RODENT COMMUNITY STRUCTURE AND THEIR DAMAGE IN COTTON CROP FIELDS IN KILOSA DISTRICT, TANZANIA

SEIF, WILLIAM

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

2022

ABSTRACT

Rodent is the one of vertebrates group causing a significant crop loss from planting, harvest to storages. This study assessed abundance, diversity, age structure, sex ratio, damage level and food categories of rodent at different cotton growth stages (seedling, vegetative as well as flowering and boll development stages). The study was conducted in Kilosa, Tanzania in two different habitats (cotton fields and fallow lands) between March 2020 and August 2020. Rodent population was sampled through capture-mark-recapture (Peterson methods) trapping technique and individual stomachs were collected from snap traps. In all cotton growth stages, *Mastomys natalensis* predominated at seedling stage (63.64%) as well as at vegetative stage (50%), while at flowering and boll development stage, *Leminscomys zebra* dominated (50%) of all captures. Higher damage levels observed only at seedling stage (33%). Different types of foods were consumed in fields, but seeds, invertebrates and plant materials were predominantly consumed. The findings highlight clearly that rodents were more abundant at seedling stage and *M. natalensis* was dominant at that stage, also cotton damages were observed at that stage while no damages were observed in other stages. The study confirms that large population of rodent and damage of cotton crops largely occurred at seedling stage. Therefore, management actions may be more effective at seedling stage of cotton growth in the fields.

DECLARATION

I, Seif William, 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 for degree award in any institution.

…………………………………….. ………..………….

Seif, William Date

(MSc. WMC Candidate)

The above declaration is confirmed by;

……………………………………….. ………………………

Prof. Vedasto. G. Ndibalema Date

(Supervisor)

……………………………………… ……………………..

Prof. Loth. S. Mulungu Date

(Supervisor)

COPYRIGHT

ACKNOWLEDGEMENTS

I wish to express my profound gratitude to the Almighty God, for His guidance and strength throughout the entire study period. My sincerely thanks go to supervisors Prof.V.G. Ndibalema (Department of Wildlife Management) and Prof. L. S. Mulungu (Institute of Pests Management) for their academic guidance and interest for the study.

Also, many thanks to the African Centre of Excellence for Innovative Rodent Pest Management and Biosensor Technology Development, for offering me a partial scholarship (research part) to undertake my MSc. in Wildlife Management and Conservation.

Finally, I am so thankful to the Head of Wildlife Management Department, Dr. Nsajigwa Mbije for nurturing me well. I would also like to express my gratefulness to my fellow colleagues in the Master of Wildlife Management and Conservation (2018/2020) and the field assistant Mr. Ramadhani from Institute of Pests Management for his field help.

DEDICATION

This work is dedicated to my father Seif and my mother Keflen, brothers and sister for their encouragement and support during my study. Although, this work is dedicated to my class mates and friends for their encouragement and moral support throughout the study period.

TABLE OF CONTENTS

ABSTRACT..ii

DECLARATION..iii

COPYRIGHT..iv

ACKNOWLEDGEMENTS...v

DEDICATION...vi

TABLE OF CONTENTS..vii

LIST OF TABLE..x

LIST OF FIGURES...xi

LIST OF ABBREVIATIONS..xii

CHAPTER ONE...1

1.0 INTRODUCTION...1

1.1 Problem Statement and Justification..2

1.2 Objectives of the Study...3

1.2.1 General objective...3

1.2.2 Specific objectives..3

CHAPTER TWO..4

2.0 LITERATURE REVIEW...4

2.1 Cotton Plant...4

2.3 Biology and Ecology of Rodents...5

2.5 Rodent Pest Species..7

2.6 Nature of the Damage...8

2.7 Rodent Damage in the Fields..9

CHAPTER THREE..11

3.0 MATERIALS AND METHODS...11

3.1 Description of the Study Area..11

3.2 Trapping Procedure and Data Collection...12

3.3 Data Analysis...14

3.3.1 Rodent species composition...14

3.3.2 Rodent abundances..15

3.3.3 Diversity of rodents..15

3.3.4 Age structure..16

3.3.5 Sex ratio...16

3.3.6 Crop damage caused by rodents in the cotton fields.............................17

3.3.7 Food categories taken on farmer’s fields..17

CHAPTER FOUR..18

4.0 RESULTS...18

4.1 Community Structure..18

4.1.1 Species composition..18

4.1.2 Rodent abundances...20

4.1.3 Diversity of rodents at different crop growth stages.............................20

4.1.4 Age structure..20

4.1.5 Sex ratio...21

4.2 Crop Damage caused by Rodents in the Cotton Fields and Food Categories Taken on Farmer’s Fields..24

4.2.1 Crop damage caused by rodents in the cotton fields.............................24

4.2.2 Food categories taken on farmer’s fields..24

CHAPTER FIVE..26

5.0 DISCUSSION...26

CHAPTER SIX...29

6.0 CONCLUSION AND RECOMMENDATIONS...29

6.1 Conclusion..29

6.2 Recommendations...29

REFERENCES...30

LIST OF TABLE

Table 1: Species composition of rodent pest species at different crop growth stages..19

LIST OF FIGURES

Figure 1: Map of Berega in Kilosa District Tanzania..11

Figure 3: Diversity (±SD) of rodent pest species between cotton crop growth stages...20

Figure 4: Age structure of *M. natalensis* (±SD) at different cotton growth stages.....21

Figure 5: Sex ratio distribution of female rodent between species at different cotton growth stages..23

Figure 6: Average percentage volume of different food categories to the diet *Mastomys natalensis*, *Gerbilliscus vicinus* and *Leminscomys zebra* in different habitats...24

LIST OF ABBREVIATIONS

FBD	Flowering and boll development
G	gram
KG	Kilogram
M	Metre
PAST	Paleontological Statistics
SS	Seedling stage
SUA	Sokoine University of Agriculture
VS	Vegetative stage
±SD	Standard diversion

CHAPTER ONE

1.0 INTRODUCTION

Rodents are the most diverse species of mammals which comprises about 29 families (Wilson and Reeder, 2006). Their diversity and distribution play a significant function in a maintenance of ecosystem balance (Adam *et al*., 2015). For example, some rodents are used as indicator in predicting different anthropogenic and climate conditions (Yihune and Bekele, 2012). On other hand, in ecosystem, rodents are used as preys, predators, pests, pollinators and seed dispersers (Magige and Senzota, 2006; Mueller, 2019) and disease transmission (Makundi *et al.,* 2008). Also, they are helping in changing soil physical and chemical properties (Liu *et al.,* 2009; Rautenbach, 2013), their interaction determines patterns and process of distribution and abundance of plants and animals in natural ecosystem (Bernardo *et al*., 2019). Hence, rodents have significant position in maintaining food chain, food web, nutrient cycles and structure and capacity of an ecosystem (Shuai *et al.,* 2006).

Despite of their ecological importance, rodent is one of vertebrates group causing a significant crop loss from planting, harvest to storages (Mulungu *et al*., 2003; Mulungu *et al*., 2013). They damage crops in all growth stage in fields to storage that reduces both quality and quantity of the crops (Fiedler, 1994; Mdangi *et al*., 2013). The level of crop damage tends to vary from one crop growth stage to another, but it tends to be higher at some growth stages than other (Sixbert, 2013; Mulungu *et al*., 2014). In the fields, for example, at plating stage, rodent may cut directly the planted crop or may dig up and eat the seed (Mwanjabe, 1993; Makundi *et al*., 1999; Brown *et al*., 2006; Mulungu, 2017). At vegetation stage rodents cut steams and use as a food (Reissig *et al*., 1985), or to make their nest (Gergon *et al*., 2008). Similarly, at maturity stage of plants, rodent use grains as food (Mulungu *et al*., 2006; Sixbert, 2013) and other end product like fibers from cotton to make their nest (Neelanarayanan *et al*., 1994; Rana *et al*., 1994).

There are almost 2021 rodent species (about 44% of all mammals) around the world, but few of them are pests in agriculture (Leirs, 2003; Mulungu *et al*., 2006). The pest level of the rodent species differs from one region to another and one continent to another. In Australia, for example, there are three rodent species termed as pests in agriculture *Rattus argentiventer*, *Rattus rattus* and *Ruttus fuscipes* but, the *Rattus rattus* is the most dominant pest (Singleton *et al*., 2003). According to Singleton and Petch (1994), at pre-harvest in each planting season *Rattus argentiventer* is the most pest causing crops damage in Australia. In Africa, more than 70 rodent species are found, but few of them (31 rodent species) are pest in agriculture (Fiedler, 1994; Mulungu, 2017).

In Tanzania, for example, around 31 rodent species are classified as pests, but *Mastomys natalensis, Arvicanthis nairobe*, *Rattus rattus* and *Mus musculus* considered as the main pest (Makundi *et al*., 1991; Fiedler, 1994; Mulungu *et al*., 2006). Among the rodent pest species in Tanzania *M. natalensis* cause more damage in agriculture than other rodent pest species (Stenseth *et al*., 2003; Sixbert, 2013). It is more abundant in farms and serious pest causes severe crop damage at different level (Sixbert, 2013; Mulungu *et al*., 2013; Mulungu, 2017). *Mastomys natalensis* can feed different type of crops (Mulungu *et al*., 2011); on average adult can feed up to 10% of its body weight of food per day (Kilonzo, 2006).

