RESPONSE OF RODENTS TO LAND USE GRADIENTS IN SMALL-HOLDER FARMS IN NORTHERN LIMPOPO: IMPLICATIONS FOR ECOLOGICALLY-BASED RODENT MANAGEMENT (EBRM)

By

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ABSTRACT

Rodents can quickly respond to land use changes whether the change positively or negatively influences their life. In the case of positive influence, rodents exploit the additional food resources and increase their numbers to potential pest level, especially in the absence of predators. Such a population increase can potentially be harmful to humans due to the diseases that rodents carry and the costs due to damage to crops, stored foods and personal possessions that they may cause to small holder farmers. Small holder farmers live in a mixed landscape that is constantly changing. Such changes are changes in land use and they do not only affect rodent population dynamics and species composition, but also their ecosystem services and integrity. Understanding how rodents respond to these land use changes (crop, grazing and settlement) will not only improve the implementation of Ecologically Based Rodent Management (EBRM), but might also enable the monitoring of ecosystem integrity. Rodent trapping was conducted in two different study sites which experience different rainfalls during wet and dry season. A 70 m x 70 m grid was set in three different land uses (crops, grazing and settlement) per study site. A mark-recapture technique was applied and all captures were processed on a temporal station on site. In all grids at a distance of 30 m a line of 20 snap traps were set. With the tapping effort of 1470 trap nights per season for both seasons in this study we captured 839 rodents and 2 shrews, which represented 469 individual rodents and 1 individual shrew. At Vyeboom, cropping land use had the highest number capture (210) and the highest in species richness (9) rodent species and 1 shrew. The settlement land use was second at 144 captures for 8 rodent species and lastly the grazing land use at 80 captures with 7 rodent species. On the other hand, at Ka-Ndengeza also cropping land use had the highest capture (186) with highest richness at 7 rodent species. When it comes to settlement and grazing, settlement was second (129) to cropping in terms of the number of capture but last in terms of richness (5) whilst grazing was last in terms of number of captures 92 and second in terms of richness (6). Despite the high diversity of rodents, only *Mastomys natalensis*, *Gerbilliscus leucogaster*, *Steatomys pratensis* and *Rattus rattus* were captured in meaningful sample sizes to allow for robust density estimation. Similarly there were strong seasonal effects on rodent captures, with almost no captures during the wet season.

Keywords: Rodents, Ecosystem services, Rangelands, Ecosystem integrity, Rodent population, Ecologically based rodent management

Declaration

I ...NEMBUDANI NKHUMELENI LESLY.... am declaring that the research dissertation is my original work and has never been submitted for any study at any other institution. The MSc did not contain other persons' work unless specifically acknowledged and referenced accordingly.

Signed (Student): .... Date: ...2017-08-07...

Signed (Supervisor): .... Date: ...2017/08/07...

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CHAPTER ONE: INTRODUCTION

1.0. Background

Throughout the world rodents are an important group of mammals and they can easily succeed in many different environments and land uses. For example, native rodent species are present on all continents except Antarctica, while their greatest diversity in form is reached in Southern America (Waggoner, 2000). The count of rodent species worldwide exceeds 2700 species, and as such rodents represent over 40% of the global mammalian species (Carleton and Musser, 2005; Happold, 2013), with 60% of living rodent species belonging to just one family; the Muridae. Rodents live in different habitats; which include forests, grasslands and deserts (Aplin *et al.*, 2003). All rodents are characterized by a jaw which has one pair of incisors which grows until the animal is dead (Waggoner, 2000).

Ecologically, rodents can play an important role in terrestrial ecosystem function and maintenance (Zhang *et al.*, 2003). For example, rodents play an important role in dispersal of seeds, pollination, predator-prey relationships and maintenance of ecological stability (Dickman, 1999). Furthermore, rodents can act as bio-engineers (Singleton *et al.*, 2003) and under many circumstances be a valuable food source for humans and other living organisms (Assogbadjo *et al.*, 2005).

Despite their ecological significance, some rodent species are a nuisance and cause a serious damage to agricultural crops in different parts of the world (Singleton *et al.*, 2003). Some rodent species are also well-adapted to human-dominated landscapes and are frequently found in agricultural landscapes, villages and settlements (Aplin *et al*., 2003). Under natural conditions rodent population cycles seem to be mediated by environmental factors such as rainfall and food supply (Belmain, 2006). As such rodents can quickly respond to human-induced land use change (e.g. from natural vegetation to agriculture) by exploiting the additional food resources and increase their numbers to potential pest levels, especially in the absence of natural predators (Salo *et al*., 2010). These increases can pose a threat to food security and can impact financial income by causing a substantial damage to agricultural produce (Singleton *et al.*, 2003). Furthermore, rodents damage food from the storage house (Mdangi *et al*., 2013) and are also carriers of diseases which affect people's health and their animals (Aplin *et al*., 2003).

Controlling rodent pests has therefore not just the potential to impact positively in rural livelihoods, but also reduce the potential of disease transmission. Recently, there has been increased focus to apply ecologically based rodent management (EBRM) principals to achieve long term rodent pest control (Singleton *et al.*, 1999). Such EBRM practice relies on a good understanding of pest rodent ecology, especially population ecology (Singleton *et al.*, 1999). Therefore this study aims to increase our understanding of rodent population cycles in response to land use change. Since humans have become the dominant driver of ecological changes, it is important to understand how different species will respond to such change. Especially for species that might become economically important by impacting on livelihoods.

