *Medical and Veterinary Entomology*, *3*(1), 17-22.

Nyirenda, S. S., Simulundu, E., Mulenga, E., Moonga, L., Misinzo, G. and Kilonzo, B. S. (2018). Molecular epidemiological investigations of plague in Eastern Province of Zambia. *BMC microbiology*, *18*(1), 1-7.

Nyirenda, V. R., Namukonde, N., Simwanda, M., Phiri, D., Murayama, Y., Ranagalage, M. and Milimo, K. (2020). Rodent assemblages in the mosaic of habitat types in the Zambezian Bioregion. *Diversity*, *12*(10), 365.

Nziku, Z. C., Asheim, L. J., Eik, L. O., Mwaseba, D. and Kifaro, G. C. (2016). Climate change adaptation in vulnerable crop and livestock production systems in Mgeta, Tanzania. *African Journal of Food, Agriculture, Nutrition and Development*, *16*(2), 10853-10865.

Oguge, N. O., Durden, L. A, Keirans, J. E., Balami, H. D. and Schwan, T. (2009). Ectoparasites (sucking lice, fleas and ticks) of small mammals in southeastern Kenya. *Medical and veterinary entomology* 23(4); 387-392

Paramasvaran, S., Sani, R. A., Hassan, L., Krishnasamy, M., Jeffery, J., Oothuman, P. and Santhana, R. L. (2009). Ectoparasite fauna of rodents and shrews from four habitats in Kuala Lumpur and the states of Selangor and Negeri Sembilan, Malaysia and its public health significance. *Trop Biomed*, *26*(3), 303-311.

Parmenter, R. R., Yadav, E. P., Parmenter, C. A., Ettestad, P. and Gage, K. L. (1999). Incidence of plague associated with increased winter-spring precipitation in New Mexico. *The American journal of tropical medicine and hygiene*, *61*(5), 814-821.

Perez-Orella, C., and A. I. Schulte-Hostedde. (2005). Effects of sex and body size on ectoparasite loads in the northern flying squirrel (Glaucomys sabrimis). Canadian Journal of Zoology 83: 1381- 1385

Pontifes, P. A., Fernández-González, A., García-Peña, G. E., Roche, B. and Suzan, G. (2022). Drivers of flea abundance in wild rodents across local and regional scales in the Chihuahuan Desert, northwestern Mexico. *Ecosphere*, *13*(4), e4013.

Pratt, H. D. (1976). *Flies of public health importance and their control*. US Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control.

Rodríguez-Pastor, R., Mougeot, F., Vidal, M. D., Jado, I., González-Martín-Niño, R. M., Escudero, R. and Luque-Larena, J. J. (2019). Zoonotic bacteria in fleas parasitizing common voles, Northwestern Spain. *Emerging Infectious Diseases*, *25*(7), 1423.

Rynkiewicz, E. C., Hawlena, H., Durden, L. A., Hastriter, M. W., Demas, G. E. and Clay, K. (2013). Associations between innate immune function and ectoparasites in wild rodent hosts. *Parasitology Research* 112(4): 1763-1770.

Shenbrot, G., Krasnov, B. and Lu, L. (2007). Geographical range size and host specificity in ectoparasites: a case study with Amphipsylla fleas and rodent hosts. *Journal of Biogeography*, *34*(10), 1679-1690.

Shihepo, F. G., Eiseb, S. and Cunningham, P. (2008). FLEAS (INSECTA: SIPHONAPTERA) ASSOCIATED WITH SMALL. *Journal NWG/. Jozurnal NSS Band/Volume*, *56*, 5.

Silverman, J. and Rust, M. K. (1983). Some abiotic factors affecting the survival of the cat flea, Ctenocephalides felis

(Siphonaptera: Pulicidae). *Environmental Entomology*, *12*(2), 490-495.

Smit, F. G. A. M. (1962). Siphonaptera collected from moles and their nests at Wilp, Netherlands, by Jhr. WC van Heurn. *Tijdschr Entomol*, *105*, 29-44.

Smith, J. E., Smith, I. B., Working, C. L., Russell, I. D., Krout, S. A., Singh, K. S. and Sih, A. (2021). Host traits, identity, and ecological conditions predict consistent flea abundance and prevalence on free-living California ground squirrels. *International Journal for Parasitology*, *51*(7), 587-598.

Stanko, M., Miklisová, D., Goüy de Bellocq, J. and Morand, S. (2002). Mammal density and patterns of ectoparasite species richness and abundance. *Oecologia*, *131*(2), 289-295.

Tay, S. T., Mokhtar, A. S., Low, K. C., Mohd Zain, S. N., Jeffery, J., Abdul Aziz, N. and Kho, K. L. (2014). Identification of rickettsiae from wild rats and cat fleas in M alaysia. *Medical and Veterinary Entomology*, *28*(S1), 104-108.

Thomas, M. B. and Blanford, S. (2003). Thermal biology in insect-parasite interactions. *Trends in Ecology & Evolution*, *18*(7), 344-350.

Torres-Castro, M. A., Medina-Espinosa, D. N., Panti-May, J. A., Hernández-Betancourt, S. F., Noh-Pech, H. R., Yeh-Gorocica, A. B., & Puerto, F. I. (2016). First molecular evidence of Toxoplasma gondii in synanthropic rodents (Mus musculus and Rattus rattus) captured in Yucatan, Mexico. *Revue de Médecine Vétérinaire*, *167*(9-10), 250-255.

Van der Mescht, L. (2011). Ectoparasite assemblage of the four-striped mouse, *Rhabdomys pumilio*: the effect of anthropogenic habitat transformation and temporal variation (Doctoral dissertation, Stellenbosch: University of Stellenbosch).

Van der Mescht, L., Le Roux, P. C. and Matthee, S. (2013). Remnant fragments within an agricultural matrix enhance conditions for a rodent host and its fleas. *Parasitology*, *140*(3), 368-377.

Verheyen, W., Hulselmans, J. L., Dierckx, T. and Verheyen, E. (2002). The Lophuromys flavopunctatus Thomas1888 sl species complex: a craniometric study, with the description and genetic characterization of two new species (Rodentia-Muridae-Africa). *Bulletin de l'Institut Royal des Sciences Naturelles de Belgique Biologie*, *72*, 141-182.

Willig, M. R. and Presley, S. J. (2016). Biodiversity and metacommunity structure of animals along altitudinal gradients in tropical montane forests. *Journal of Tropical Ecology*, *32*(5), 421-436.

Young, H. S., Dirzo, R., McCauley, D. J., Agwanda, B., Cattaneo, L., Dittmar, K. and Helgen, K. M. (2015). Drivers of intensity and prevalence of flea parasitism on small mammals in East African savanna ecosystems. *The Journal of Parasitology*, *101*(3), 327-335.

Zimba, M., Loveridge, J., Pfukenyi, D. M. and Mukaratirwa, S. (2014). Seasonal abundance and epidemiological indices of potential plague vectors Dinopsyllus lypusus (Siphonaptera: Hystrichopsyllidae) and Ctenophthalmus calceatus (Siphonaptera: Ctenophthalmidae) on rodents captured from three habitat types of Hatcliffe and Dzivarasekwa Suburbs of Harare, Zimbabwe. *Journal of Medical Entomology*, *49*(6), 1453-1459.

CHAPTER FOUR

4.0 GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

4.1 Discussion

To our knowledge, this is the first study reporting on the diversity and temporal fluctuations of rodents, shrews and their flea ectoparasites in Mgeta. A total of 207 rodent and shrew individuals belonging to 11 rodents, and two shrew species were collected. Compared with a previous survey done in the northern part of Uluguru Mountains (Chidodo *et al*., 2020), this study has presented a higher abundance and richness of rodents and shrews. However, the opposite was the case for surveys on other Eastern Arc Mountains (Stanley and Hutterer, 2007; Ademola *et al*., 2021). This could be as a result of differences in the number of habitats studied, seasons and the methodology used. Despite being characterized with the same activity status, a few of the habitats sampled along the elevation gradient on the former survey could have similarly trailed the number of individuals. This is because the low number of strata sampled means there will be less forages (Gebrezgiher *et al*., 2022) consequently leading to low abundance and species.

The overall abundance of rodents and shrews varied with elevation, with the the lower elevations having higher overall small mammal abundance than the higher elevations. This is contrary to the findings in Mount Rungwe Forest Nature Reserve, which showed that abundance increases with elevation and significantly decreases at very high altitudes (Richard *et al*., 2022), linking the fluctuation to extreme weather experienced on the mountain as one climbs higher. Nonetheless, current results could be attributed to the fact that on the high elevations of this study area, the rodent species may be habitat specialists or less acclimatized to human presence, which may have made them hesitant to enter traps and hence were less attracted to the baits (Bonvicino *et al.,* 2002).

In line with Isabirye-Basuta and Kasenene 1987, in Uganda, this study has revealed differences in specie richness with disturbed forest showing highest number compared to minimal or undisturbed habitats. Higher species richness in disturbed forest might be related to the proximity to the cultivated lands and human settlements (Mortelliti and Boitani, 2006). This scenario further encourages massive locomotion and successive foundation of non-forest rodent species while in search of food and shelter, therefore, increasing rodent species richness (Mortelliti and Boitani, 2006).

Inhabitation of some rodent species such as *B. hindei* in forest habitat agrees with the report by Stanley and Goodman (2011). The species has been reported to prefer areas with high shrub density and canopy cover in Arabuko Sokoke forest in Kenya (Fitzgibbon *et al.,* 1995). Another study by Sabuni *et al.* (2015) has reported on the occurrence of the species in undisturbed coastal forests in Saadani National Park, Tanzania.