1.1 Problem Statement and Justification

Rodent outbreak in different fields with crops cause severe crop loss and food shortages (Zehrer, 1998 in Singleton *et al*., 1999; Mulungu *et al*., 2003). Many studies reported on the effect of rodent damage on cereal crop (Mulungu, 2003; Singleton *et al*., 2005;

Meerburg *et al*., 2009; Meheretu *et al*., 2010; Sixbert, 2013). This study focused on cotton fields where cases on rodent damage have not been reported in Tanzania. In India, for example, about 5 - 10% damage were reported on cotton (Malhi and Parshad, 1990) and the responsible rodent's species were identified to be *Rattus meltada*, *Tatera indica* and *Bandicota bengalensis* (Advan, 1987; Malhi and Parshad, 1990). Reports indicate that these rodents use cotton seeds for feeding, fibers for making nest, also drag the cotton bolls to their burrow for nesting development. Despite of this vast body of knowledge, there is still knowledge gap on rodent community structure and their damage level at different cotton growth stages. An information obtained will help in designing management action hence higher productivity to the cotton growers in Tanzania.

1.2 Objectives of the Study

1.2.1 General objective

To assess the effect of rodent damage to the crop in cotton fields in order to increase cotton production in Kilosa District, Tanzania.

1.2.2 Specific objectives

i. To determine rodent species richness, abundance and diversity recorded at different cotton growth stages (i.e., seedling, vegetative, flowering and boll development stages).

ii. To determine community structure of rodents (i.e., Age, sex and species composition) at different cotton growth stages.

iii. To estimate damage level caused by different rodent species and food categories consumed at different cotton growth stage from farmer's fields.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cotton Plant

The cotton is commercial crops produced worldwide, ranging from temperate to tropical regions and is leading among those crops in the production of fibres (Naveed *et al*., 2007; Khadi *et al*., 2010). According to the Beltrão *et al*. (2010), cotton is the second in source of protein and is fifth in oil production. The oil and protein in the cotton are obtained from the seed, in one 1kg can roughly contained 21% oil and 23% protein (Wallace *et al*., 2008; Benzouba *et al*., 2010). About 34 million hectares occupied with cotton across around 60 countries in the world, the leading countries in cotton production worldwide are Australia, Brazil, China, India, United State of America and Pakistan (Khadi *et al*., 2010; Acquaah, 2012).

Tanzania grows cotton for export and internal activities that contribute in generating household and national income (Busi and Lyaro, 2008). According to Baffes (2002) cotton is second commercial export revenue earner after coffee and it was introduced as plantation crop by Germany. It is source of household income; about 500,000 rural households are employed as the results of cotton production. Smallholders are primarily producer of cotton and it range from a farm of 0.5 to 2 hectares. In Tanzania, more than 90% cotton is produced in south of the Lake Victoria in Shinyanga, Simiyu, Mwanza, Tabora and Kigoma, Shinyanga accounting for 80% of it, but also there are regions like Singida, Moshi and Morogoro, Kilimanjaro and Costal region are producing cotton (Baffes, 2002).

2.3 Biology and Ecology of Rodents

Rodents represent a large taxonomical group in the order Rodentia (Wilson and Reeder, 2005) which comprises many species having the same biological and ecological characteristics. A group of rodents are nocturnal and few are diurnal. Nocturnal and diurnal are used as defensing mechanism for the rodents because large numbers of their enemies are in active during night hours, also these help rodents to escape from resources competitions (Delany, 1994).

Rodents can be herbivorous, omnivores, insectivorous and some are resourceful generalists, and others are specialized predators (Bergstrom, 2013). They can have varieties of diet in term of plants they can grain roots, steam and leaves, animals such as insects and meat and household materials such as soap, building materials and rubbish, also they have habits to carry foods to burrows and store (Senzota, 1982; Leirs and Verheyen, 1995; Mulungu *et al*., 2011a; Mulyashimbi *et al*., 2018). They have wide range of shelters from tree holes, or simple burrows to hidden nests on the floor, leaf and stick structures in tree crowns and mounds of cut vegetation built in aquatic environments (Mueller, 2019). Rodents are more influenced by feeding material for their distribution and abundance (Mulungu *et al.*, 2011; Mulungu *et al.*, 2015). Therefore, diet has a significantly part in the breeding activity to many rodent species because it used to activate on the reproductive physiology after assimilation of food materials (Leirs, 1994; Mulungu *et al*., 2014).

According to Single *et al.* (2001) rodent is characterized by continues growing paired of incisors which help them during feeding, dig burrows, and self-defense in danger. Rodents have an ability to adapt and tolerate faster in the given habitats (Single *et al.*, 2001), this making them to be easily found in different areas including human settlements (Nowak, 1999; Mdangi *et al*., 2013).

The rodent morphology differs from one specie to another, the largest rodent species morphologically is the Capybara, it weight is estimated to be around 66 kg, while most rodents weight is not more than 100 g and the smallest rodent being weigh around 3.75 g and it is said to be Baluchistan pygmy jerboa (Waggoner, 2000).

It has been reported that out of the 5416 species of living mammals, around 2200 living species are rodents (IPM, 2016). Rodents are more distributed all over the world, they are successful small mammals one the Earth’s surface accounting 40% (Bantihun and Bekele, 2015) of mammalian species with 29 living families, 468 genera and more than 2065 species (Kassa and Bekele, 2008). In Africa, more than 1150 species are currently listed, while East Africa rodents account for 28% of the total mammalian fauna with 62 genera and 161 species (Venance, 2010), Tanzania rodents account with 11 families, 43 genera and more than 101 species (IUCN, 2019).

Ecologically, rodents are essential tool in ecosystem; they play vital part in ecosystem s like the influence on vegetation generation (Garshong *et al*., 2013). They are used in pollination and used as the biological controller of pests (Cook *et al.*, 2007). They used determines patterns and process of distribution and abundance of flora and fauna in natural ecosystem (Gupta, 2011). Hence, they have significant position maintaining food chain, food web, nutrient cycles and structure and capacity an ecosystem (Shuai *et al.*, 2006; Sabuni *et al.*, 2015).

2.5 Rodent Pest Species

Among vertebrate pests, rodents can be a main source of damage to agriculture by eating on pasture, or consuming crops (Rao *et al*., 2002). About two thousand species of rodents found in the world, but there is limited number of rodents that can cause disturbance in agriculture (Leirs, 2003). In Africa, there are more than 70 rodent species, but only few of them are considered as agricultural pests (Fiedler, 1994). Survey in different parts of Tanzania show that more than 30 rodent pest species are involved in crop damage (Mulungu *et al*., 2006). The status of damage by rodents varies from one crop to another because some rodent pest prefers a certain type of crop, for example, *Bandicota* spp. prefer wheat (Poche´ *et al*., 1982) and to rice (Islam *et al*., 1993), *Mastomys natalensis* and *Xerus erythropus* cause more disturbance on maize (Mulungu *et al*., 2003; Mwanjabe *et al*., 2002), *Microtus* cause damage on alfalfa (Sterner *et al*., 1996), *Rattus rattus* prefers on macadamia nuts and more damage occurs on it (Tobin *et al*., 1997), *R. sordidus* and *R. rattus* cause more damage on sugarcane (Whisson, 1996), *R. tiomanicus* damage to oil palms (Wood and Liau, 1984), and *R. argentiventer* damage to lowland irrigated rice (Singleton *et al*., 2005).

The level of damage is not uniform throughout the agricultural season therefore, it tends to be higher in some season than other, for example, in dry season, severe crop damage has been observed (Jahn *et al*., 1999; Sixbert, 2013). In irrigated rice, Sixbert (2013) reported that during dry season, crop damage was high (11%) than wet season crop damage was 6% and this resulted into yield loss. Also, some cases have been reported on cereal such as wheat where damage by rodent pests during winter season is higher than other season (Brown and Singleton, 2002).

The severity of crop damage differs from one crop growth stage to another, it can be higher at some growth stages (Sixbert, 2013). Crop damage mostly tends to occur in pre-harvest of the crops especially at sowing stage and at seedling stage this is because species favor seedling/soft steams of the young plant, also at maturity stage damage occurred especially in maize crop (Mulungu *et al.*, 2013). At early stage of crop growth, for example, rodent pest may dig up and eat the planted seeds or directly planted in the fields (Makundi *et al*., 1999; Mulungu, 2003). At vegetative stage rodent cut plants while growing use as the food and use for building their nests (Reissig *et al*., 1985). At maturity, rodent pest species use both milky and mature grains (Mulungu *et al.,* 2006; Sixbert, 2013). Rodents cause damage at all crop growth stage by digging up planted seeds, cutting the growing plants to access nutrients contained within or access the grain as the crop matures (Mulungu, 2017)

2.6 Nature of the Damage

The damage of crops by rodents depends on many factors such as type crops and crops growth stages, nature of surrounding habitat and types of species (Mulungu *et al*., 2006), these factors help to describe the extent and pattern of damage of crops in the fields (Mulungu *et al*., 2015b). Understanding the factors that can cause fluctuations numbers of rodent is very important for developing an effective management plan for the rodent pests (D'Andrea, 2007). Rodent species demonstrate spatial and temporal fluctuations in numbers, as the results of ecological and environmental factors.