1.1. Problem Statement

Small holder farmers live in a mixed landscape that is constantly in a state of flux. Such changes can not only affect rodent population dynamics and species composition, but also their ecosystem services and integrity. Understanding how rodents respond to these changes will not only improve the implementation of EBRM, but might also enable the monitoring of ecosystem integrity.

1.2. Research questions

- How does difference in land uses (crops, grazing and settlement) affect rodent population dynamics, species richness and species composition?
- What is the impact of rodents on the livelihoods of community members and what are the indigenous methods used for their control?
- Which land use is mostly dominated by introduced alien species of rodents as compared to indigenous species
- What is the diet of rodent species in different land uses (crops, grazing and settlement)?

1.3. Research Objectives

1.3.1. General objectives

This study's general objective is to investigate the effect of land use change on rodent population ecology and species composition and how such data can be used to implement EBRM and monitor ecosystem integrity.

1.3.2. Specific objectives

- Investigate rodent population dynamics and species composition under different land uses (cropping, grazing and settlement).
- To determine the diet of rodent species in different land uses
- To determine the impacts of rodents on the livelihood of community members

1.4. Research hypotheses

The following hypotheses were made:

1) Species richness will be equal among all three land use types (crop, grazing and settlement)
2) Abundance of pest rodent species will be higher in settlement compared to crop and grazing area
3) The community members will admit that rodents are major pests in the area

1.5. Significance of the Study

Rodent species have been a constant and a significant problem to agricultural activities worldwide, which has led to financial losses during various stages in agricultural production. This study will help to understand how rodent species respond to land use change, will also be used to predict rodent occurrence under land use changes. It will also bring about community awareness of the impacts of rodents on the small-holder community as well as helping the community to reduce the impacts. Such data will be important to predict future impacts because rodents are good ecosystem indicators (Avenant, 2000). Furthermore population ecology data will help in the implementation of (EBRM).

1.6. Expected outcomes

- It is expected that there might be a difference in species composition in different land uses (crop, grazing and settlement) because different species have a different magnitude of tolerance to human disturbance and also due to availability of food.
- That should also influence the diet of different species to differ following the types of food available per area.

- The expectations are that the stomach contents of the animals in crop and settlement areas might contain high percentage of different crops whereas the stomach contents of animals from natural areas might contain high percentage of insects.
- We expected most community members to be aware of rodent problems and also having a specific method to deal with the problem.

CHAPTER TWO: LITERATURE REVIEW

2.0. Rodent damage in small holder farming communities

The abundance and diversity of rodents in all kinds of habitats makes them important to human health and food security (Assogbadjo *et al.*, 2005). In small holder farming communities rodents occupy a range of habitats including crop fields, grazing areas, settlements and households. Rodents are a key pest in small holder farming communities (Makundi *et al.*, 2005) where their impact is not just limited to the agricultural crops (during all cropping stages) but also include damaging stored food through contamination (Makundi and Massawe, 2011). For example, in Africa rodent pests create serious problems in rural croplands/rangelands, where rodents damage planted and stored grain (Makundi *et al.*, 1999). Furthermore rodent populations can also be potentially harmful to humans because they carry diseases which affect human health (Meerburg *et al.*, 2009). For example in terms of the general community health, rodents are carriers of various zoonotic diseases which can affect both humans and livestock (WHO, 2006; Makundi and Massawe, 2011).

In the African continent rodents are seen as a significant issue in agriculture and general community health (Makundi *et al.*, 1999). Pest rodents are responsible for large financial losses in crops which are routinely eaten, especially vegetables like potatoes and cereals (Makundi and Massawe, 2011). For example, (Makundi *et al.* 1999) have reported that in Tanzania the rodent damage amount to about 15% in cereals, whereas the loss of maize seedlings was between 40-80% in Morogoro, Tanzania (Mwanjabe and Leirs, 1997, Mulungu *et al*., 2003). Similarly, (Bekele *et al* 2003) estimated maize damage and losses in Central Ethiopia to be up to 26%. In Kenya, losses seems to be associated with rapid population increases (pest outbreaks) (Taylor, 1968), which concurs with observations from Tanzania, which normally leads to significant crop damages (Mwanjabe, 1990). Estimates for east Africa suggests that the impact of such outbreaks can significantly affect food security, e.g. up to 80% of the expected harvest might be lost during rodent outbreak years (Mulungu *et al*., 2003). However, even at densities of around 40 rodents per hectare losses of maize in the field soon after planting may amount approximately 40% (Mwanjabe *et al*., 2002). In Tanzania, it was estimated that rodents caused losses to maize production of 5-15% amounting to an average of 412,500 tons per annum, sufficient to feed two million people (Makundi *et al*., 1999). As such rodents present a serious threat to farming outcomes for many poor farmers in the African continent due to the damage and losses they cause and high management costs (Makundi *et al.*, 1999). Yet, despite the financial importance of rodent control, most small-holder farmers claim that they have little control on rodent pests (Schiller *et al*., 1999). This is because chemical methods are expensive; waste more time and when applied alone may not be able to reduce the rodent population to acceptable level (Douangbouph *et al*., 2009). As such there still remain many unresolved research questions related to the sustainable control of rodent pests under small holder farming conditions.