Regardless of their zoonotic potential in the ecosystem, this study has demonstrated fewer flea species as well as abundance than other surveys in Northern Tanzania (Njunwa *et al.,* 1989; Makundi *et al*., 2005; Haule *et al.,* 2013). This could, however, be due to differences in microclimate parameters, which are always assumed to influence flea assemblage on different hosts (Krasnov *et al*., 1998, 2005; Sanchez and Lareschi, 2019). The overall temporal fluctuation of rainfall, humidity and temperature prevailing across Northern Tanzania might be of optimum level to attract different flea species assemblage.

Despite the fact that fallow and cultivated lands had lower SFI than forest lands, the possility of the fleas in transmitting *Y pestis* should not be underestimated (Kimaro *et al*., 2014; Hieronimo *et al*., 2014; Meliyo *et al*., 2014). This is because continuous agricultural land conversion and manipulation always tends to trigger hosts' behavior and the overall distribution, as a result causing flea population on other hosts Van der Mescht *et al*., 2013).

With the exception of *Haemaphysalis* spp which was low in number, *Laelaps* spp dominated total captures of ectoparasites on rodents and shrews. This phenomenon may be related to the overall genus' character of mites having high infestation rate than fleas and ticks. Mawanda *et al*. (2020) further reported that members in family *Laelapidae* are generalists capable of parasitizing wide number of rodent and shrew species but also being a potential vector of *Coxiella brunetii.*

4.2 Conclusion

This study demonstrated a variation in the abundance and diversity of rodents, shrews and their flea-ectoparasites. Rainfall played a significant role as opposed to other climatic variables in dictating species distribution in various habitats along the western slope of the Uluguru Mountains.

Fallow habitats in both elevations had the lowest abundance and diversity of rodents, shrews and flea species compared to other habitats, implying that disturbance has strongly influenced species distribution. Therefore, human activities must be effectively controlled to preserve species diversity. However, the opposite was true regarding forest habitat which presented the highest abundance and diversity of species (rodents, shrews and fleas). Again indicating the urgent need for protecting the remaining forest patches in the area. Furthermore, this study brought to light some of the important rodent, shrew and flea species implicated in harboring and transmitting plague, elsewhere in Tanzania..

4.3 Recommendations

Although this study shed more light on potential reservoirs and efficient vectors of plague, however, it did detect signs of plague in the study area.. Additionally, despite SFI being below the threshold level for plague transmission in this study, it is still recommended that preparedness strategies be developed for human communities in the area. This is crucial to detect unpredictable rise in any of the factors that are responsible for plague occurrence, such as specific abundance and distribution of hosts, or the presence of *Y. pestis* in hosts, as well as climatic parameters particularly temperature, relative humidity and rainfall.

Furthermore, it is recommended that additional flea surveillance on the rodents and shrew be carried out over a longer period and preferably in more habitats along the elevation gradient to gain a thorough understanding of flea species seasonal fluctuations and their zoonotic potential.

REFERENCES

Abu-Madi, M. A., Behnke, J. M., Mikhail, M., Lewis, J. W. and Al-Kaabi, M. L. (2005). Parasite populations in the brown rat Rattus norvegicus from Doha, Qatar between years: the effect of host age, sex and density. *Journal of Helminthology*, *79*(2), 105-111.

Ademola, O. J., Vanden Broecke, B., Leirs, H., Mulungu, L. S., Massawe, A. W. and Makundi, R. H. (2021). Effects of forest disturbance on the fitness of an endemic rodent in a biodiversity hotspot. *Ecology and Evolution, 11*(5), 2391-2401.

Avenant, N. (2011). The potential utility of rodents and other small mammals as indicators of ecosystem ‘integrity’of South African grasslands. *Wildlife Research*, *38*(7), 626-639.

Avenant, N. L. and Cavallini, P. (2007). Correlating rodent community structure with ecological integrity, Tussen-die-Riviere Nature Reserve, Free State province, South Africa. *Integrative Zoology*, *2*(4), 212-219.

Bonvicino, C. R., Lindbergh, S. M. and Maroja, L. S. (2002). Small non-flying mammals from conserved and altered areas of Atlantic Forest and Cerrado: comments on their potential use for monitoring environment. *Brazilian Journal of Biology*, *62*, 765-774.

Brown, J. H. and Ernest, S. M. (2002). Rain and rodents: complex dynamics of desert consumers: although water is the primary limiting resource in desert ecosystems, the relationship between rodent population dynamics and precipitation is complex and nonlinear. *BioScience*, *52*(11), 979-987.

Burgess, N., Butynski, T. M., Cordeiro, N. J., Doggart, N. H., Fjeldså, J., Howell, K. M. and Stuart, S. N. (2007). The biological importance of the Eastern Arc Mountains of Tanzania and Kenya. *Biological Conservation, 134*(2), 209 - 231.

Byron, C. D., Herrel, A., Pauwels, E., Muynck, A. D. and Patel, B. A. (2015). Mouse hallucal metatarsal cross-sectional geometry in a simulated fine branch niche. *Journal of Morphology*, *276*(7), 759-765.

Capizzi, D., Bertolino, S. and Mortelliti, A. (2014). Rating the rat: global patterns and research priorities in impacts and management of rodent pests. *Mammal Review*, *44*(2), 148-162.

Chae, J. S., Yu, D. H., Shringi, S., Klein, T. A., Kim, H. C., Chong, S. T. and Foley, J. (2008). Microbial pathogens in ticks, rodents and a shrew in northern Gyeonggi-do near the DMZ, Korea. *Journal of Veterinary Science*, *9*(3), 285-293.

Changbunjong, T., Weluwanarak, T., Chamsai, T., Sedwisai, P., Ngamloephochit, S., Suwanpakdee, S. and Ratanakorn, P. (2010). Occurrence of ectoparasites on rodents in Sukhothai Province, northern Thailand. *Southeast Asian Journal of Tropical Medicine and Public Health*, *41*(6), 1324.

Chidodo, S., Kilawe, C. J., Mnyone, L. L., Broecke, B. V. and Mulungu, L. S. (2020). Factors affecting the composition of rodent assemblages in the North Uluguru Mountains, Tanzania. *Journal of Vertebrate Biology,* 69(2), 20047-1.

Clark, N. J., Seddon, J. M., Šlapeta, J. and Wells, K. (2018). Parasite spread at the domestic animal-wildlife interface: anthropogenic habitat use, phylogeny and body mass drive risk of cat and dog flea (Ctenocephalides spp.) infestation in wild mammals. *Parasites & Vectors*, *11*(1), 1-11.

Daly, M., Behrends, P. R., , M. I. and Jacobs, L. F. (1992). Behavioural modulation of predation risk: moonlight avoidance and crepuscular compensation in a nocturnal desert rodent, *Dipodomys merriami*. *Animal Behaviour*, *44*(1), 1-9.

de Bellocq, J. G., Krasnov, B. R., Khokhlova, I. S. and Pinshow, B. (2006). Temporal dynamics of a T-cell mediated immune response in desert rodents. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, *145*(4), 554-559.

Fantozzi, M. C., Sanchez, J. P., Lareschi, M. and Beldomenico, P. M. (2022). Effects of host factors on the dynamics of fleas (Siphonaptera) in Sigmodontinae rodents (Cricetidae) from El Espinal Ecoregion, Argentina. *Acta Tropica*, *225*, 106177.

Fitzgibbon, C. D., Leirs, H. and Verheyen, W. (1995). Distribution, population dynamics felled and mature tracts of Kibale Forest, Uganda. *Biotropica, 19*(3), 260–266.

Flores-Peredo, R. and Vázquez-Domínguez, G. (2016). Influence of vegetation type and season on rodent assemblage in a Mexican temperate forest mosaic. *Therya*, *7*(3), 357-369.

Friggens, M. M. and Beier, P. (2010). Anthropogenic disturbance and the risk of flea-borne disease transmission. *Oecologia*, *164*, 809-820.

Gebrezgiher, G. B., Makundi, R. H., Meheretu, Y., Mulungu, L. S. and Katakweba, A. A. (2022). A Decade-Long Change in the Elevational Distribution of Non-Volant Small Mammals on Mount Meru, Tanzania. *Diversity, 14*(6), 454.

Goldberg, A. R., Conway, C. J. and Biggins, D. E. (2020). Flea sharing among sympatric rodent hosts; *Implications for Potential Plague Effects on a Threatened Sciurid, 11*(2), e 20039.

Guevara, J. N. A. and Ball, B. A. (2018). Urbanization alters small rodent community composition but not abundance. *Peer Journal*, *6*, e4885.

Gutiérrez, R., Morick, D., Cohen, C., Hawlena, H. and Harrus, S. (2014). The effect of ecological and temporal factors on the composition of Bartonella infection in rodents and their fleas. *The ISME Journal*, *8*(8), 1598-1608.

Haule, M., Lyamuya, E. E., Hang'ombe, B. M. and Matee, M. I. (2013). Investigation of fleas as vectors in the transmission of plague during a quiescent period in North-Eastern, Tanzania.

Herrero confreces, S., Flechoso, M.F., Rodriguez pastor, R., (2021). Patterns of flea infestation in rodents and insectivores from intensified agro-ecosystem, northwest spain. *Parasites & Vectors, 14*(1), 1-13

Hieronimo, P., Kihupi, N. I., Kimaro, D. N., Gulinck, H., Msanya, B. M., Leirs, H. and Deckers, J. A. (2014). Contribution of land use to rodent flea load distribution in the plague endemic area of Lushoto District, Tanzania. *Tanzania Journal of Health Research, 16*(3).