Rodent pest species can show important spatio-temporal differences that can actually disturb crop damage patterns and severity (Mulungu *et al*., 2006; Mulungu *et al*., 2015). The crop damage can be over part of the farm depends on nature of surrounding habitat and types of species (Mulungu *et al*., 2006), or can be in fine scale depends on the phenomenon that contribute fine than large scale (Krohne and Burgin 1990; Bowman *et al*., 2000). The distribution of crop damage over a large area is related to the pest distribution in both time and space (Kumar, 1984).

Agricultural fields that are nearly bush and fallow land are exposed to the rodent pests which cause crop damage especially at crop-sowing and the seedling stage because most of rodents prefer seeds (Leirs *et al*., 1996; Mwanjabe & Leirs 1997; Mulungu *et al*., 2006; Odhiambo *et al*., 2005). Also, rodents can exhibit spatial and temporal distribution of crop damage at different crop growth stage (Mulungu *et al*., 2015a). The distribution of crop damage within the fields depends local conditions like presence of land that giving harborage to rodents that make easy attack or areas nearby to other infested crops (Mulungu *et al*., 2006). Timing of rodent damage and spreading in the crop area differ significantly with the rodent species, the local environment and the age of the crop (Hampson, 1984; Mulungu, 2003).

2.7 Rodent Damage in the Fields

Among mammalian agricultural pests, rodents have been considered as the most important pest at the global level (Cuong *et al*., 2002). The rodent can cause directly or indirectly crop damage by spoilage, gnawing and hoarding activities (Mdangi *et al*., 2013). Large amount of crop lost and food shortage occurred as the results of rodent’s damage in the fields (Fayenuwo *et al*., 2007). Abundant of rodent pest are common in fields with cereal crops, a huge quantity of crops has been lost during pre and post harvesting periods in every year in different parts of the world (Meerburg and Kijlstra, 2008).

There are many studies which reported on extent of damage caused by rodents in different part of the world. In Asia, for example, about 5 - 10% of rice losses was assessed in the pre- harvest stage (Singleton, 2003; Singleton *et al*., 2005; Meerburg *et al*., 2009). While in Philippines around 90% losses have been valued in crops fields (Fall, 1977). In Africa, many cases have been reported on crops damage caused rodent, for example, in Northern Ethiopia, about 9-44% losses were reported at pre- harvest stages in annual production of cereal crops (Meheretu *et al*., 2010), in Western Kenya, about 20% damage in maize were estimated after rodent outbreak. According to Bekele *at al*. (2003) who reported that 26.4% loses of maize were in Central Ethiopia. In every cropping season about 5 to 10% damage is common in India (Malhi and Parshad, 1990) and the responsible rodent's species were identified to be *Rattus meltada*, *Tatera indica* and *Bandicota bengalensis* (Advan, 1987; Malhi and Parshad, 1990).

In 1989/90 cropping season, for example, in Tanzania, a sum of yield loss of 48% in maize, sorghum, paddy, and pulses was reported and ascribed to seed destruction by rats 11 % (Mwanjabe *et al*., 2002). Makundi *et al*. (1991) reported that the annual pre-harvest loss of maize in Tanzania is valued to reach 15%. Mulungu *et al*. (2003) reported that maize damage at sowing and seedling stages might range between 40 and 80%, depending on cropping seasons and location. Also, more than 352173 acres of various grain crops were destroyed by rodent pests in Lindi region (Mwanjabe *et al*., 2002). In Morogoro region Tanzania, rodent damage in the rice fields show that during dry season 12% of yield loss occurred which is sufficient to feed nearly 7568 people/year, but during wet season yield loss of 4.75%, an amount that can feeds around 2996 people/year (Sixbert, 2013).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

The study was conducted at Mtakuja in Berega village (6 ^{0} 10’ 59” S, 37 ^{0} 7’ 0” E), Kilosa District, Morogoro Region, Tanzania between 23th March, 2020 and 20th, August 2020. Crop production is the major economic activity for almost 84.2% of the people in the district (URT, 2012). An average annual rainfall in the study area varies between 600 and 800 mm from year to year, various crops such as maize, millet, beans, sorghum, banana, sunflower, cotton and different varieties of vegetable are grown in the area (URT, 2012). The District is bordered by Gairo to the East, Kilombero and Kilolo (in Iringa) district to the South, Mpwapwa District (in Dodoma) to the West and Kongwa District (in Dodoma) to the South West. This area has been selected because of its high potential for cotton production in Morogoro Region and the various reports from different farmer on rodent pest’s crop damages.

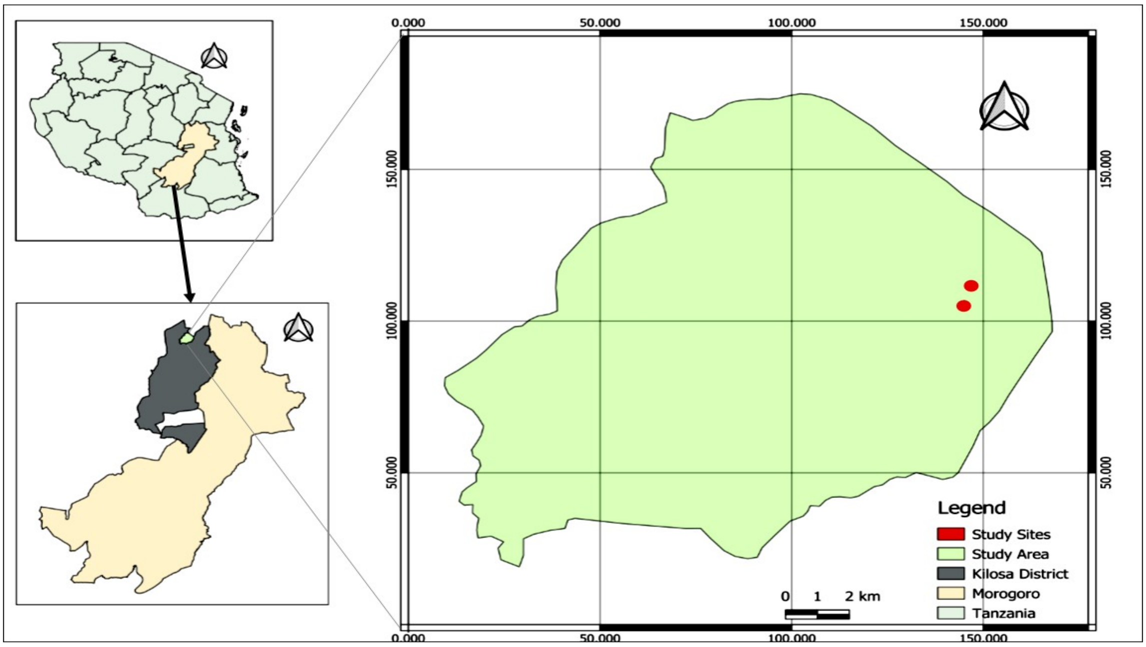
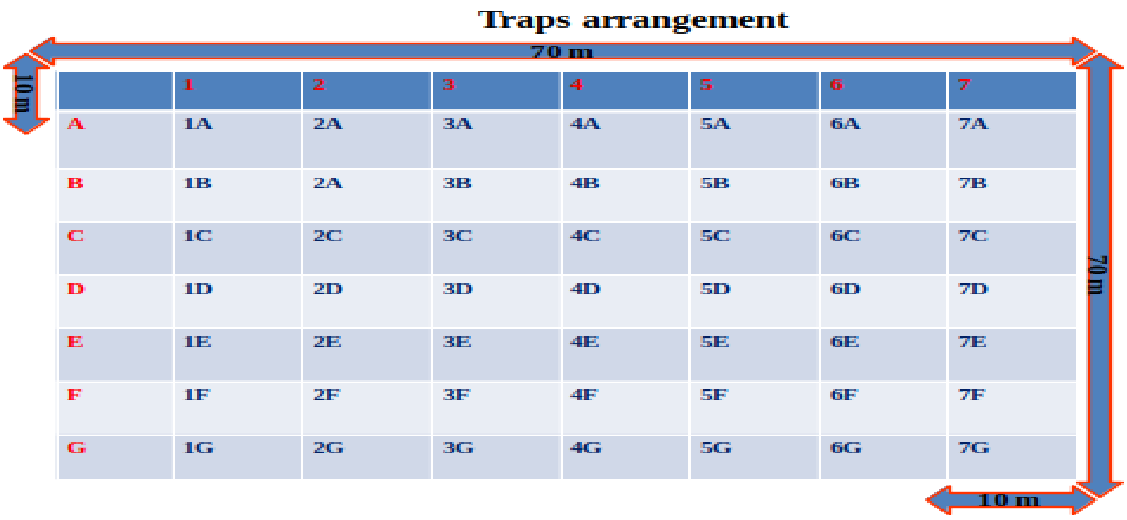


Figure 1: Map of Berega in Kilosa District Tanzania. Colors; light green shows the study area namely Berega; dotted red show location of each grid sampling site.

3.2 Trapping Procedure and Data Collection

Permanent trapping was conducted at Mtakuja in Berega village after survey of the site. A total of 148 traps (98 Sherman live traps and 50 snap traps) were used and 98 Sherman Live traps (23 x 9.5 x 8 cm, H. B. Sherman Traps Inc.) were set in the two trapping grids (i.e., cotton crop fields). A grid comprised of seven parallel lines separated at a distance of 10 m apart. The traps were set in seven trapping stations per line each 10 m apart making a total of 49 trapping stations per grid (Fig. 2).