2.1. Rodent control in small-holder farming areas

Rodent control in developing countries is often limited to individual landowners and collective communal control seems to be limited (Singleton *et al.*, 2004). In most instances, farmers have little working technologies that can be employed to minimize the damage of rodents in their cropping systems (Makundi and Massawe, 2011). Rodent control technologies and practices seem to be shaped by the local social economic conditions and past practices utilized by the communities (Sudarmaji *et al.*, 2003). As such local knowledge of individual farmers on factors that affect crop damage will play an important part in pest control, which seems to depend on the level of crop liability, the population of rodent pest during the most susceptible crop stage and will determine the control intensity farmers are willing to invest in (Makundi *et al.*, 2005). Nonetheless, little is known on how the impacts of rodents affect the choice and management action used by small holder farmers (Stenseth *et al.*, 2003).

Small holder farmers often seem to use inappropriate techniques to reduce rodent impact, relying heavily on chemical control which not only negatively impacts non-targeted species (and the environment), but seems to also provide a low financial return on investment (Singleton, 2003). To increase cost effectiveness, most small holder farmers prefer the use of Zinc phosphide to control rodents during outbreaks due to the fact that it is cheap and fast acting (Mwanjabe, 1998; Buckle, 1999). Chemical control of rodents requires knowledge of rodent population dynamics to guide deployment, which is often lacking under small holder farming conditions, which often limits its effectiveness (Makundi *et al*., 1999). Nevertheless, chemicals are likely to stay as the main management tool to control rodent damage in many cropping areas (Wood and Fee, 2003).

Nonetheless, due to various environmental factors associated with the use of poisons, integrated management methods based on the ecology of the principal rodent pests have been promoted for developing countries (Singleton *et al.*, 1999; Wood and Fee, 2003 and Singleton *et al.* 2003) have taken into consideration the economics of rat-control techniques or strategies in less developed countries. Studies on integrated management of rodents in the rural areas under replicated conditions have been lacking, whereas it is important to rate its economic value in comparison to conventional management based on rodent killing chemicals.

2.2. The limitations of rodenticides to control rodent pests in small-holder farms

If rodenticides are applied in a correct manner they can successfully be used in suppressing rodent populations. However, rodenticide use has several limitations. First, most small holder farmers lack the skill and financial resources to apply rodenticide in quantities needed to reduce rodent populations (Singleton *et al*., 1996). Secondly, some rodents do not always consume the lethal dose (Buckle *et al*., 2010). Thirdly, impacted rodents can compensate with increased survival and breeding performance (Singleton *et al*., 1999). Finally, rodenticide use normally coincides with secondary killing of predators, which could increase the rodent problems (Ward, 2008). As such the correct, effective and sustainable deployment of chemical control for rodent pest under small holder farming conditions still remains elusive (Ward, 2008).

2.3. The concept of EBRM on small-holder farms

The most significant development in rodent pest control techniques has been an increase in the understanding of the ecology of the rodent pest species (Singleton *et al*., 1999). Combined with the re-appearance of awareness of the fact that rodents are significant pests in agriculture in Asian and African continent (Leirs, 2003) and the need for environmental friendly management resulted on re-visitation of former techniques that were used to manage rodent pest (Singleton, 1997). From this Integrated Pest Management (IPM; Singleton *et al*., 2004) arose as an attractive approach to control agricultural pests. Essentially Ecologically based rodent management (EBRM) is an extension of IPM. EBRM tries to address the need for rodent conservation as well as optimized crop production and protection (Taylor et al., 2012). As such, EBRM is heavily reliant on a thorough understanding of rodent population dynamics, biology, ecology community dynamics as well as habitat use (Makundi and Massawe, 2011; Taylor *et al*., 2012). While great strides have been made to understand the ecology and biology of certain rodent pest and how it affects EBRM (e.g. *M. natalensis*; Makundi and Massawe, 2003), little is known about the vast majority of potential rodent-pest species to effectively implement EBRM strategies (Singleton *et al*., 2003; Makundi and

Massawe, 2011).This is especially true for small holder farming units that are commonly distributed throughout mixed landscapes, which makes it also important to understand how rodents respond to such land use changes. Such mixed landscapes can have a dramatic effect on rodent population cycles and species composition, which could in turn affect the implementation of EBRM. This concept also aims on controlling the population of the rodents and keeping it at the minimum which would reduce their impact on crop yields (Singleton, 2007).

Nonetheless, great strides have been made by the adoption of EBRM in agricultural systems. From many studies there has been a positive economic outcome with the adoption of EBRM (Davis *et al.*, 2004). As such EBRM is taking center stage in rodent management for small holder farming areas and it is gaining stronger impacts. In the past years rodenticides were the only solution farmers had to trust in the crops areas and surrounding buildings (Pelz, 2001). However, in the recent years it was emphasized greatly that EBRM is the way to go on rodent management both in developed (Cowan *et al.*, 2003) and developing countries (Belmain *et al.*, 2003). For example, a study conducted in Indonesia showed that a high number of farmers strongly agreed that working together will help to manage rodents, however only one third did work together in the beginning. But after three years of EBRM application, about 84% of the farmers worked together to manage rodents whereas in areas where there was no EBRM practiced only 62% worked together. The perception of farmers practicing EBRM was changed and they started to shift to more ecologically benign methods to control rodent populations (Singleton *et al.*, 2004).