Isabirye-Basuta, G. and Kasenene, J. (1987). Small rodent populations in selectively in a Kenyan relict tropical rainforest. *Biodiversity and Conservation, 15,* 1425–1440.

John, I. (2012). *How successful has payment for environmental services improved welfare* (Doctoral dissertation, Dissertation for Award of MA Degree, University of Dar es Salaam, Tanzania).

Katakweba, A. A. S. (2018). The prevalence of haemoparasites in rodents and shrews trapped from domestic and peridomestic houses in Morogoro Municipality, Tanzania. A Hidden Public Health Threat. *Tanzania Veterinary Journal*, *36*, 75-82.

Kay, E. H. and Hoekstra, H. E. (2008). Rodents. *Current Biology*, *18*(10), R406-R410.

Keränen, S. V., Kettunen, P., Åberg, T., Thesleff, I. and Jernvall, J. (1999). Gene expression patterns associated with suppression of odontogenesis in mouse and vole diastema regions. *Development Genes and Evolution*, *209*, 495-506.

Khokhlova, I.S., Dlugosz, E.M. and Krasnov, B.R. (2015). Fitness responses to coinfestation in fleas exploiting rodent hosts. *Parasitology, 142*(12), 1535 – 1542

Kia, E. B., Moghadas, S. H., Hasanpour, H., Vatandoust, H., Zahabioun, F., Akhavan, A. A. and Telmadarehei, Z. (2009). Ectoparasites of rodents captured in Bandar Abbas, southern Iran.

Kimaro, D. N., Msanya, B. M., Meliyo, J., Hieronimo, P., Mwango, S., Kihupi, N. I. and Deckers, J. A. (2014). Anthropogenic soils and land use patterns in relation to small mammal and flea abundance in plague endemic area of Western Usambara Mountains, Tanzania. *Tanzania Journal of Health Research, 16*(3).

Kotti, B. K. (2015). Fleas (Siphonaptera) of mammals and birds in the Great Caucasus. *Entomological Review*, *95*, 728-738.

Krasnov, B. R. (2008). *Functional and Evolutionary Ecology of Fleas: a model for ecological parasitology*. Cambridge University Press.

Krasnov, B. R., Burdelova, N. V., Khokhlova, I. S., Shenbrot, G. I. and Degen, A. (2005). Larval interspecific competition in two flea species parasitic on the same rodent host. *Ecological Entomology, 30*(2), 146-155.

Krasnov, B. R., Khokhlova, I. S., Fielden, L. J. and Burdelova, N. V. (2001). Effect of air temperature and humidity on the survival of pre-imaginal stages of two flea species (Siphonaptera: Pulicidae). *Journal of Medical Entomology*, *38*(5), 629-637.

Krasnov, B. R., Poulin, R., Shenbrot, G. I., Mouillot, D. and Khokhlova, I. S. (2004). Ectoparasitic “jacks-of-all-trades”: relationship between abundance and host specificity in fleas (Siphonaptera) parasitic on small mammals. *The American Naturalist*, *164*(4), 506-516.

Krasnov, B. R., Poulin, R., Shenbrot, G. I., Mouillot, D. and Khokhlova, I. S. (2005). Host specificity and geographic range in haematophagous ectoparasites. *Oikos*, *108*(3), 449-456.

Krasnov, B., Khokhlova, I. and Shenbrot, G. (2002). The effect of host density on ectoparasite distribution: an example of a rodent parasitized by fleas. *Ecology*, *83*(1), 164-175.

Krasnov, B., Shenbrot, G., Khokhlova, I., Medvedev, S. and Vatschenok, V. (1998). Habitat dependence of a parasite-host relationship: flea (Siphonaptera) assemblages in two gerbil species of the Negev Desert. *Journal of Medical Entomology*, *35*(3), 303 -313.

Lang, J. D. (2014). Factors affecting the seasonal abundance of ground squirrel and wood rat fleas (Siphonaptera) in San Diego County, California. *Journal of Medical Entomology*, *33*(5), 790-804.

Magnusson, W., Rosa, C., Layme, V. M. G., Ghizoni Jr, I. R. and Lima, A. P. (2021). Local effects of global climate on a small rodent Necromys lasiurus. *Journal of Mammalogy*, *102*(1), 188-194.

Makundi, R. H., Massawe, A. W., Borremans, B., Laudisoit, A. and Katakweba, A. (2015). We are connected: flea–host association networks in the plague outbreak focus in the Rift Valley, northern Tanzania. *Wildlife Research,* 42(2),196-206.

Makundi, R. H., Massawe, A. W., Mulungu, L. S., Katakweba, A., Mbise, T. J. and Mgode, G. (2008). Potential mammalian reservoirs in a bubonic plague outbreak focus in Mbulu District, northern Tanzania, in 2007.

Maleki-Ravasan, N., Solhjouy-Fard, S., Beaucournu, J. C., Laudisoit, A. and Mostafavi, E. (2017). The fleas (Siphonaptera) in Iran: diversity, host range, and medical importance. *PLoS Neglected Tropical Diseases*, *11*(1), e0005260.

Mawanda, P., Rwego, I., Kisakye, J. J. and Sheil, D. (2020). Rodents as potential hosts and reservoirs of parasites along the edge of a Central African forest: Bwindi impenetrable national park, South Western Uganda. *African Health Sciences*, *20*(3), 1168-1178.

McCauley, D. J., Keesing, F., Young, T. and Dittmar, K. (2008). Effects of the removal of large herbivores on fleas of small mammals. *Journal of Vector Ecology*, *33*(2), 263-268.

Medvedev, S. G. (2002). Specific features of the distribution and host associations of fleas (Siphonaptera). *Entomological Review*, *82*(9), 1165-1177.

Meliyo, J. L., Kimaro, D. N., Msanya, B. M., Mulungu, L. S., Hieronimo, P., Kihupi, N. I. and Deckers, J. A. (2014). Predicting small mammal and flea abundance using landform and soil properties in a plague endemic area in Lushoto District, Tanzania. *Tanzania journal of Health Research,* 16(3).

Metzger, M. E. and Rust, M. K. (1999, July). Abiotic factors affecting the development of fleas (Siphonaptera) of California ground squirrels (Rodentia: Sciuridae) in southern California, USA. In: *Proceedings of the 3rd International Conference on Urban Pests* (pp. 235-239).

Miarinjara, A., Bland, D. M., and Hinnebusch, J. M. (2021). Poor vector competency of the human flea, Pulex irritans to transmit Yersinia Pestis. *Parasites and Vectors, 14*(1), 1 – 15

Milstead, W. B., Meserve, P. L., Campanella, A., Previtali, M. A., Kelt, D. A. and Gutiérrez, J. R. (2007). Spatial ecology of small mammals in north-central Chile: role of precipitation and refuges. *Journal of Mammalogy*, *88*(6), 1532-1538.

Mortelliti, A. and Boitani, L. (2006). Patterns of rodent species diversity and abundance

Mostafavi, E., Shahraki, A. H., Japoni-Nejad, A., Esmaeili, S., Darvish, J., Sedaghat, M. M. and Carniel, E. (2017). A field study of plague and tularemia in rodents, Western Iran. *Vector-Borne and Zoonotic Diseases*, *17*(4), 247-253.

Mukherjee, S., Goyal, S. P., Johnsingh, A. J. T. and Pitman, M. L. (2004). The importance of rodents in the diet of jungle cat (Felis chaus), caracal (Caracal caracal) and golden jackal (Canis aureus) in Sariska Tiger Reserve, Rajasthan, India. *Journal of Zoology*, *262*(4), 405-411.

Mulungu, L. S., Makundi, R. H., Massawe, A. W., Machang'u, R. S. and Mbije, N. E. (2008). Diversity and distribution of rodent and shrew species associated with variations in altitude on Mount Kilimanjaro, Tanzania. *Mammalia, 72*, 178-185.

Njunwa, K. J., Mwaiko, G. L., Kilonzo, B. S. and Mhina, J. I. K. (1989). Seasonal patterns of rodents, fleas and plague status in the Western Usambara Mountains, Tanzania. *Medical and Veterinary Entomology, 3*(1), 17-22.

Ofori, B. Y., Attuquayefio, D. K., Owusu, E. H., Musah, Y. and Ntiamoa-Baidu, Y. (2016). Spatio-temporal variation in small mammal species richness, relative abundance and body mass reveal changes in a coastal wetland ecosystem in Ghana. *Environmental Monitoring and Assessment*, *188*, 1-10.

Pakdeenarong, N., Siribat, P., Chaisiri, K., Douangboupha, B., Ribas, A., Chaval, Y. and Morand, S. (2014). Helminth communities in murid rodents from southern and northern localities in Lao PDR: the role of habitat and season. *Journal of Helminthology*, *88*(3), 302-309.

Paramasvaran, S., Sani, R. A., Hassan, L., Krishnasamy, M., Jeffery, J., Oothuman, P. and Santhana, R. L. (2009). Ectoparasite fauna of rodents and shrews from four habitats in Kuala Lumpur and the states of Selangor and Negeri Sembilan, Malaysia and its public health significance. *Trop Biomed*, *26*(3), 303-311.

Previtali, M. A., Lima, M., Meserve, P. L., Kelt, D. A. and Gutiérrez, J. R. (2009). Population dynamics of two sympatric rodents in a variable environment: rainfall, resource availability, and predation. *Ecology*, *90*(7), 1996-2006.