	1	2	3	4	5	6	7
A	1A	2A	3A	4A	5A	6A	7A
B	1B	2A	3B	4B	5B	6B	7B
C	1C	2C	3C	4C	5C	6C	7C
D	1D	2D	3D	4D	5D	6D	7D
E	1E	2E	3E	4E	5E	6E	7E
F	1F	2F	3F	4F	5F	6F	7F
G	1G	2G	3G	4G	5G	6G	7G

Figure 2: Sketch of Sherman live traps design in a grid

Fifty (50) Snap traps were set in transect line (25 snaps in fallow and another 25 in cotton farm). Individual stomachs were collected from snap traps, removed from rodents captured and placed in a labeled small bottle and preserved in 70% alcohol for diet analysis.

Traps were set on the evening of the first day and baited with a mixture of peanut butter and maize flour replaced with new ones after every trap check which was conducted every early morning and late evening for two consecutive nights per each stage of cotton growth. This is for the reason that some rodent species are diurnal and other are nocturnal (Senzota, 1982; Mulungu *et al*., 2008; Magige, 2016).

A Capture–Mark–Release trapping technique (Petersen methods) for the single marking and capturing was used whereby; the a number of individuals marked over short time, released and then, do recapture individuals to check for marks with assumptions that; the population is closed so that the population is constant, all animals have the same chance of getting caught in the 1st sample, marking individuals do not affect their catchability, animals do not loss marks between the two sampling period and all marks are reported upon discovery in the second sample. Rodent species caught in Sherman Live traps were recognized to species level (Happold *et al*., 2013; Kingdon, 2015) and age classification (*M. natalensis*) was based on body weight (Leirs and Verheyen, 1995). Their taxonomic groups were appropriately classified based on field guide books (Happold *et al*., 2013; Kingdon, 2015) and the help of animal identification experts. All the new captured rodents were marked through toe clipping using a certain number for all individual. Their weights, trapping stations, sex and reproductive status were recorded. The sex and reproductive conditions were also considered to include males and females (either a perforated or closed vagina in females and scrotal or non-scrotal testes in males) and rodents were then released at the same station of capture.

The actual plant emergence was compared to the potential emergence based on details provided by the farmers in order to determine the crop damage caused by rodents at seedling, the emergence plants were counted in all farms along crops row for one meter from plant to plant.

The preserved stomach contents from the fields were spread out in a Petri dish and sorted under a binocular stereoscope, using 25× and/or 50× magnification as described by Smith *et al*. (2002). In the stomach contents were identified as seeds, plant material (roots, stems and leaves), invertebrates, animal hairs and other food categories. If necessary, a lugol solution was used to determine the presence of starch for seeds or grains (Smith *et al.*, 2002).

The method used was as described by Smith *et al.* (2002) where average percentage volume (PV; the contribution of each item to the volume of the particular stomach's content) was estimated to the nearest 10%, with an additional category of 5% where an item was present but contributed <10% to stomach content volume.

3.3 Data Analysis

3.3.1 Rodent species composition

Rodent species composition is the proportions (%) of several rodent species in relation to the total on a given area to reflect the relative contribution of a species to a community and dominance of a specific species on a site. Species composition was calculated in terms of percentages (%) where by the number of each species in relative to others were calculated obtained by dividing the number of captured individuals of each species by the total number of captured animals in each habitat (Cotton farms), and multiplied by 100. The percentage (%) of each species was computed using the formula;

$$\% \, Composition \, spp \, A = \left(\frac{Number \, of \, spp \, A}{Total \, number \, of \, individuals} \right) x \, 100 \ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

.

3.3.2 Rodent abundances

The number of individuals captured for each species, farms and stages of cotton growth were recorded and the rodent abundance estimated as the actual number of rodents captured per each field and crop growth stages since the captured individuals were few hence Petersen method formula could not give good estimates. Mann-Whitney test was used to test if there was significant different of rodent abundance between two cotton farms and Kruskal-Wallis test was used to test the significant different of rodent abundance between cotton growth stages.

3.3.3 Diversity of rodents

Species diversity was calculated and compared between cotton growth stages using Simpson diversity index (λ = 1-D) (Jiang *et al.*, 2017).

Where;

Simpson's Dominance (D)

$$D = \frac{N(N-1)}{\sum(n-1)} \qquad \text{(2)}$$

Where by

n = the total number of organisms of a particular (each individual) species

N = the total number of organisms of all species

D = the Simpson's Dominance (D)

The index of dominance was measured in order to find the probability of taking randomly two individuals belonging to different species. Dominance measures the extent of common species in the cotton farm and it ranges from 0 to 1.

In order to get species diversity, D were subtracted from 1 to give Simpson's Index of Diversity 1 – D.

Simpson's Diversity Index (1 - D)

$$\lambda = 1 - \left(\frac{N(N-1)}{\Sigma n(n-1)}\right)$$

………………………..……………………………………………….

(3)

The value of the index ranges from 0 (low species diversity) to 1.0 (high species diversity).

3.3.4 Age structure

Age structure of individuals were determined for one species *Mastomys natalensis* as the only species studied in terms of age by categorizing juveniles, sub adults or adults following the relationship between age and body weight (gm) (Leirs and Verheyen, 1995). Individuals weighing > 24 g were grouped as adults, 21 g to 24 g were grouped as sub adults, while those weighing ≤ 20 g were grouped as juveniles. The presence of active adult rodents (including sub-adult individuals) was used as an indicator of reproduction and the presence of juveniles in a population was used as proof of recent reproduction and was determined in each farm and each stage of cotton growth. Because data was not uniform, the significant different of age structure between cotton growth stages was tested using one-way ANOVA.

3.3.5 Sex ratio

Sex ratio was determined as the ratio of the number of individuals of one sex (females) to that of the other sex (males) in the population (normalized to 100 or 1). Typically fluctuated around in a ratio of 1:1 (expected ratio) as the most common evolutionary stable strategy (ESS), led by frequency-dependent natural selection due to competition for mates among individuals of the same sex (Jennions and Fromhage, 2017). Sex ratio variation was determined in each farm and at different stages of cotton growth. In this study, the sex ratio was the proportion of females in the whole population and is in favor of females, because males can be active throughout the time and one male can impregnate many females in one breeding season. The minimum expected number is at least 1, and less likely than the one observed (Campbell, 2007; Mulungu *et al*., 2013).

Where by Female Population is given

$$r=\frac{f}{m+f}$$

……………………………………………………………………………(4)

Where, r = Gender (sex) Ratio m = Number of Males f = Number of Females

Kruskal-Wallis test was used in this study to test if there was a significance association of sex ratio between cotton growth stages and between rodent pest species.

3.3.6. Crop damage caused by rodents in the cotton fields

The level of plants damaged was converted into percentage by taking damaged plants over total plants in all farms; the method was modified from Rennies (1979) in describing damage to wheat crops by rodent % of plant damaged = 100 (a/b)…………………….(5)

Where:

a = number of damaged plants;

b = total number of plants in the farms.

The significance different of means percent damaged of cotton from various growth stages was compared using one-way ANOVA.

3.3.7 Food categories taken on farmer's fields

Diet variety was the number of dietary items recorded per individual during the sampling period and diet diversity was calculated following Ebersole and Wilson (1980) as Levins' index (Levins 1968), as:

$$D = \frac{1}{\sum P_i^2} \quad \text{...(6)}$$

Where P (= PV/100) is the mean proportion in volume of each of the dietary items. Levins' index ranges from 1 to n (n = total number of food item categories).

CHAPTER FOUR

4.0 RESULTS

4.1 Community Structure

4.1.1 Species composition

A total of 43 individuals were captured in over 888 trap nights. Only 14 individuals among the total capture were used for diets analysis because were captured in snap traps. Three species (*Mastomys natalensis*, *Gerbilliscus vicinus* and *Leminscomys zebra*) were observed at three cotton growth stages over the study time. Species composition of *Mastomys natalensis* (48.27%) was relatively higher than that of *Gerbilliscus vicinus* (31.03%) and *Leminscomys zebra* (20.69%) at all stage of crop growth. *Mastomys natalensis* was the most dominant rodent pest species in two cotton growth stages, seedling stage and at vegetative stage 63.64% and 50% respectively, *Leminscomys zebra* dominated at flowering and boll development by 50% of all captures (Table 1).

Table 1: Species composition of rodent pest species at different crop growth stages

S/N	Species	Cotton growth stages					
		Seedling stage	**% Contribution**	**Vegetative stage**	**% Contribution**	**Flowering and Boll Development**	**% Contribution**
1	*Mastomys natalensis*	7	63.6	5	50	2	25
2	*Lemniscomys Zebra*	1	9.1	1	10	4	50
3	*Gerbilliscus vicinus*	3	27.3	4	40	2	25
	Total	**11**	**100**	**10**	**100**	**8**	**100**

4.1.2 Rodent abundances

There was no significant difference in terms of rodent abundance between farms (χ^2 = 0.011, df = 1, p = 0.92) and crop growth stages (χ^2 = 0.30; df = 2; p = 0.86). Rodents were more abundant at seedling stage (mean = 19.26) as well as at flowering and boll formation stage (mean = 18.52) and were less abundant at vegetative stage (mean = 17.72).