2.4. Rodents as indicator species of ecosystem integrity

Despite their negative financial and health impacts, rodents are also important indicator species of ecosystem integrity (Avenant and Cavallini, 2007). Habitat change affects rodent diversity and community structure as well as the presence of key indicator species, and rodents can therefore be considered significant indicators of habitat integrity (Avenant and Cavallini, 2007). For example, the multimammate mouse *Mastomys coucha* can reproduce at a very high rate and it is seen as a good indicator of disturbance (Avenant, 2011). (Avenant *et al* 2008) reported that *Mastomys* sp. numerically dominates other small mammals in areas which are just coming out of natural disturbances such as drought, overgrazing, cultivation and veld fire. Ecosystem integrity is a major contributor in managing natural resources effectively. If the ecosystem is in a good condition it can play an important role controlling climate change and provides good adaptation opportunities locally

(Wittmer and Gundimeda, 2012). A good natural ecosystem profits the surrounding environment and living organisms with important goods and services that they need for their day to day existence (Wittmer and Gundimeda, 2012).

CHAPTER THREE: DESCRIPTION OF THE STUDY AREAS

3.0. Location of the Study Areas

Vyeboom is located three km south of Luvuvhu River and four km from Vuwani town in Vhembe District under Makhado Municipality on Farm Vygeboomdrift 53. The geographical coordinates of the study site are E 30.37657^0, S 23.14407^0 and the altitude is about 611 m above sea level. This area experiences two different seasons which are hot wet season and cool dry season. The hot wet season runs from October to March with the temperature ranging between 16^oC and 30^oC monthly, whereas the cool dry season runs from May to August with temperature ranging between 9^oC and 25^oC monthly. The mean annual precipitation experienced in this study site is about 791 mm (Hijmans *et al*., 2005).

Ka-Ndengeza is located 2 km south of Middle Letaba River and 30km north of Giyani town in Mopani District under Greater Giyani Municipality on the farm Greater-Giyani 891. The geographical coordinates of the study site is E 30.40779^0, S 23.30389^0 at the altitude of about 546 m above sea level. The dry season runs from October to March, with temperatures ranging between 16^oc and 30^oc, whereas the cool dry season runs from May to August, with temperatures ranging between 9^oc and 24^oc. The mean annual precipitation in this area is about 718 mm (Hijmans *et al*., 2005).