Psaroulaki, A., Antoniou, M., Papaeustathiou, A., Toumazos, P., Loukaides, F. and Tselentis, Y. (2006). First detection of Rickettsia felis in Ctenocephalides felis fleas parasitizing rats in Cyprus. *The American Journal of Tropical Medicine and Hygiene*, *74*(1), 120-122.

Richard, U., Byamungu, R. M., Magige, F. and Makonda, F. B. (2022). Microhabitat, altitude and seasonal influence on the abundance of non-volant small mammals in Mount Rungwe forest nature reserve. *Global Ecology and Conservation*, *35*, e02069.

Sabuni, C. A., Sluydts, V., Mulungu, L. S., Maganga, S. L. S., Makundi, R. H. and Leirs, H. (2015). Distribution and ecology of lesser pouched rat, *Beamys hindei*, in Tanzanian coastal forests. *Integrative Zoology* 10: 531–542.

Sanchez, J. and Lareschi, M. (2019). Diversity, distribution and parasitism rates of fleas (Insecta: Siphonaptera) on sigmodontine rodents (Cricetidae) from Argentinian Patagonia. *Bulletin of Entomological Research, 109*(1), 72-83.

Shenbrot, G., Krasnov, B. and Lu, L. (2007). Geographical range size and host specificity in ectoparasites: a case study with Amphipsylla fleas and rodent hosts. *Journal of Biogeography*, *34*(10), 1679-1690.

Ssuuna, J., Makundi, R. H., Isabirye, M., Sabuni, C. A., Babyesiza, W. S. and Mulungu, L. S. (2020). Rodent species composition, relative abundance, and habitat association in the Mabira Central Forest Reserve, Uganda. *Journal of Vertebrate Biology*, *69*(2), 20021-1.

Stanley, W. T and Goodman, S. M. (2011). Small mammal inventories in the East and West Usambara Mountains, Tanzania. 4. Rodentia. *Fieldiana Life and Earth Sciences, 4,* 53–73.

Stanley, W. T. and Hutterer, R. (2007). Differences in abundance and species richness between shrews and rodents along an elevational gradient in the Udzungwa Mountains, Tanzania. *Acta Theriologica, 52*, 261-275.

Thomas, S. M., Soka, G. E. and Mulungu, L. S. (2022). Influence of vegetation structure, seasonality, and soil properties on rodent diversity and community assemblages in west Mount Kilimanjaro, Tanzania. *Ecology and Evolution*, *12*(9), e9211.

Vallée, J., Thaojaikong, T., Moore, C. E., Phetsouvanh, R., Richards, A. L., Souris, M. and Newton, P. N. (2010). Contrasting spatial distribution and risk factors for past infection with scrub typhus and murine typhus in Vientiane City, Lao PDR. *PLoS Neglected Tropical Diseases*, *4*(12), e909.

Van der Mescht, L., Le Roux, P. C. and Matthee, S. (2013). Remnant fragments within an agricultural matrix enhance conditions for a rodent host and its fleas. *Parasitology*, *140*(3), 368-377.

Wallace, K. M., van Jaarsveld, B., Bennett, N. C. and Hart, D. W. (2021). The joint effect of micro-and macro-climate on the thermoregulation and heat dissipation of two African mole-rat (Bathyergidae) sub-species, Cryptomys hottentotus mahali and C. h. pretoriae. *Journal of Thermal Biology*, *99*, 103025.

Wilson, D. E. and Reeder, D. M. (Eds.). (2005). *Mammal species of the world: a taxonomic and geographic reference* (Vol. 1). JHU press.

Xiao, Z., Zhang, Z. and Wang, Y. (2005). The effects of seed abundance on seed predation and dispersal by rodents in Castanopsis fargesii (Fagaceae). *Plant Ecology*, *177*, 249-257.

Yin, J. X., Geater, A., Chongsuvivatwong, V., Dong, X. Q., Du, C. H. and Zhong, Y. H. (2011). Predictors for abundance of host flea and floor flea in households of villages with endemic commensal rodent plague, Yunnan Province, China. *PLoS Neglected Tropical Diseases*, *5*(3), e997.

Young, H. S., McCauley, D. J., Dirzo, R., Nunn, C. L., Campana, M. G., Agwanda, B. and Helgen, K. M. (2017). Interacting effects of land use and climate on rodent-borne pathogens in central Kenya. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *372*(1722), 20160116.

APPENDICES

Appendix 1: Raw data of the number of rodent and shrew species captured, ectoparasites collected from each species and other variables measured.

Month	ID	Host Species	Habitat	Elevation	Host sex	Sex cond	Flea spp	Mite spp	Tick spp
Dec	2	*L. flavopunctatus*	Forest	Low	F	PSN	2 Dinopsylla	Laelaps	0
Dec	4	*L. flavopunctatus*	Forest	Low	M	AN	3 Nosopsylla	0	0
Dec	14	L. flavopunctatus	Forest	Low	F	PSY	2Dinopsylla	0	0
Dec	6	L. flavopunctatus	Fallow	Low	M	AN	7 Dinopsylla	2 Laelaps	0
Dec	9	L. flavopunctatus	Fallow	Low	M	AN	Dinopsylla	0	0
Dec	10	L. flavopunctatus	Fallow	Low	F	PSN	Dinopsylla/2 Ctenopthalmus	0	0
Dec	176	L. kilonzoi	Forest	High	M	SV	4 Dinopsylla	10 laelaps	0
Dec	177	L. kilonzoi	Forest	High	F	CSN	2 Dinopsylla/Ctenopthalmus	6 laelaps	0
Dec	8	M. minutoides	Fallow	Low	F	CSN	0	0	0
Dec	5	M. musculus	Cultivated land	Low	M	AN	Dinopsylla	5 laelaps	0
Dec	7	M. natalensis	Fallow	Low	M	SV	0	2 Laelaps	0
Dec	12	M. natalensis	Fallow	Low	M	SV	2 Dinopsylla	2 Laelaps	0
Dec	11	Dasmys spp	Fallow	Low	F	PLN	Nosopsylla		
Dec	15	C. hirta	Forest	Low	F	CSN	0	Laelaps	0

Dec	16	G. Ibeanus	Forest	Low	M	AN	0	3 laelaps	0
Dec	1	P. delectorum	Forest	Low	M	AN	Dinopsylla	5 laelaps	0
Dec	17	P. delectorum	Forest	Low	F	CSN	0	0	0
Dec	3	P. delectorum	Forest	High	M	AN	2 Dinopsylla	4 laelaps	0
Dec	13	P. delectorum	Forest	High	F	CSN	2 Dinopsylla	Laelaps	0
Dec	18	P. delectorum	Forest	High	M	SV	0	5 laelaps	Haemophysalis
Jan	20	L. flavopunctatus	Forest	Low	M	SV	1 Dinopsylla	0	0
Jan	28	L. flavopunctatus	Forest	Low	F	PSY	0	0	0
Jan	31	L. flavopunctatus	Forest	Low	F	CSN	Nosopsylla/ Dinopsylla	0	0
Jan	32	L. flavopunctatus	Forest	Low	M	AN	Ctenopthalmus	0	0
Jan	179	M. minutoides	Fallow	Low	M	SV	0	0	0
Jan	181	M. musculus	Cultivated land	Low	M	SV	0	0	0
Jan	22	P. delectorum	Forest	Low	M	SV	2 Dinopsylla	Laelaps	0
Jan	25	P. delectorum	Forest	Low	M	AN	0	0	0
Jan	27	P. delectorum	Forest	Low	.;	SV	0	0	0
Jan	30	P. delectorum	Forest	Low	M	SV	Dinopsylla	0	Haemophysalis
Jan	21	P. delectorum	Forest	High	M	SV	2 Dinopsylla	Laelaps	0
Jan	23	P. delectorum	Forest	High	F	CSN	2 Dinopsylla	0	0
Jan	24	P. delectorum	Forest	High	F	CSN	Dinopsylla	0	0

Jan	26	P. delectorum	Forest	High	M	SV	0	5 laelaps	0
Jan	19	B. hindei	Forest	Low	M	AN	Dinopsylla	0	0
Jan	29	G. murinus	Forest	Low	F	PSN	0	0	0
Feb	33	L. flavopunctatus	Forest	Low	M	AN	0	0	0
Feb	34	L. flavopunctatus	Forest	Low	M	SV	0	0	0
Feb	35	L. flavopunctatus	Forest	Low	F	CSN	0	Laelaps	0
Feb	42	L. flavopunctatus	Forest	High	M	CSN	0	5 laelaps	0
Feb	41	L. flavopunctatus	Fallow	Low	F	CSN	2 Ctenopthalmus	0	0
Feb	38	L. flavopunctatus	Cultivated land	Low	F	PSY	0	Laelaps	0
Feb	180	M. minutoides	Cultivated land	High	F	PSY	2 Dinopsylla	3 laelaps	0
Feb	182	M. minutoides	Cultivated land	High	F	PSN	2 Dinopsylla	2 Laelaps	0
Feb	185	M. natalensis	Fallow	Low	F	CSN	2 Dinopsylla	Laelaps	0
Feb	36	M. natalensis	Cultivated land	Low	F	PSN	2 Dinopsylla	Laelaps	0
Feb	191	M. natalensis	Cultivated land	Low	M	SV	0	Laelaps	0
Feb	188	M. natalensis	Cultivated land	Low	F	PSY	3 Dinopsylla	Laelaps	0
Feb	43	C. olivieri	Forest	High	F	PSY	0	0	0
Feb	183	C. olivieri	Forest	High	M	SV	2 Dinopsylla	0	Haemophysalis
Feb	40	C. olivieri	Forest	Low	M	PSY	0	6 laelaps	0
Feb	201	C. hirta	Forest	High	F	CSN	2 Dinopsylla	2 laelaps	0