4.1.3 Diversity of rodents at different crop growth stages

High diversity was observed at vegetative stage (mean = 0.63) followed by flowering and boll formation stages (mean = 0.58) as well as at seedling stage (mean = 0.54) (Fig. 3).

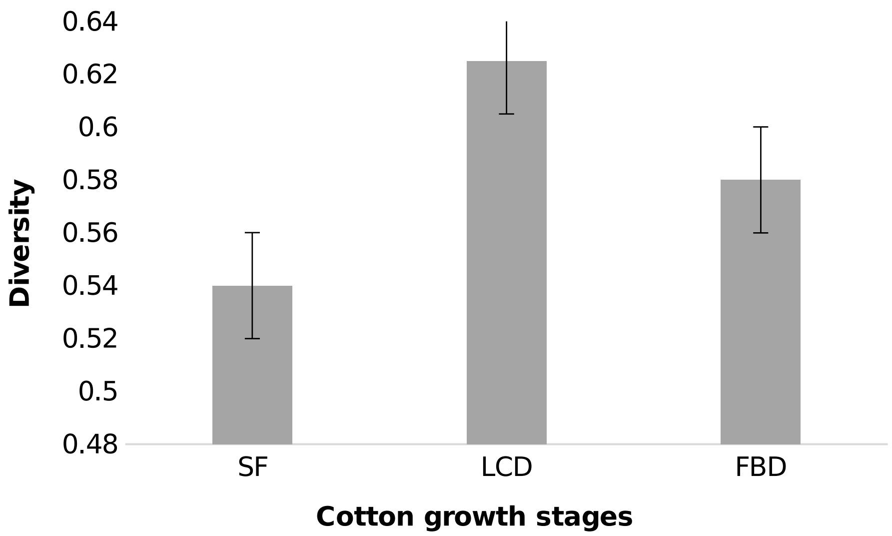


Figure 3: Diversity (±SD) of rodent pest species between cotton crop growth stages Note: SS= seedling stage VS= vegetative stage and FBD= flowering and boll development

4.1.4 Age structure

There was no significance difference of age classes between age group ($F_{2, 11}$ = 13.0; p = 0.554), and crop growth stages ($F_{2, 11}$ = 0.297; p = 0.749). Among trapped individuals, adults (85.71%) were dominant than sub-adult (7.14%) and juvenile (7.14%). Adults were not present at vegetive stage, they were captured only at seedling stage and flowering and boll development stage. Subadults were only captured at seedling stage and not in other stages of growth; Similarly, juveniles were only captured at vegetative stage and not during seedling stage and flowering and boll development stage (Figure 4).

There was little variation in age structure between cotton growth stages. During the entire study time, more adults were captured compared to sub- adults and juvenile.

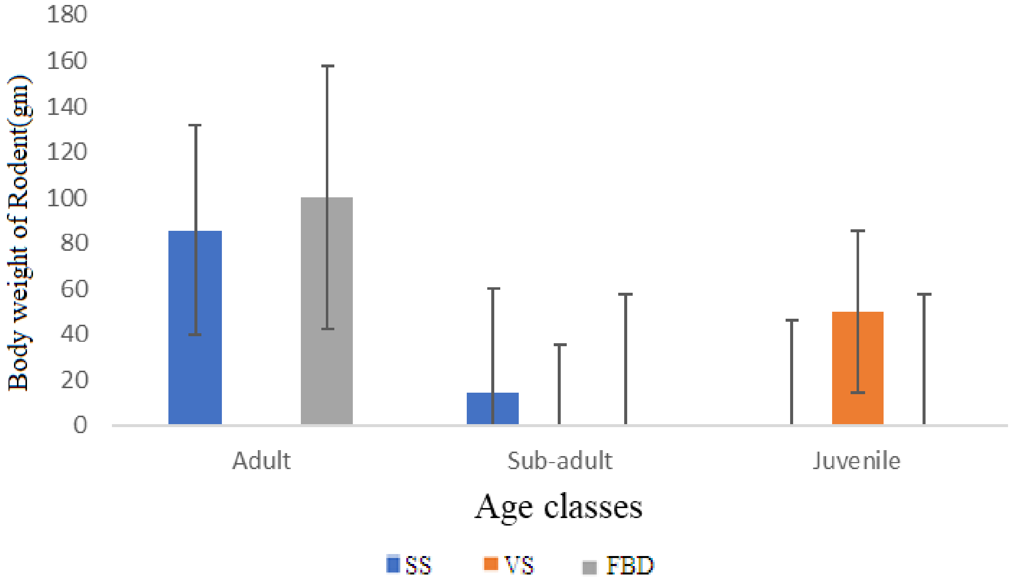


Figure 4: Age structure of *M. natalensis* (±SD) at different cotton growth stages

4.1.5 Sex ratio

There was no significant difference in sex ratio between crop growth stages ($\chi^2 = 0.132$; df = 2; p = 0.878), however, the difference was significant ($\chi^2 = 4.357$; df = 2; p = 0.0475) among rodent species. The interaction between stages and species also is significant ($\chi^2 = 3.14$; df = 4; p = 0.0473). Higher sex ratio value was observed at seedling stage and at flowering and boll development stages compared to the vegetative stage between three species.

The percentage female of *Gerbilliscus vicinus* was relatively higher at vegetative stage as well as seedling stage than at flowering and boll development stage. Similarly, *Mastomys natalensis* had higher percentage of female at flowering and boll development stage and at vegetative stage compared to seedling stage. But the percentage of female *Leminscomys zebra* was low at seedling stage and flowering and boll development stages compared to that at vegetative stage (Figure 5).

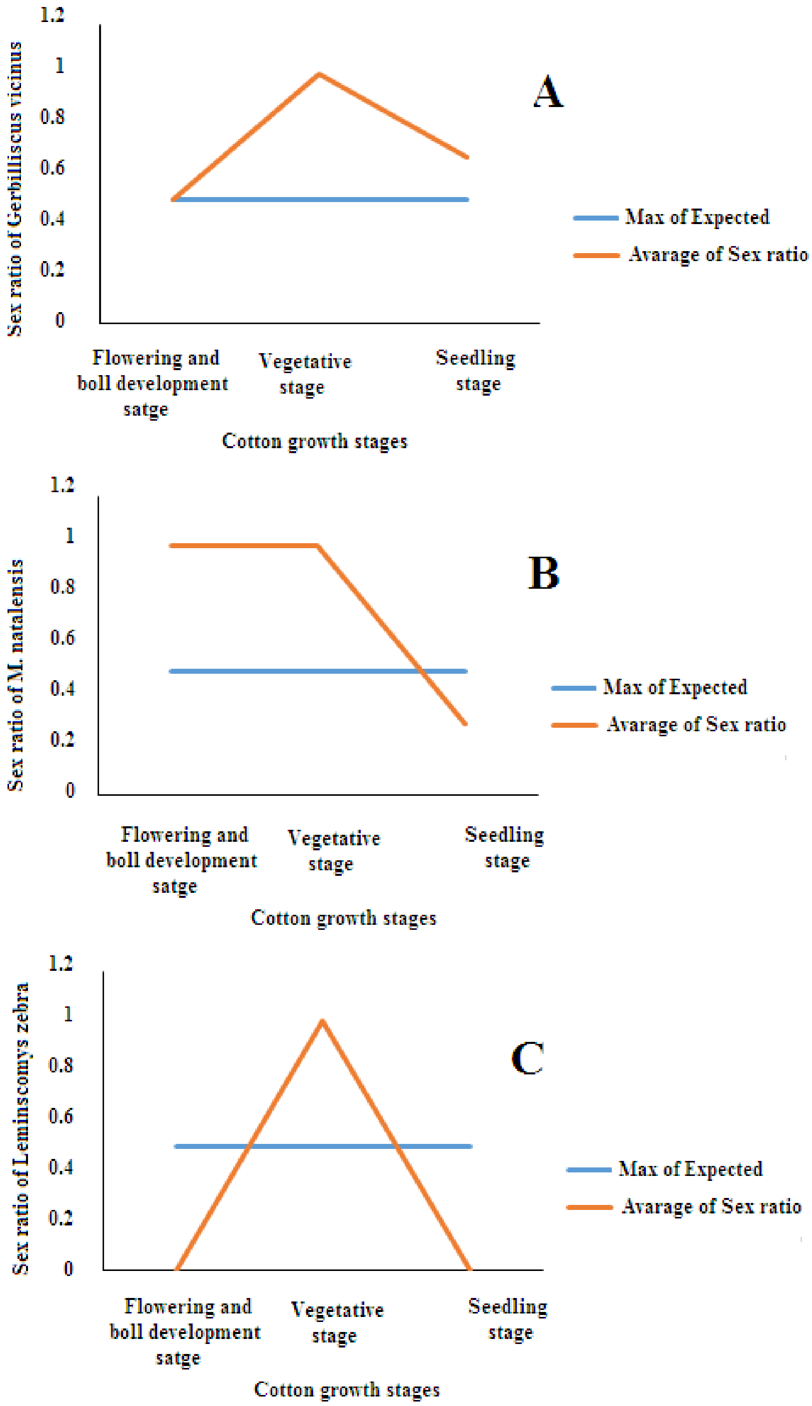


Figure 5: Sex ratio distribution of female rodent between species at different cotton growth stages, where by A= *Gerbilliscus vicinus*, B= *M. natalensis*, C= *Leminscomys zebra*

4.2 Crop Damage caused by Rodents in the Cotton Fields and Food Categories Taken on Farmer's Fields

4.2.1 Crop damage caused by rodents in the cotton fields

Damage level between crop growth stages was significant different ($F_{2, 15}$ = 12.79; p = 0.0005). There were relatively higher damage levels during seedling stage (33% of damage), but no any damages were observed at vegetative stage as well as flowering and boll development stages.