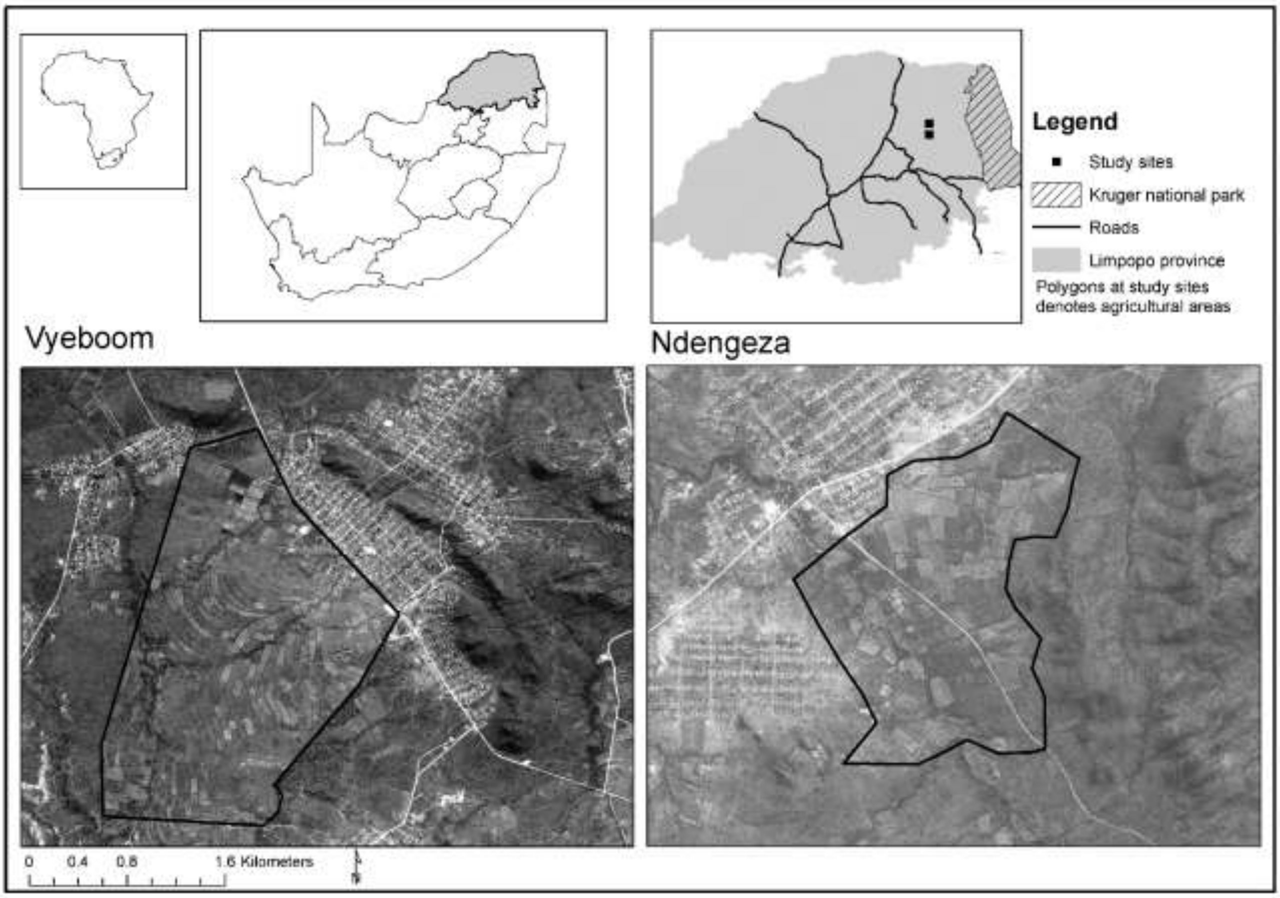

Figure 1: Map showing the study sites (Vyeboom [top] and Ka-Ndengeza [bottom] study sites)

3.1. Vegetation of the study areas

The vegetation of the study site is classified as both Granite Lowveld (in the areas around the rocky kopjes) and Gravelotte rocky bushveld (on the rocky kopjes). Granite Lowveld has a vulnerable conservation status whilst Gravelotte rocky bushveld is Least Threatened (Mucina and Rutherford, 2006). Vegetation is characterized by tall shrubs with few trees to moderately dense low woodland on the deep sandy uplands with *Combretum zeyheri* and *Capiculatum sp.* Bottomlands are characterized by dense thicket to open Savanna with *Acacia nigrescens*, *Dichrostachys cinerea* and *Grewia bicolor* dominating the woody layer (Mucina and Rutherford, 2006).

3.2. Vyeboom land uses (Fig. 2)

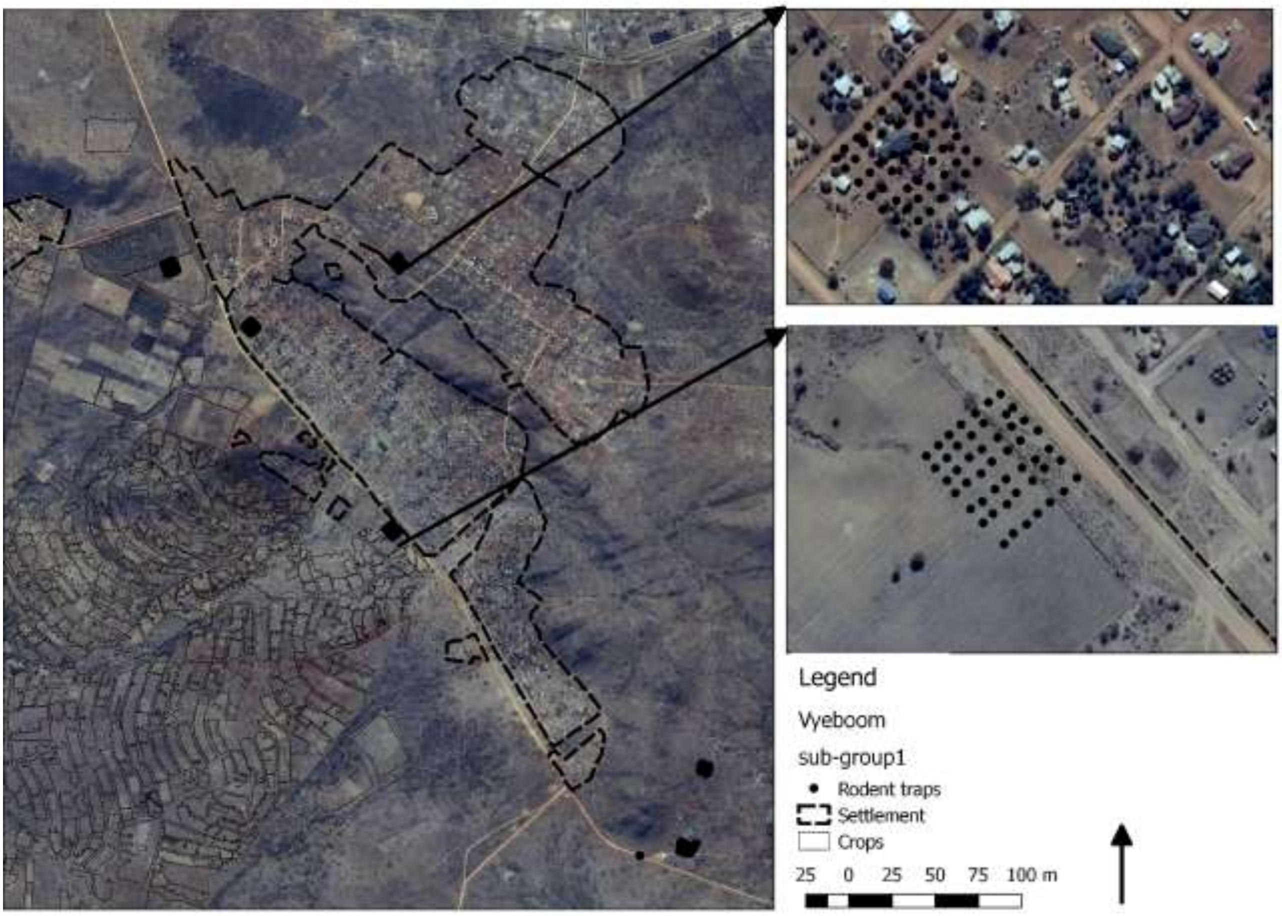

Figure 2: Map showing the Vyeboom study site, insets show the placement of live traps in Settlement (top inset) and cropping fields (bottom inset)