Feb	204	C. hirta	Forest	Low	F	PSY	Dinopsylla	2 laelaps	0
Feb	175	C. hirta	Forest	Low	M	AN	Dinopsylla	Laelaps	0
Feb	39	P. delectorum	Forest	Low	F	PSN	2 Dinopsylla	0	0
Mar	61	L. flavopunctatus	Forest	Low	M	SV	0	0	0
Mar	70	L. flavopunctatus	Forest	Low	F	PSY	0	0	0
Mar	56	L. flavopunctatus	Forest	High	F	PSY	Ctenopthalmus	Laelaps	0
Mar	47	L. flavopunctatus	Forest	High	F	CSN	2 Ctenopthalmus	2 Laelaps	0
Mar	48	L. flavopunctatus	Forest	High	F	CSN	2 Nosopsylla	2 Laelaps	0
Mar	52	L. flavopunctatus	Fallow	High	M	SV	Dinopsylla/2 Nosopsylla	2 Laelaps	0
Mar	55	L. flavopunctatus	Cultivated land	High	F	PSN	0	2 laelaps	0
Mar	68	L. kilonzoi	Forest	Low	M	SV	0	2 laelaps	0
Mar	69	L. kilonzoi	Forest	Low	F	PSY	0	2 laelaps	0
Mar	71	L. kilonzoi	Forest	Low	M	SV	Dinopsylla	2 laelaps	0
Mar	207	M. minutoides	Cultivated land	Low	M	SV	0	0	0
Mar	178	M. minutoides	Cultivated land	Low	F	CSN	0	0	0
Mar	190	M. musculus	Cultivated land	High	F	PSN	0		
Mar	49	M. natalensis	Fallow	High	F	PSY	3 Dinopsylla	2 Laelaps	0
Mar	51	M. natalensis	Fallow	High	M	SV	2 Dinopsylla	Laelaps	0
Mar	206	M. natalensis	Fallow	Low	M	AN	Dinopsylla	0	0

Mar	186	M. natalensis	Cultivated land	Low	M	SV	Dinopsylla	Laelaps	0
Mar	72	C. olivieri	Forest	Low	F	CSN	0	2 Laelaps	0
Mar	50	C. olivieri	Fallow	High	F	PSY	0	2 laelaps	0
Mar	184	C. hirta	Forest	High	F	CSN	0	Laelaps	0
Mar	59	P. delectorum	Forest	Low	M	SV	0	0	0
Mar	62	P. delectorum	Forest	Low	M	SV	Dinopsylla	0	0
Mar	63	P. delectorum	Forest	Low	M	SV	0	0	0
Mar	44	P. delectorum	Forest	High	F	CSN	0	0	0
Mar	45	P. delectorum	Forest	High	F	PSY	3 Dinopsylla	4 laelaps	Haemophysalis
Mar	46	P. delectorum	Forest	High	M	SV	0	0	0
Mar	57	P. delectorum	Forest	High	M	AN	0	laelaps	0
Mar	58	P. delectorum	Forest	High	F	SV	0	0	0
Mar	64	P. delectorum	Forest	High	M	CSN	0	5 laelaps	0
Mar	65	P. delectorum	Forest	High	M	SV	3 Dinopsylla	0	0
Mar	66	P. delectorum	Forest	High	M	SV	0	laelaps	2 haemophysalis
Mar	67	P. delectorum	Forest	High	F	CSN	0	0	0
Mar	53	P. delectorum	Forest	High	M	SV	4 Dinopsylla	laelaps	0
Mar	54	P. delectorum	Forest	High	F	PSN	6 Dinopsylla	5 laelaps	0
Mar	60	G. murinus	Forest	Low	M	AN	0	0	0

Apr	174	L. flavopunctatus	Forest	Low	M	AN	Ctenopthalmus	0	0
Apr	81	L. flavopunctatus	Forest	Low	M	SV	2Dinopsylla	0	0
Apr	83	L. flavopunctatus	Forest	Low	F	PSY	Dinopsylla	0	0
Apr	87	L. flavopunctatus	Forest	Low	F	PSY	2 Ctenopthalmus	0	0
Apr	110	L. flavopunctatus	Forest	Low	M	SV	2 Dinopsylla	2 Laelaps	0
Apr	111	L. flavopunctatus	Forest	Low	M	SV	Dinopsylla	0	0
Apr	115	L. flavopunctatus	Forest	Low	F	CSN	Dinopsylla	0	0
Apr	116	L. flavopunctatus	Forest	Low	M	AN	2 Dinopsylla	0	0
Apr	96	L. flavopunctatus	Forest	High	F	CSN	5 Dinopsylla/Ctenopthalmus	Laelaps	0
Apr	100	L. flavopunctatus	Forest	High	F	CSN	2 Ctenopthalmus	Laelaps	0
Apr	102	L. flavopunctatus	Forest	High	F	PSN	0	Laelaps	0
Apr	121	L. flavopunctatus	Forest	High	M	SV	2 Ctenopthalmus	Laelaps	0
Apr	122	L. flavopunctatus	Forest	High	F	PSN	0	5 laelaps	0
Apr	119	L. flavopunctatus	Cultivated land	High	F	PSN	Dinopsylla	10 laelaps	0
Apr	103	M. natalensis	Cultivated land	High	F	PSY	2 Dinopsylla	0	0
Apr	104	M. natalensis	Cultivated land	High	F	PSY	3 Ctenopthalmus	laelaps	0
Apr	117	M. natalensis	Cultivated land	High	F	CSN	0	laelaps	0
Apr	118	M. natalensis	Cultivated land	High	F	PSY	2 Dinopsylla	laelaps	0
Apr	106	M. natalensis	Cultivated land	High	F	PSN	0	laelaps	0

Apr	114	G. Ibeanus	Forest	Low	F	PSY	0	0	0
Apr	76	G. Ibeanus	Forest	High	M	SV	Dinopsylla	laelaps	0
Apr	77	G. Ibeanus	Forest	High	F	CSN	0	0	0
Apr	78	G. Ibeanus	Forest	High	M	AN	0	laelaps	0
Apr	79	G. Ibeanus	Forest	High	M	SV	Dinopsylla	0	0
Apr	95	G. Ibeanus	Forest	High	M	SV	0	laelaps	0
Apr	80	P. delectorum	Forest	Low	F	PSN	0	6 laelaps	0
Apr	82	P. delectorum	Forest	Low	M	SV	0	0	0
Apr	84	P. delectorum	Forest	Low	M	SV	0	0	0
Apr	85	P. delectorum	Forest	Low	F	CSN	Dinopsylla	0	Haemophysalis
Apr	88	P. delectorum	Forest	Low	F	PSN	0	0	0
Apr	89	P. delectorum	Forest	Low	F	PSN	0	3 laelaps	0
Apr	90	P. delectorum	Forest	Low	M	SV	0	0	0
Apr	91	P. delectorum	Forest	Low	F	PSN	0	0	0
Apr	93	P. delectorum	Forest	Low	M	SV	0	0	0
Apr	94	P. delectorum	Forest	Low	M	SV	Dinopsylla	4 laelaps	0
Apr	107	P. delectorum	Forest	Low	F	PSN	0	0	0
Apr	108	P. delectorum	Forest	Low	M	SV	Dinopsylla	0	Haemophysalis
Apr	109	P. delectorum	Forest	Low	M	SV	0	0	0
Apr	112	P. delectorum	Forest	Low	M	SV	0	2 Laelaps	0

Apr	120	P. delectorum	Forest	Low	M	SV	0	0	0
Apr	123	P. delectorum	Forest	Low	F	PSN	Dinopsylla	0	0
Apr	124	P. delectorum	Forest	Low	M	SV	0	2 laelaps	0
Apr	125	P. delectorum	Forest	Low	F	CSN	0	0	0
Apr	73	P. delectorum	Forest	High	M	SV	0	4 laelaps	0
Apr	74	P. delectorum	Forest	High	F	CSN	0	0	0
Apr	75	P. delectorum	Forest	High	F	CSN	0	5 laelaps	0
Apr	97	P. delectorum	Forest	High	M	SV	0	laelaps	0
Apr	98	P. delectorum	Forest	High	M	SV	0	4 laelaps	Haemophysalis
Apr	99	P. delectorum	Forest	High	M	SV	Nosopsylla/4 Dinopsylla	0	0
Apr	101	P. delectorum	Forest	High	M	SV	2 Ctenopthalmus	5 laelaps	0
Apr	105	P. delectorum	Forest	High	F	CSN	0	4 laelaps	0
Apr	86	B. hindei	Forest	Low	F	CSN	Nosopsylla	0	0
Apr	92	B. hindei	Forest	Low	F	PSN	0	0	0
Apr	113	R. rattus	Forest	Low	F	PSN	3 Dinopsylla	2 Laelaps	0
May	130	L. flavopunctatus	Forest	Low	F	PSN	Ctenopthalmus	0	0
May	127	L. flavopunctatus	Forest	Low	M	SV	0	0	0
May	128	L. flavopunctatus	Forest	Low	F	PSN	2 Dinopsylla	0	0
May	172	L. flavopunctatus	Forest	Low	F	PSN	0	0	0
May	197	L. flavopunctatus	Forest	Low	M	SV	0	0	0