4.2.2 Food categories taken on farmer's fields

The total of 14 individuals from three species *Mastomys natalensis, Gerbilliscus vicinus* and *Leminscomys zebra* were trapped in two habitats (cotton farm and fallow), where by 8 rodents from cotton farm and 6 in fallow were captured at different stages of cotton growth.

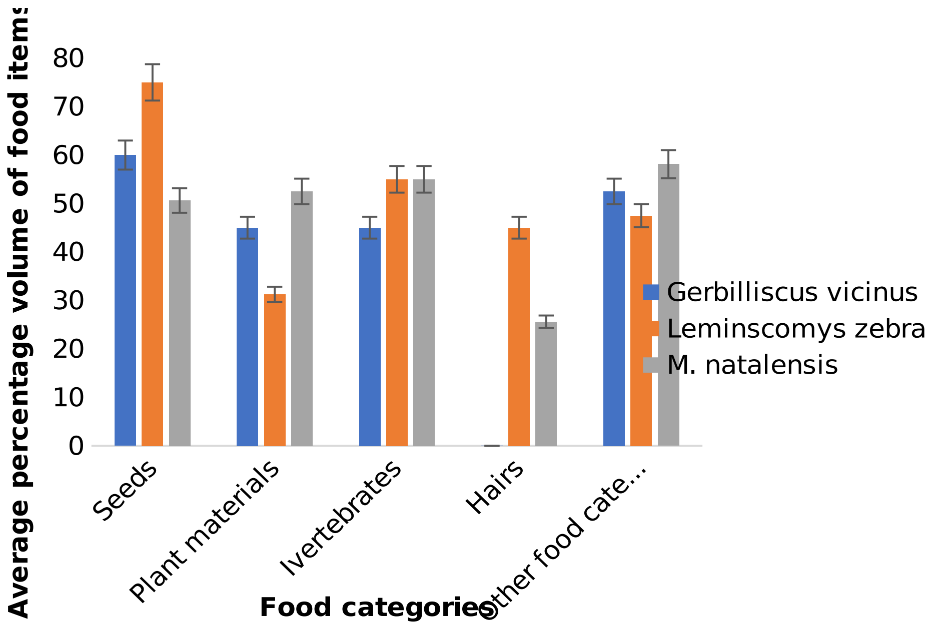


Figure 6: Average percentage volume of different food categories to the diet *Mastomys natalensis*, *Gerbilliscus vicinus* and *Leminscomys zebra* in different habitats: fallow fields and cotton fields

In general, *Mastomys natalensis* are opportunists, consuming nearly all food categories in the environment, high intake of invertebrates was observed compared to that of plant materials and seeds in all cotton growth stages (Figure 6). In *Gerbilliscus vicinus*, was consuming more seeds, but intake of plant materials and invertebrates was almost the same. *Leminscomys zebra* high ratio of seeds and invertebrates was observed in the stomach of rodent compared to the plant materials.

CHAPTER FIVE

5.0 DISCUSSION

This study aimed to assess the effect of rodent damage to the crop in cotton fields, the study found variations in rodent composition between cotton growth stages (i.e., seedling stage, vegetative stage, and flowering and boll development stage). Three species of rodents were captured during the entire study time (*Mastomys natalensis*, *Gerbilliscus vicinus* and *Leminscomys zebra*). *Mastomys natalensis* was observed to be dominant during seedling stage as well as at vegetative stage while *Leminscomys zebra* was dominant at flowering and boll development stage. *Mastomys natalensis* is agriculture field rodent pest distributed all-over sub-Saharan Africa (Leirs, 1995). The species is also the main pest responsible for damaging field crops in Tanzania (Leirs *et al.*, 1996). Therefore, justify the high trapping of this species in the study area.

There were significantly higher number of individuals captured at seedlings stage, but the diversity of rodents was observed to be higher at the vegetative stage compared to seedling stage and flowering and boll development possibly because it is associated with presence of cover in farms. This enables rodents to establish their habitats.

The number of rodents in an area tends to change from time to time depending on several factors like food availability, environment factors and reproductive potential of rodents (Mulungu *et al*., 2015b). This study observes variation of number of rodents between the study areas. However, variations of rodents were observed on different crops growing stages. There were high rodents' numbers during seedlings stage, which was the early stage of cotton growth and flowering and boll development, the maturity stage comparing to vegetative stage. This could be attributed with availability of food (i.e., planted seed and seed developed from bolls that offers foods to rodents). The low abundance of rodents in vegetative stage was attributed by low food availability from the cotton field due to the fact that, at this stage there was no access of seeds and stem that can be consumed by rodents. Meheretu *et al*. (2014) and Mulungu *et al*. (2011a) observed high number of rodents during maturity stage of rice production, both of these could be associated with the facts that rodents prefer seeds/grains.

The unsteadiness between sexes is common among different animals' species mostly depending on behaviors of that animals, place of occurrence and other related factors. In this study, the rodent sex ratio did differ between species but did not differ between crop growth stages, the high sex ratio value was observed during seedling stage as well as flowering and boll development stages compared to the vegetative stage. The females were captured more than males especially during flowering and boll development stage, this suggests that females were actively searching for food more than males because of physiological demands like pregnancy and lactation. The study by Mulungu *et al*. (2013a) showed more females of *M. natalensis* captured in cultivated rice fields. Duque *et al*. (2005) associated maturity of crops with rodents breeding as more females were captured. The present study also shows more adults capture due to big home range, actively in movement, and high social ranking (Assefa and Srinivasulu, 2019).

The results from this study have indicated that rodents had higher damage on cotton during seedling stage than any other stages of cotton growth and this can be proved by some factors like; the destroyed crops were cut at 45 degrees and presence of husks around the planted hole in the farms. Other studies recorded have similar findings with this study. Buckle *et al*. (1979) reported that rodent damage on rice was higher at each growth stage than at maturity of the crop.

The three rodent species were opportunists, consuming nearly all food categories in the environment. The different between in diet of the three species was that *Gerbilliscus vicinus and Leminscomys zebra* consumed predominantly seeds while invertebrate and plant materials ingested in small amount, *Mastomys natalensis* ate seeds in large amount compared to invertebrate and plant materials, this observation supported by the findings reported Mulungu *et al*. (2011a).

In all stages of cotton growth, seeds were observed in the stomachs of the rodent, but at seedling stage large number of seeds in the rodents' stomach was observed compared to other stages. Seeds are vital type of food especially during the breeding season, because it required to provide high amount of energy needed for reproduction, the observation agrees with finding reported by Leirs and Verheyen (1995). Also, during the study period invertebrates observed in the stomachs of the rodent in all stages of cotton growth, The invertebrates like insects are used as the sources of protein required by rodent especially during pregnancy, the same observation showed by Monadjem (1998) who described the importance of both seeds and invertebrates in *M. natalensis* in Swaziland during the breeding season.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Rodents damage to the fields with crop tends to vary from one crop growth stage to another, but it tends to be higher at some growth stages than other, depends on the type of rodent species and kind of crop. Therefore, from the study we can conclude that rodent species were more abundant at seedling stage which is the early stage of cotton growth and *M. natalensis* was dominant at that stage. Also damages on cotton plantation were observed at seedling stage and not in other stages. In addition, seeds were mostly consumed by all rodent species but, were highly consumed by *Gerbilliscus vicinus* compared to other species.

6.2 Recommendations

The study confirms that large population of rodent and damage of cotton crops largely occurred at seedling stage. Therefore, from the study we recommend that management actions should be more effective at early stage of cotton growth in the fields. This would help in reducing the number of rodents and level of cotton crop damage in the fields hence, increasing level of crop production.

REFERENCES

Acquaah, G. (2012). *Principles of Plant Genetics and Breeding*. (2nd Edition), Wiley-Blackwell, Oxford. 758pp.

Adam, M., Welegerima, K., and Meheretu, Y. (2015). Abundance and community composition of small mammals in different habitats in Hugumburda forest, northern Ethiopia. *International Journal of Biodiversity and Conservation* 7(2): 119–125.

Assefa, A. and Srinivasulu, C. (2019). Species composition and abundance of rodents in Kafta-Sheraro National Park, Ethiopia: Preliminary results. *Journal of Threatened Taxa* 11(6): 13680 – 13689.

Baffes, J. (2002). Tanzania's cotton sector: Constraints and challenges. *Journal of International Development* 17(1): 21 – 43.

Bantihun, G. and Bekele, A. (2015). Diversity and habitat association of small mammals in Aridtsy forest, Awi Zone, Ethiopia. *Zoological Research* 36(2): 88 – 94.

Bekele, A., Leirs, H. and Verhagen, R. (2003). Composition of rodents and damage estimates on maize farms at Ziway, Ethiopia. *ACIAR Monograph Series* 96: 262-263.