3.2.1. Grazing area

The natural vegetation is comprised of small grass, shrubs and tall trees. This area is mainly used for livestock grazing where all the livestock around the community depend on the natural environment for pasture (Huduk, 1999). The community also relies on this environment for fire wood and hunting. However, due to poor land management practices the grazing areas are severely overgrazed with woody plants replacing shrubs and grass are dominated on low lying areas by *Dichrostachys cinerea*. (Huduk, 1999).

3.2.2. Crop growing area

Cropping in the Vyeboom community area is based on rotational cropping between corn, peanuts and Pinto beans (*Phaseolus vulgaris*). Land preparation start early October to mid-November and plant of crops commence early December depending on rainfall. Harvests normally start around February until late April depending on the farmer. Yield varies between landowners, but single household is able to harvest at least five bags of maize (5x 50 kg) to as many as twenty bags (20 x 50 kg) and at least three bags of peanuts (3 x 50 kg) to as many as ten bags of peanuts (10 x 50 kg) from their farms which are 500 m^2 at average. Only few farmers can afford to hire a tractor to plough their land where as the rest of the farmers still depend on human power to prepare their land for plantation. Other farmers hire people to come and help them to cultivate their land where as other farmers work collectively helping each other as a family. Crop residues from the cropping areas are also used in the dry season for livestock fodder.

3.2.3. Settlement areas

The settlement areas are places of residence for small holder farmers, as well as non-farming community members. Settlement areas are also used to kraal livestock and to store harvested crops. The majority of household have large yards (50 m x 40 m) where cropping can also take place. Gardens (or small lots in settlement areas) are normally used to grow corn, peanuts, beans, ground nuts, avocados mango trees, bananas, litchis and oranges depending on their different choices. A large proportion of community members also own dogs, cats, goats, sheep and poultry which is all housed in the settlement areas.