May	152	L. flavopunctatus	Forest	High	F	PSY	0	3 laelaps	0
May	167	L. flavopunctatus	Forest	High	F	PSN	0	laelaps	0
May	169	L. flavopunctatus	Forest	High	M	SV	0	8 laelaps	0
May	168	M. minutoides	Forest	High	F	PSY	2 Dinopsylla	0	0
May	166	M. natalensis	Forest	High	M	AN	Dinopsylla	3 laelaps	0
May	205	M. natalensis	Cultivated land	Low	F	CSN	0	0	0
May	37	M. natalensis	Cultivated land	Low	M	SV	3 Dinopsylla	0	0
May	187	M. natalensis	Cultivated land	Low	M	SV	Dinopsylla	0	0
May	192	M. natalensis	Cultivated land	High	M	AN	5 Dinopsylla	laelaps	0
May	141	C. olivieri	Forest	High	M	AN	0	0	0
May	145	C. olivieri	Forest	High	F	CSN	0	0	0
May	199	C. olivieri	Forest	High	F	PSY	2 Dinopsylla	0	0
May	202	C. hirta	Forest	Low	F	CSN	2 Dinopsylla	2 laelaps	0
May	189	C. hirta	Forest	Low	F	CSN	0	laelaps	0
May	126	G. Ibeanus	Forest	Low	M	SV	0	0	0
May	132	G. Ibeanus	Forest	Low	M	SV	Dinopsylla	0	0
May	137	G. Ibeanus	Forest	Low	M	SV	0	0	0
May	157	G. Ibeanus	Forest	Low	F	PSN	Ctenopthalmus	0	0
May	143	G. Ibeanus	Forest	High	M	SV	0	0	0

May	146	G. Ibeanus	Forest	High	M	SV	0	laelaps	0
May	148	G. Ibeanus	Forest	High	F	PSN	3 Nosopsylla	laelaps	0
May	149	G. Ibeanus	Forest	High	F	CSN	2 Dinopsylla	laelaps	0
May	161	G. Ibeanus	Forest	High	F	CSN	0	laelaps	0
May	164	G. Ibeanus	Forest	High	M	SV	2 Dinopsylla	laelaps	0
May	173	G. Ibeanus	Cultivated	High	M	SV	0	0	0
May	129	P. delectorum	Forest	Low	M	AN	Dinopsylla	3 laelaps	0
May	131	P. delectorum	Forest	Low	M	SV	0	0	0
May	133	P. delectorum	Forest	Low	F	CSN	Ctenopthalmus	2 laelaps	0
May	134	P. delectorum	Forest	Low	F	PSN	0	0	0
May	135	P. delectorum	Forest	Low	F	PSN	Nosopsylla	0	0
May	136	P. delectorum	Forest	Low	F	CSN	2 Dinopsylla	0	0
May	153	P. delectorum	Forest	Low	F	PLN	0	0	0
May	154	P. delectorum	Forest	Low	M	SV	3 Dinopsylla	0	0
May	155	P. delectorum	Forest	Low	M	SV	0	0	0
May	156	P. delectorum	Forest	Low	M	SV	0	0	0
May	158	P. delectorum	Forest	Low	M	SV	0	0	0
May	198	P. delectorum	Forest	Low	F	PSN	0	0	0
May	203	P. delectorum	Forest	Low	M	AN	0	4 laelaps	0
May	200	P. delectorum	Forest	Low	F	CSN	0	0	0

May	196	P. delectorum	Forest	Low	F	PLN	0	0	0
May	138	P. delectorum	Forest	High	M	SV	0	5 laelaps	0
May	139	P. delectorum	Forest	High	F	PSN	0	laelaps	0
May	140	P. delectorum	Forest	High	M	AN	0	laelaps	0
May	142	P. delectorum	Forest	High	M	SV	0	4 laelaps	0
May	144	P. delectorum	Forest	High	M	SV	0	laelaps	0
May	147	P. delectorum	Forest	High	M	SV	Dinopsylla	5 laelaps	0
May	150	P. delectorum	Forest	High	M	SV	2 Ctenopthalmus	5 laelaps	0
May	151	P. delectorum	Forest	High	M	SV	Dinopsylla	0	0
May	159	P. delectorum	Forest	High	F	PSN	0	laelaps	0
May	160	P. delectorum	Forest	High	M	SV	2 Nosopsylla	4 laelaps	0
May	162	P. delectorum	Forest	High	F	CSN	Dinopsylla	0	0
May	163	P. delectorum	Forest	High	M	AN	2 Dinopsylla	Laelaps	0
May	165	P. delectorum	Forest	High	F	PLN	2 Dinopsylla	Laelaps	0
May	170	P. delectorum	Forest	High	F	CSN	0	4 laelaps	0
May	194	P. delectorum	Cultivated land	Low	M	SV	0	4 laelaps	0
May	195	G. murinus	Forest	Low	F	PLN	0	0	0
May	193	R. rattus	Forest	Low	M	SV	3 Dinopsylla	2 Laelaps	0
May	171	R. rattus	Cultivated	High	F	PSN	3Dinopsylla	7 laelaps	0

Appendix 2: Climatic data

MONTH	RAINFALL	TEMPERATURE	HUMIDITY
December	43.8	26.9	76
January	248.9	27.1	74
February	234.2	26	83
March	89.3	26.7	80
April	103.4	25.9	84
May	11.1	24.1	81

Appendix 3: Monthly variation of rodent and shrew species diversity

	December	January	February	March	April	May
Individuals	**20**	**16**	**19**	**35**	**53**	**63**
Shannon index	1.81	1.39	1.67	1.78	1.37	1.62

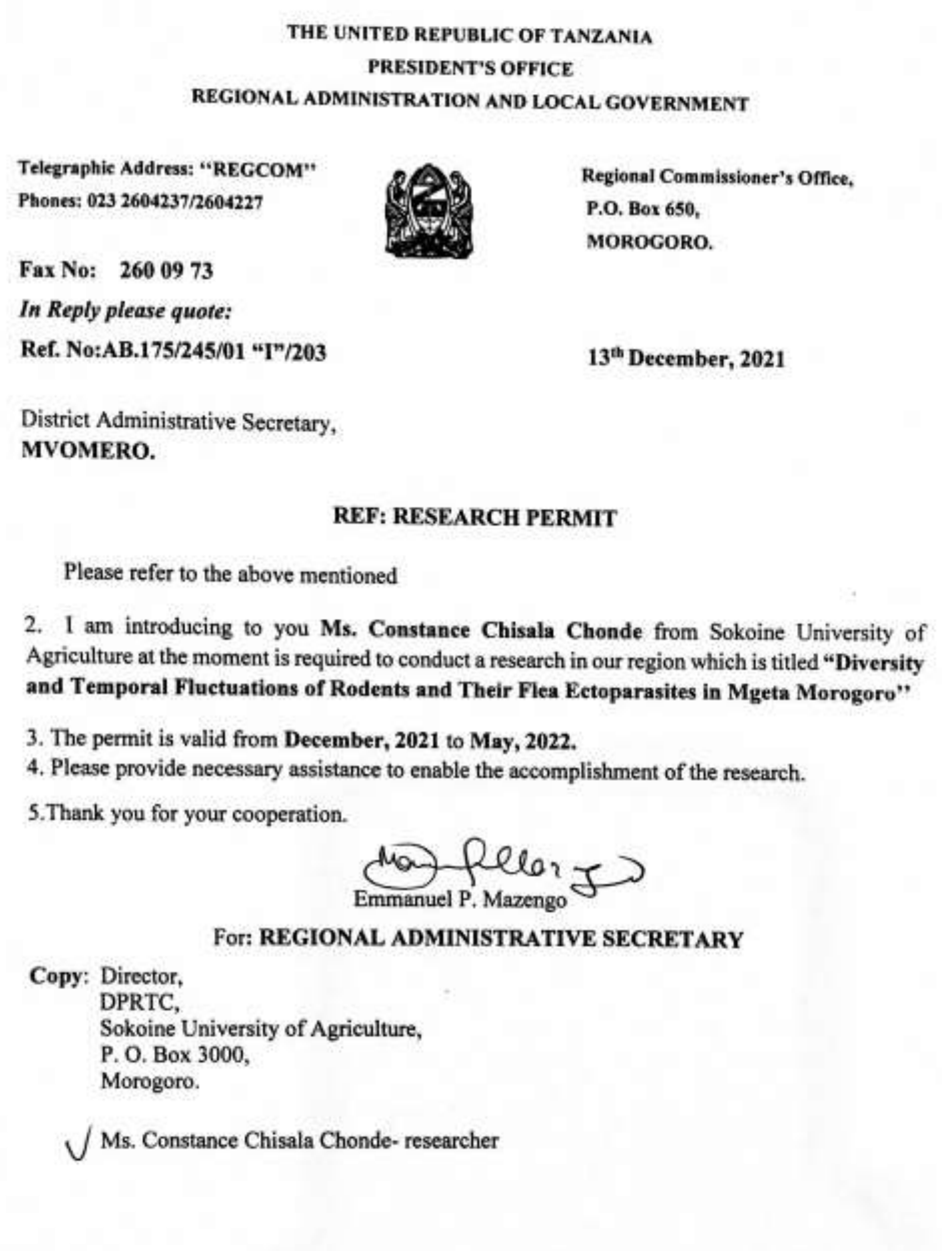
Appendix 4: Ectoparasite groups infesting rodents and shrews

Group	Order	Family/subfamily	Species
Flea	Siphonaptera	Dinopsyllinae	*D. lypusus*
	Siphonaptera	Hystrichopsyllidae	*C. calceatus*
	Siphonaptera	Ceratophyllidae	*N. fasciatus*
Mite	Mesostigmata	Laelapidae	*Laelaps* spp
Tick	Ixodida	Ixodidae	*Haemaphysalis* spp

Appendix 5: Monthly variation in flea diversity on rodents

Month	Dec	Jan	Feb	March	April	May
Shannon index	0.613	0.536	0.315	0.613	0.776	0.654

Appendix 6: Research permits



THE UNITED REPUBLIC OF TANZANIA
PRESIDENT'S OFFICE
REGIONAL ADMINISTRATION AND LOCAL GOVERNMENT

Telegraphic Address: "REGCOM"
Phones: 023 2604237/2604227

Fax No: 260 09 73

Regional Commissioner's Office,
P.O. Box 650,
MOROGORO.