Beltrão, N. E. M., Vale, L. S., Marques, L. F. and Cardoso, G. D. (2010). O cultivo do algodão orgânico no semiárido Brasileiro. *Revista Verde* 5: 8 – 13.

Bergstrom, B. J. (2013). Would East African savanna rodents inhibit woody encroachment? Evidence from stable isotopes and microhistological analysis of feces. *Journal of Mammalogy* 94(2): 436–447.

Bernardo, L., Medellín, R. A. and Cameron, G. N. (2019). American society of mammalogists population and community ecology of small rodents in Montane Forest of Western Mexico: *American Society of Mammalogists* 81(1): 77–85.

Bowman, T., Garcia, R., Turkson, J. and Jove, R. (2000). STATs in oncogenesis. *Oncogene* 19(21): 2474-2488.

Buckle, A. P., Yong, Y. C. and Rowe, F. P. (1979). Yield response of the rice variety (Improved Mashuri) to simulated rat damage. *Malaysian Agricultural Journal* 52: 135 – 144.

Busi, M. and Lyaro, S. (2008). *Cotton Market Development Strategy for Central Tanzania.* Rural livelihood Development Company, Dar es Salam, Tanzania. 23pp.

Campbell, I. (2007). Chi-squared and Fisher–Irwin tests of two-by-two tables with small sample recommendations. *Statistics in Medicine* 26(19): 3661 – 3675.

Cook, S. M., Khan, Z. R. and Pickett, J. A. (2007). The use of push-pull strategies in integrated pest management. *Annual Review of Entomology* 52: 375 – 402.

Cuong, N. K., Saeki, N., Kataoka, S. and Yoshikawa, S. (2002). Hydrophilic improvement of PET fabrics using plasma-induced graft polymerization. *Hyomen Kagaku* 23(4): 202-208.

D'Andrea, A. (2007). *Global Nomads: Techno and New Age as Transnational Countercultures in Ibiza and Goa*. Routledge. 264pp.

Delany, H. M., John, J., Teh, E. L., Li, C. S., Gliedman, M. L., Steinberg, J. J. and Levenson, S. M. (1994). Contrasting effects of identical nutrients given parenterally or enterally after 70% hepatectomy. *The American journal of Surgery* 167(1): 135-144.

Ebersole, J. P. and Wilson, J. C. (1980). Optimal foraging: the responses of Peromyscus leucopus to experimental changes in processing time and hunger. *Oecologia* 46(1): 80-85.

Fall, M. W. (1977). *Rodents in Tropical Rice. Impacts of Rodentson Rice Production in Asia*. Discussion Paper Series No. 45. International Rice Research Institute, Los Banos, Philippines. 14pp.

Fayenuwo, J. O., Olakojo, S. A., Ak, M., Amusa, N. A. and Olujimi, O. A. (2007). Comparative evaluation of vertebrate pest damage on some newly developed quality protein maize (QPM) varieties in south-western Nigeria. *African Journal of Agricultural Research* 2(11): 592-595.

Fiedler, L. A. (1994). *Rodent Pest Management in Eastern Africa.* Plant Protection and Production Paper No. 23. 83pp.

Fielder, L. A. and Fall, M. W. (1994). *Rodent Control in Practice: Tropical Field Crops*. Denver Wildlife Research Centre, Colorado, USA. pp. 313 – 338.

Garshong, R. A. and Attuquayefio, D. (2013). Aspects of the ecology of rodents in the Owabi Wildlife Sanctuary, Ghana: sex-ratio, age structure and reproductive characteristics. *Asian Journal of Applied Sciences* 1(4).

Garshong, R. A., Attuquayefio, D. K., Holbech, L. H. and Adomako, J. K. (2013). Distribution and abundance of small mammals in different habitat types in the Owabi Wildlife Sanctuary, Ghana. *Journal of Ecology and the Natural Environment* 5(5): 83 – 87.

Gergon, B. E., Catudan, B. M. and Desamero, N. V. (2008). Ecology based rat management system in Banaue and Hungduan rice terraces. In: *Philippines Rats: Ecology 76 and Management*. (Edited by Singleton, G. R., Joshi, R. C. and Sebastian, L. S.). Philippine Rice Research Institute, Luzon. pp. 85 – 100.

Gupta, A. (2011). *Tropical Geomorphology*. John Wiley and Sons, Ltd., Cambridge University Press. 409pp.

Hampson, R. K., Taylor, M. K. and Olson, M. S. (1984). Regulation of the glycine cleavage system in the isolated perfused rat liver. *Journal of Biological Chemistry* 259(2): 1180-1185.

Happold, D. and Lock, J. M. (2013). The biotic zones of Africa. *Mammals of Africa* 1: 57-74.

IUCN (2019). The IUCN red list of threatened species. Mammals of Tanzania. [http://www.iucnredlist.org] site visited on 13/9/2019.

Jennions, M. D. and Fromhage, L. (2017). Not all sex ratios are equal: The Fisher condition, parental care and sexual selection. *Philosophical Transactions of the Royal Society B: Biological Sciences* 372: 1 – 10.

Kassa, D. and Bekele, A. (2008). Species composition, abundance, distribution and habitat association of rodents of Wondo Genet, Ethiopia. *Ethiop*ia *Journal of Science* 31(2): 141–146.

Khadi, B. M, Santhy, V. and Yadav, M. S. (2010). Cotton: an introduction. *Biotechnology of Agriculture Forest* 65: 1 – 149.

Kingdon, J. (2015). *The Kingdon Field Guide to African Mammals*. Bloomsbury Publishing, London, England. 640pp.

Kingdon, J., Happold, D., Butynski, T., Hoffmann, M., Happold, M., and Kalina, J. (2013). *Mammals of Africa*. Bloomsbury Publishing, London, England. 352pp.

Krohne, D. T. and Burgin, A. B. (1990). The scale of demographic heterogeneity in a population of Peromyscus leucopus. *Oecologia* 82(1): 97-101.

Kumar, G. and Gupta, K. C. (1984). Broad-band microstrip antennas using additional resonators gap-coupled to the radiating edges. *IEEE Transactions on Antennas and Propagation* 32(12): 1375-1379.

Leirs, H. (2003). Management of rodents in crops: Pied Piper and his orchestra. In: Rats, mice and people: *Rodent Biology and Management*. (Edited by Singleton, G. R., Hinds, L.A., Krebs, C. J. and Spratt, D. M.). Australia Centre for International Agriculture Research, Canberra. pp. 183 – 190.

Leirs, H. and Verheyen, W. N. (1995). *Population ecology of Mastomys natalensis (Smith 1834). Implications for rodent control in Africa.* Series No. 35. Belgium Administration for Development Cooperation Brussels, Antwerp, Belgium. 268pp.

Leirs, H., Verhagen, R., Verheyen, W., Mwanjabe, P. and Mbise, T. (1996). Forecasting rodent outbreaks in Africa: an ecological basis for Mastomys control in Tanzania. *Journal of Applied Ecology* 33: 937–943.

Levins, R. and MacArthur, R. (1969). An hypothesis to explain the incidence of monophagy. *Ecology* 50(5): 910-911.

Liu, J., Du, H., Tian, G., Yu, P., Wang, S. and Peng, H. (2009). Community structure and diversity distributions of small mammals in different sample plots in the eastern part of Wuling Mountains. *Zoological Research* 29(6): 637–645.

Magige, F. (2016). Variation of small mammal populations across different habitat types in the Serengeti ecosystem. *Tanzania Journal of Science* 42(1): 15 – 23.

Magige, F. and Senzota, R. (2006). Abundance and diversity of rodents at the human–wildlife interface in western Serengeti, Tanzania. *African Journal of Ecology* 44(3): 371 – 378.

Makundi, R. H., Massawe, A. W., Mulungu, L. S., Katakweba, A., Mbise, T. J. and Mgode, G. (2008). Potential mammalian reservoir in bubonic plague outbreak focus in Mbulu District, northern Tanzania, in 2007. *Mammalia* 72(3): 253 – 257.

Makundi, R. H., Mbise, T. J and Kilonzo, B. S. (1991). Observations on the role of rodents in crop losses in Tanzania and control strategies. *Beitrage Tropical Landwirsch Veterinary Medicine* 29: 465 – 474.

Malhi, C. S. and Parshad, V. R. (1990) Rodent pest problems in India. Asia pacific plant prot. *Documentary* 33: 24–6.

Martin, P., Dickson, J. I. and Baïlon, J. P. (1985). Stress corrosion cracking in aluminium alloy 7075-T651 by discrete crack jumps as indicated by fractography and acoustic emission. *Materials Science and Engineering* 69(1): L9-L13.

Mdangi, M., Mulungu, L. S., Massawe, A. W., Eiseb, S. J., Tutjavi, V., Kirsten, F. and Belmain, S. R. (2013). Assessment of rodent damage to stored maize (*Zea may*s L.) on smallholder farms in Tanzania. *International Journal of Pest Management* 59(1): 55-62.

Meerburg, B. G., Singleton, G. R. and Leirs, H. (2009). The Year of Rat ends – time to fight hunger! Society of Chemical Industry. *Pest Management Science* 65: 351 – 352.