3.3. Ka-Ndengeza land uses and trap layout (Fig. 3)

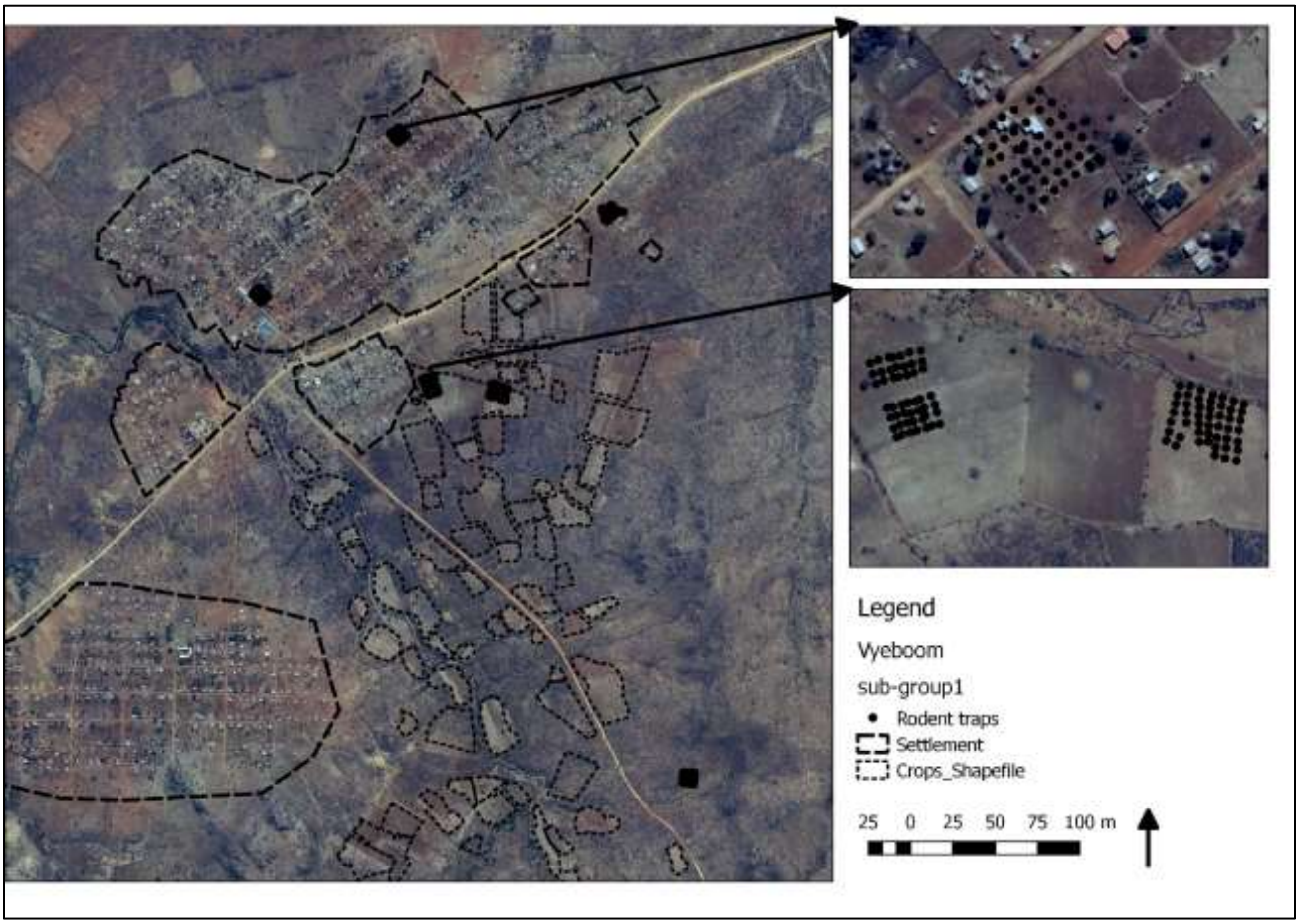

Figure 3: Map showing the Ka-Ndengeza study sites, insets show the placement of live traps in Settlement (top inset) and cropping fields (bottom inset)

3.3.1. Grazing areas

These areas are highly dominated by grass, small and tall trees which are being overtaken by *Dichrostachys cinerea* leading to encroachment (Huduk and Wessman, 2000). The area is mainly used for livestock grazing, firewood as well as hunting.

3.3.2. Crop growing areas

In this area the community plant corn, peanuts, ground nuts and beans. Preparation for cultivation begins around late October and the whole of November either by means of a tractor or manpower (or hired help/family help). Planting of crops commences as soon as they have received enough rain from late November through the whole December. Harvest start from February to late April depending on the pace and man power from different farmers. Yield varies between farmers; however a single farmer can harvest at least two bags of maize (2x 50 kg) to as many as ten bags of maize (10x 50 kg) and at least one bag of peanuts (1x 50 kg) to as many as five bags of peanuts (5x 50 kg) from their farms which are mostly 500 m^2 at average.

3.3.3. Settlement areas

The settlement is a place of residence for both the small holder farmers and non-farming community members. However because of the bigger size of their yards (60 m x 50 m) different agricultural activities are also practiced on plots. These activities include cultivation of different fruit trees and vegetables ranging from mango trees, peaches, corn, peanuts, ground nuts, pumpkins and oranges depending on the choices of individual households. Different livestock, including cows, goats, pigs, sheep and chickens, are also housed on the plots. The storage house for the harvested crops is also found in the settlement areas.

CHAPTER FOUR: METHODOLOGY

4.0. Ethical Approval

Ethical approval was obtained from UNIVEN for rodent capture (SMNS-/14/ZOO/03/2803). Also, capture permits were obtained from the Limpopo Department of Environmental Affairs (Permit number 0089-MKT001-00004).

4.1. Rodent trapping/population ecology

4.1.1. Live-trapping

In each of the two villages Sherman live traps were deployed in all three land uses (crop, grazing and settlement). All traps were baited with a mixture of oats, peanuts and peanut butter. In each land use we replicated a 7 x 7 grid (traps were 10 m apart). Vegetation cover was measured and all traps were covered with grass and leaves to prevent exposure to the sun. Each trapping site was georeferenced using a Garmin Etrex GPS unit. Captured rodents were taken to the field working station, where they were weighed, identified to species level and their sex identified (using rodent key; Newbery, 1999), age identified, uniquely marked and released at a point of capture. Trapping was conducted for five days per grid and traps were monitored twice daily (Avenant & Cavallini, 2007). Trapping was conducted two times a year, in the wet season (3rd to 6th of February 2015 at Vyeboom and 9th to 12th of February 2015 at Ka-Ndengeza) and during dry season (8th to 25th of April 2014 in Vyeboom and 3rd to 15th of June 2014 at Ka-Ndengeza).

4.1.2. Processing of sacrificed animals

At each replicated live trapping site a further 20 snap traps were deployed around 60 m from the live trapping grid. Snap traps were baited with peanut and oats. Snap traps were check twice daily, trapped animals were processed in the field for sex, age, weight and species (using Newbery key: (Newbery, 1999) from there they were frozen. Once in the laboratory rodents were thawed and dissected to remove stomachs (Mulungu *et* al., 2014). Stomach content data was analyzed in the laboratory by spreading the contents of each stomach on a plastic Petri dish for microscopic analysis using a binocular dissecting microscope (LEICA ZE4D). The average percentage volume (PV – which is the contribution of a particular food item to the volume of stomach content) was estimated to nearest 10% (Mulungu *et al.,* 2014). If the percentage contribution were less than 10% it was awarded a value of 5% (Mulungu *et al.,* 2014). The contents were sorted into different categories namely; corn, seeds, vegetation, insects and unknown particles. The presence of starch was checked by adding an iodine solution to the stomach content (Mulungu *et al.,* 2014).