In Reply please quote:
Ref. No:AB.175/245/01 "I"/203

13th December, 2021

District Administrative Secretary,
MVOMERO.

REF: RESEARCH PERMIT

Please refer to the above mentioned

2. I am introducing to you **Ms. Constance Chisala Chonde** from Sokoine University of Agriculture at the moment is required to conduct a research in our region which is titled **"Diversity and Temporal Fluctuations of Rodents and Their Flea Ectoparasites in Mgeta Morogoro"**

3. The permit is valid from **December, 2021** to **May, 2022.**
4. Please provide necessary assistance to enable the accomplishment of the research.

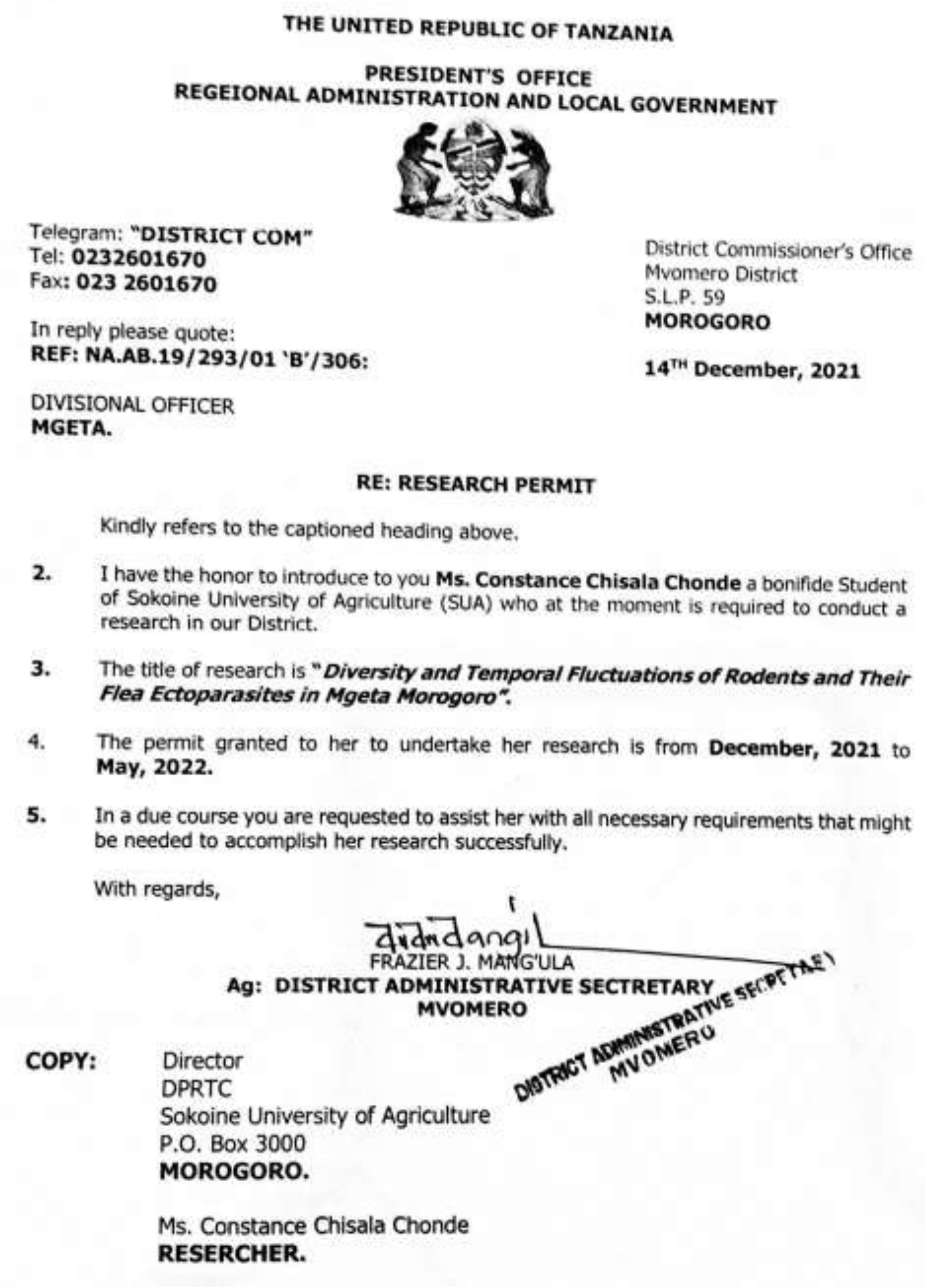
5.Thank you for your cooperation.

Emmanuel P. Mazengo

For: **REGIONAL ADMINISTRATIVE SECRETARY**

Copy: Director,
DPRTC,
Sokoine University of Agriculture,
P. O. Box 3000,
Morogoro.

✓ Ms. Constance Chisala Chonde- researcher



THE UNITED REPUBLIC OF TANZANIA

PRESIDENT'S OFFICE
REGEIONAL ADMINISTRATION AND LOCAL GOVERNMENT

Telegram: **"DISTRICT COM"**
Tel: **0232601670**
Fax: **023 2601670**

District Commissioner's Office
Mvomero District
S.L.P. 59
MOROGORO

In reply please quote:
REF: NA.AB.19/293/01 'B'/306:

14TH December, 2021

DIVISIONAL OFFICER
MGETA.

RE: RESEARCH PERMIT

Kindly refers to the captioned heading above.

2. I have the honor to introduce to you **Ms. Constance Chisala Chonde** a bonifide Student of Sokoine University of Agriculture (SUA) who at the moment is required to conduct a research in our District.

3. The title of research is ***"Diversity and Temporal Fluctuations of Rodents and Their Flea Ectoparasites in Mgeta Morogoro".***

4. The permit granted to her to undertake her research is from **December, 2021** to **May, 2022.**

5. In a due course you are requested to assist her with all necessary requirements that might be needed to accomplish her research successfully.

With regards,

FRAZIER J. MANG'ULA
Ag: DISTRICT ADMINISTRATIVE SECRETARY
MVOMERO

DISTRICT ADMINISTRATIVE SECRETARY
MVOMERO

COPY: Director
DPRTC
Sokoine University of Agriculture
P.O. Box 3000
MOROGORO.

Ms. Constance Chisala Chonde
RESERCHER.

Jamhuri ya Muungano wa Tanzania
WIZARA YA MALIASILI NA UTALII
WAKALA WA HUDUMA ZA MISITU TANZANIA

Anwani: **"HIFADHI ULUGURU"**
Simu Na. : (+255) (023) 2600870
Nukushi : (+255) (023) 2603275
Barua pepe: uluguruna tureforestreserve@gmail.com
Tovuti: http/www.easternarc.or.tz

Ofisi ya hifadhi asilia ya Uluguru,
S.L.P. 1020,
Morogoro.

28/12/2021

Unapojibu tafadhali taja
Kumbukumbu No.TFS/UNR/

Mkuu wa Safu ya Bunduki,
Hifadhi Mazingira Asilia Uluguru,
S.L.P 1020,
Morogoro.