Meheretu, Y., Kiros, W., Deckers, S., Raes, D., Makundi, R. and Leirs, H. (2010). Farmers’ perspectives of rodent damage and management from the highlands of Tigray, Northern Ethiopia. *Journal of Crop* 29(6): 532 – 539.

Meheretu, Y., Sluydts, V., Welegerima, K., Bauer, H., Teferi, M., Yirga, G., Mulungu, L.S., Haile, M., Nyssen, J., Deckers, J., Makundi, R. and Leirs, H. (2014). Rodent abundance, stone bund density and its effects on crop damage in the Tigray highlands, Ethiopia. *Journal of Crop Protection* 55: 61 – 67.

Monadjem, A. (1998). Relative brain size of some southern African myomorph rodents. *South African Journal of Zoology* 33(1): 47-49.

Mueller, J. (2019). How do rodents help the ecosystem? [https://animals.mom.me/rodents-ecosystem-7390.html] site visited on 4/5/2019.

Mulungu, L. S. (2017). Control of rodent pests in maize cultivation: The case of Africa. In: *Achieving Sustainable Maize Cultivation*. Burleigh Dodds Science Publishing, Burleigh. 22pp.

Mulungu, L. S., Lagwen, P. P., Mdangi, M. E., Kilonzo, B. S. and Belmain, S. R. (2014) Impact of spatio-temporal simulations of rat damage on yield of rice (*Oryza sativa* L.) and implications for rodent pest management. *International Journal of Pest Management* 60(4): 269 – 274.

Mulungu, L. S., Makundi, R. H and Leirs, H (2003). Robustness of techniques for estimating rat damage and yield loss in maize fields. In: *Rats, Mice and People: Rodent biology and Management*. (Edited by Singleton, G. R., Hinds, L., Krebs, C. J. and Spratt, D. M.), Australia Centre for International Agriculture Research, Canberra. pp. 224 – 228.

Mulungu, L. S., Makundi, R. H and Massawe, A. W. (2006). Characteristics of rodent damage to major crops in Tanzania and crop loss assessment technique. In:

Management of Selected Crop Pest in Tanzania (Edited by Makundi, R.H.), Tanzania Publishing House, Dar es Salaam. pp 248 – 267.

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., Sixbert, V., Ngowo, V., Mdangi, M., Katakweba, A. S., Tesha, P., Mrosso, F. P., Mchomvu, M., Kilonzo, B. S. and Belmain, S. R. (2015). Spatio – temporal patterns in the distribution of the multimmate mouse, Mastomys natalensis in rice crop and fallow land habitats in Tanzania. *Mammalia* 79: 177 – 184.

Mulungu, L. S., Themb'alilahlwa, A. M., Massawe, A. W., Kennis, J., Crauwels, D., Eiseb, S. and Belmain, S. R. (2011). Dietary differences of the multimammate mouse, *Mastomys natalensis* (Smith, 1834), across different habitats and seasons in Tanzania and Swaziland. *Wildlife Research* 38(7): 640 – 646.

Mwanjabe, P. S. (1993). The role of weeds on population dynamics of Mastomys natalensis in Chunya (Lake Rukwa) valley. In: *Economic Importance and Control of Rodent Pests in Tanzania Workshop Proceedings*. (Edited by Machang'u, R.S.), 6 - 8 July, 1992. Sokoine University of Agriculture, Morogoro, Tanzania. pp. 229 – 232.

Mwanjabe, P. S. and Sirima, F. B. (1993). Large scale rodent control in Tanzania: Present status. In: *Economic Importance and Control of Rodent Pest in Tanzania*. (Edited by Machang'u, R. S.), Workshop proceedings July 6 - 8, 1992, Sokoine University of Agriculture, Morogoro, Tanzania. pp. 134 – 142.

Mwanjabe, P. S., Sirima, F. B. and Lusingu, J. (2002). Crop losses due to outbreaks of Mastomys natalensis (Smith 1834) Muridae, Rodentia, in the Lindi region of Tanzania. *International Biodiet and Biodigestion* 49: 133 – 137.

Naveed M., Nadeem, M. and Islam, M. (2007). AMMI analysis of some upland cotton genotypes for yields stability in different milieus. *World Journal of Agriculture Science* 3: 39 – 43.

Neelanarayanan, P., Nagarajan, R. and Kanakasabai, R. (1994). Vertebrate pests as prey and their composition in the diet of common barn owl, Tyto alba. *Rodent Newl*, 18: 5-6.

Nowak, R. M. and Walker, E. P. (1999). Walker's *Mammals of the World*. Johns Hopkins University Press, Maryland. 786pp.

Poché, R. M., Mian, M. Y., Haque, M. E. and Sultana, P. (1982). Rodent damage and burrowing characteristics in Bangladesh wheat fields. *The Journal of Wildlife Management* 1982: 139-147.

Rana, B. D., Jain, A. P. and Tripathi, R. S. (1994). *Fifteen years of Coordinated Research on Rodent Control.* Technical Bulletin No. 3. Indian Council of Agricultural Research, New Delhi. 141pp.

Rao, S. R. and Ravishankar, G. A. (2002). Plant cell cultures: chemical factories of secondary metabolites. *Biotechnology Advances* 20(2): 101-153.

Rautenbach, A. (2013). *Patterns and processes of rodent and shrew assemblages in the Savanna Biome of KwaZulu-Natal, South Africa*. Doctoral Dissertation for Award Degree of Master of Science in the School of Life Sciences at University of KwaZulu-Natal Durban. 85pp.

Reissig, W. H., Heinrich, E. A., Lit singer, J. A., Moody, K., Fiedler, L., Mew, T. W. and Barrio, A. T. (1985). *Illustrated Guide to Integrated Pest Management in Rice Tropical Asia*. International Rice Research Institute, Philippines. 411pp.

Rennie, P. S. (1979). Binding of androgen receptor to prostatic chromatin requires intact linker DNA. *Journal of Biological Chemistry* 254(10): 3947-3952.

Sabuni, C. A., Sluydts, V., Mulungu, L. S., Maganga, S. L., Makundi, R. H. and Leirs, H. (2015). Distribution and ecology of lesser pouched rat, Beamys hindei, in Tanzanian coastal forests. *Integrative Zoology* 10(6): 531-542.

Senzota, R. B. M. (1982). The habitat and food habits of the grass rats (*Arvicanthis niloticus*) in the Serengeti National Park, Tanzania. *African Journal of Ecology* 20(4): 241 – 252.

Shuai, J., Rose, H. J. and Parker, I. (2006). The number and spatial distribution of IP3 receptors underlying calcium puffs in Xenopus oocytes. *Biophysical Journal* 91(11): 4033-4044.

Singleton, P. A., Dudek, S. M., Chiang, E. T. and Garcia, J. G. (2005). Regulation of sphingosine 1-phosphate-induced endothelial cytoskeletal rearrangement and barrier enhancement by S1P1 receptor, PI3 kinase, Tiam1/Rac1, and α-actinin. *The FASEB Journal* 19(12): 1646-1656.

Sixbert, V. (2013). *Population dynamics and breeding patterns of rodent pest species and crop loss assessment in irrigated rice in Mvomero district*. Dissertation for Award of MSc. Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 72pp.

Smith, D. A. V. I. D. and Trennery, P. A. U. L. (2002). Non-Rodent Selection in Pharmaceutical Toxicology. *A Points to Consider document, developed by the ABPI in conjunction with the UK Home Office*. 7pp.

Sterner, G., Frennby, B., Hultberg, B. and Almén, T. (1996). Iohexol clearance for GFR-determination in renal failure—single or multiple plasma sampling? *Nephrology Dialysis Transplantation* 11(3): 521-525.

Tobin, K. and McRobbie, C. J. (1997). Beliefs about the nature of science and the enacted science curriculum. *Science and Education* 6(4): 355-371.

URT (2012). *National Sample Census of Agriculture 2007/08 Volume Ve: Regional Report: Morogoro Region*. National Bureau of Statistics, Dar es Salaam. 345pp.

Venance, J. (2010). Small mammal communities in the Mikumi National Park, Tanzania. *Hystrix-the Italian Journal of Mammalogy* 20(2): 91 – 100.

Waggoner, B. (2000). Introduction to the Rodentiaa. [https://ucmp.berkeley.edu › mammal › rodentia] site visited on 02/06/2019.

Wallace T. P., Bowman, D., Campbell, B. T. Chee, P. (2008). Status of the USA cotton germplasm collection and crop vulnerability. *Genetic Research for Crop Evolution* 56: 507 – 532.

Whisson, D. (1996). The Effect of Two Agricultural Techniques on Populations of the Cane Field Rat (Rattus Sordidus) in Sugarcane Crops of North Queensland. *Wildlife Research* 23(5): 589-604.

Wilson, D. E. and Reeder, D. M. (2006). Mammal Species of the World: A Taxonomic and Geographic Reference. *Taxon* 42(2): 313-321.

Wood, B. J. and Liau, S. S. (1984). A long-term study of Rattus tiomanicus populations in an oil palm plantation in Johore, Malaysia: II. Recovery from control and economic aspects. *Journal of Applied Ecology* 1984: 465-472.

Yihune, M. and Bekele, A. (2012). Diversity, distribution and abundance of rodent community in the afro-alpine habitats of the Simien Mountains National Park, Ethiopia. *International Journal of Zoological Research* 8(4): 137 – 149.