***Yah:* RUHUSA YA KUTEMBELEA HIFADHI YA MAZINGIRA ASILI YA ULUGURU**

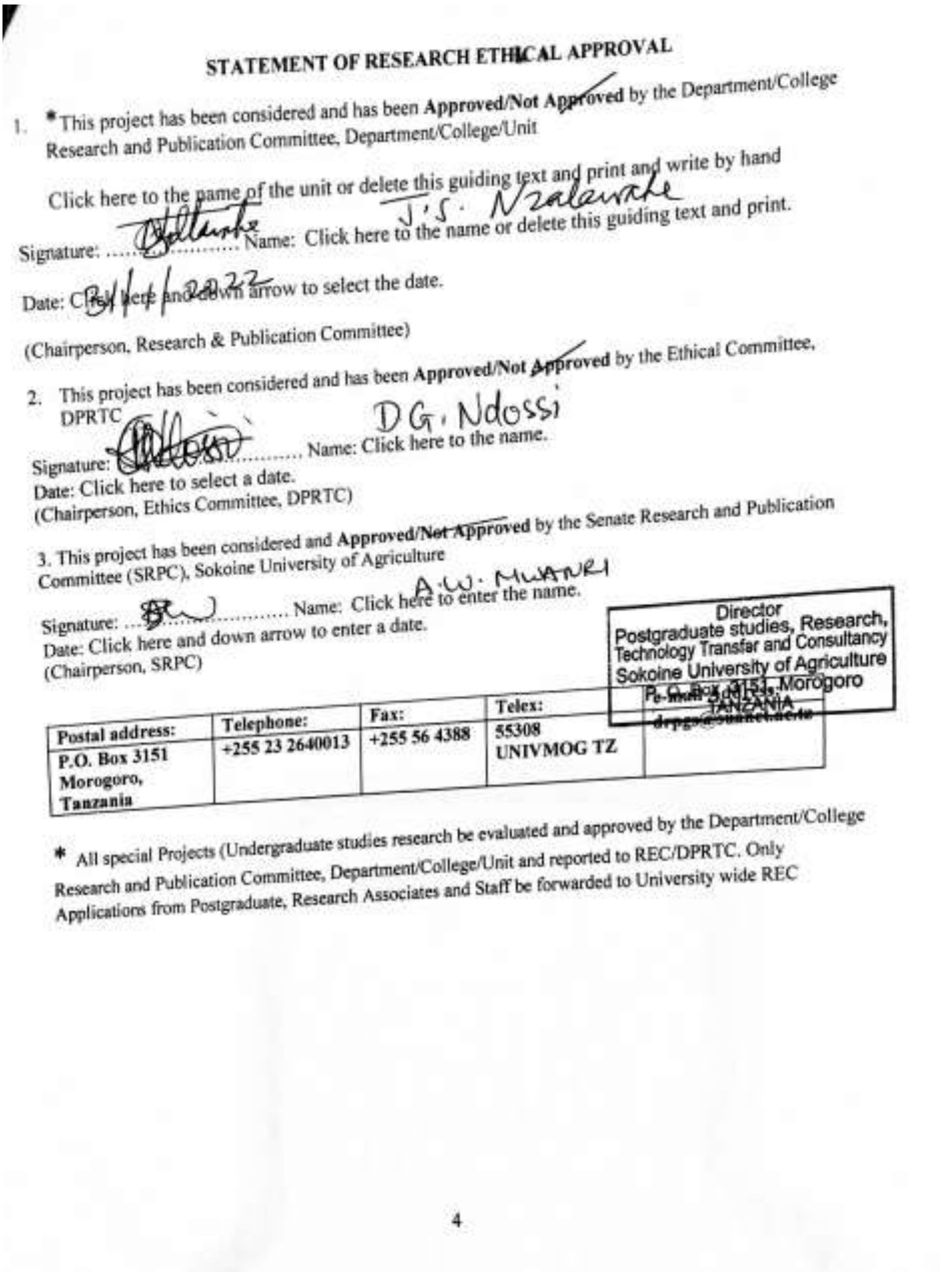
Ndugu ***Costance Chisala Chonde*** wa Chuo cha Kilimo Sokoine (SUA) Morogoro, ameruhusiwa kuingia/kutembelea Hifadhi ya Mazingira asili ya Uluguru eneo la ***Mgeta Safu ya Bunduki*** kwa ajili ya kufanya utafiti wa kimasomo.

Kibali hiki kitatumika kwa muda wa siku 30 kuanzia tarehe 28/12/2021 mpaka Tarehe 28/~~01~~/2022.
12

Ofisi inakuagiza kumpatia ushirikiano ili kufanikisha lengo lake.

MHaule
Mhifadhi, Mazingira Asili Ya Uluguru
MOROGORO

Conservator B. Chile 0653 077 664
MICHAEL H. HAULE 0788-598089
Zarina Haridi: 0713 87 77 87



STATEMENT OF RESEARCH ETHICAL APPROVAL

1. *This project has been considered and has been **Approved/Not Approved** by the Department/College Research and Publication Committee, Department/College/Unit

Click here to the name of the unit or ~~delete this~~ guiding text and print and write by hand

J.S. Nzalawahe

Signature: ……………… Name: Click here to the name or delete this guiding text and print.

Date: 31/1/2022 Click here and down arrow to select the date.

(Chairperson, Research & Publication Committee)

2. This project has been considered and has been **Approved/Not Approved** by the Ethical Committee, DPRTC

D.G. Ndossi

Signature: ……………… Name: Click here to the name.
Date: Click here to select a date.
(Chairperson, Ethics Committee, DPRTC)

3. This project has been considered and **Approved/~~Not~~ Approved** by the Senate Research and Publication Committee (SRPC), Sokoine University of Agriculture

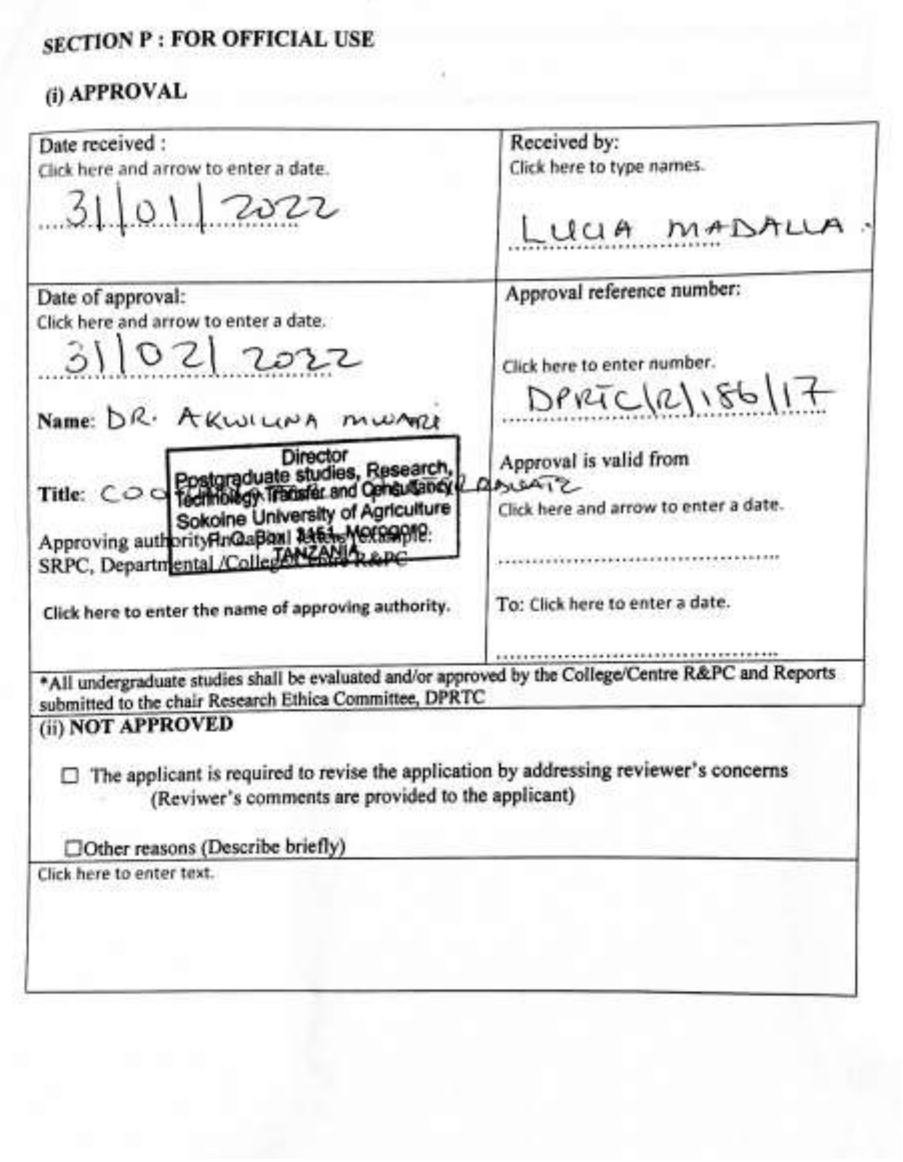
A.W. MWANRI

Signature: ……………… Name: Click here to enter the name.
Date: Click here and down arrow to enter a date.
(Chairperson, SRPC)

Director
Postgraduate studies, Research,
Technology Transfar and Consultancy
Sokoine University of Agriculture
P. O. Box 3151, Morogoro
TANZANIA

Postal address:	**Telephone:**	**Fax:**	**Telex:**	**E-mail address:**
P.O. Box 3151 Morogoro, Tanzania	**+255 23 2640013**	**+255 56 4388**	**55308 UNIVMOG TZ**	**drpgs@suanet.ac.tz**

* All special Projects (Undergraduate studies research be evaluated and approved by the Department/College Research and Publication Committee, Department/College/Unit and reported to REC/DPRTC. Only Applications from Postgraduate, Research Associates and Staff be forwarded to University wide REC



SECTION P : FOR OFFICIAL USE

(i) APPROVAL

Date received : Click here and arrow to enter a date. 31|01|2022	Received by: Click here to type names. LUCIA MADALLA .
Date of approval: Click here and arrow to enter a date. 31|02|2022 **Name**: DR. AKWILINA MWARI **Title**: COO[illegible]ADUATE Director Postgraduate studies, Research, Technology Transfer and Consultancy Sokoine University of Agriculture P. O. Box 3151, Morogoro. TANZANIA Approving authority(In Capital letters) example: SRPC, Departmental /College/Centre R&PC Click here to enter the name of approving authority.	Approval reference number: Click here to enter number. DPRTC|R|186|17 Approval is valid from Click here and arrow to enter a date. …………………………………… To: Click here to enter a date. ……………………………………

*All undergraduate studies shall be evaluated and/or approved by the College/Centre R&PC and Reports submitted to the chair Research Ethica Committee, DPRTC

(ii) NOT APPROVED

☐ The applicant is required to revise the application by addressing reviewer's concerns
(Reviwer's comments are provided to the applicant)

☐Other reasons (Describe briefly)

Click here to enter text.