4.2. Questionnaire/Focus group discussions

To better understand the impact of rodents on community members, as well as local management actions, focus group discussions was held on 1st to 5thof April 2014 at Vyeboom and 25th to 30th of April 2014 at Ka-Ndengeza. Before the study commenced permission was obtained from both community chiefs (chief Nkavele of Ka-Ndengeza and chief Masia of Vyeboom) and community elders to discuss rodent related issues with community members. The focus group discussion framework focuses on small groupings of community members. (Kitzinger, 1994; Makundi *et al.,* 2005: Eisen *et al.,* 2013). This rodent study was part of a larger study and to facilitate comparison and cooperation between studies the sampling design were adapted to replicate other studies during some time (camera trapping). Therefore, the settlements where divided into grids of 300 m x 300 m each (which was used in camera trapping study; Maree Msc study). From each settlement ten 300 m x 300 m grids where randomly selected. From each of the ten grids, groups of 10 members each from the communities were also randomly selected, which means 10 community members were interviewed as a group which resulted in 10 questionnaires filled out, which represented 100 community members. From each group of 10 community members a leader was appointed which were interviewed separately on a later stage during a stakeholder workshop (Stakeholder workshop was not part of this MSc study; Swanepoel *et al,* In Review). The questions were formulated in a way that their answers reveal the views of community members on the issue of rodent damage.

Questionnaire data (Appendix A) was used to access the socio-economic impact of rodents on small-scale farming. Estimated grain loss due to rodent pests was pooled across interviewees and used to quantify rodent impact on small-scale farming.

4.3. Data Analysis

4.3.1. Species diversity, composition and capture rate

To compare species richness between the different sites and land uses, as well as sampling adequacy, species accumulation curves were generated (Gotelli and Colwell, 2001). Species accumulation curves were generated using the MaoTau' function in EstimateS (Colwell *et al.*, 2004). We used general linear models with a logit link function and Poisson distribution to investigate the effect of land use, species and season on rodent capture rates (number of rodent captured). Study sites were characterized by a large number of zero detections which resulted in over dispersion for Ka-Ndengeza (c= 5.7 "dispersion test" in AERR package [Kleiber and Zeileis, 2008]) and Vyeboom (c=7.2). The work was therefore, corrected for over dispersion by using a negative binomial model (Ver Hoef & Boveng, 2007), and then modeled the effect of season, land use and species on capture data. We did not fit interaction between variables because of low sample sizes. We ranked models using Akaike information criterion (AIC) and regard models with >2 delta AIC as models with most support (Mulungu *et* al., 2003: Burnham *et al.*, 2011), and used AIC weight (*w*) to further guide variable importance. Finally, since there was a large discrepancy in capture rates between the sites, we applied a model to each village separately. All analysis was done in R (R Development Core Team, 2011) using the following packages; AER (Kleiber and Zeileis, 2008), MASS (Venables and Wickham, 2002) and ggplot2 (Wickham, 2009).

4.3.2. Mark recapture model

Rodent density was estimated by using spatially explicate mark capture recapture models (SECR; Efford and Fewster, 2013). This model was favored since it empirically estimates density (density is an integral part of fitted model) and avoids the computational difficulties in defining 'effective trapping area' when using traditional non-spatial capture recapture models (Efford and Fewster, 2013). In SECR models density is estimated by using spatial capture-recapture data to model the distribution of animal home ranges in space (Effort, 2004). SECR models assume fixed circular home ranges and that the encounter rate declines from the center of the home range (Efford, 2004). The observation model essentially describes the rate of decline from the home range center (also defined as activity center), and is defined by a detection function. The half normal detection function is the commonly used and is defined by a scale parameter (sigma) and encounter rate at home range level (similar to detection probability; Efford, 2004). SECR models also allow the incorporation of covariates to account for heterogeneity in both detection probabilities and density (Efford and Fewster, 2013). However, field sexing rodents proved to be difficult and reliable sex data were therefore not available. Therefore a SECR model was fitted by maximizing the likelihood in which the densities of rodents were modeled to vary by season, study site and land use. To achieve this, each season (wet and dry), land use (crops growing, Grazing, and Settlement), site (Vyeboom and Ndengeza) and species combination were grouped into a specific session (e.g. *Mastomys* Ndengeza Dry Grazing). SECR models were then constructed to allow density to vary by session (Effort and Fewster 2013). The full session models were contrasted against a null model in which density was modeled as constant between sessions. Akaike Information Criterion (AIC; Akaike, 1974) was used to selected most parsimonious models and models with a delta AIC >2 were considered to have equal support (Burnham *et al*., 2011). SECR models were fitted using the ('secr': Efford, 2012) package in R (R: Team, 2012).

4.3.3. Dietary analysis

Mulungu *et al.,* 2014 was followed to describe rodent diet. For the different food categories the average percentage volume (PV is defined as the contribution of each food category to the volume of that particular stomach) was estimated to the nearest 10%. For food categories that contributed less than 10% an additional category of 5% were used (Mulungu et al., 2014).

CHAPTER FIVE: RESULTS

5.0. Rodent trapping/population ecology for Vyeboom and Ka-Ndengeza villages

During a trapping effort of 1470 trap nights per season for both seasons we captured 839 rodents and 2 shrews (Table 1), which represented 469 individual rodents and 1 individual shrew (Table 1). At both sites the negative binomial models had adequate model fit (Ka-Ndengeza, Goodness of Fit test [GOF]; $\chi^2 = 0.074$ & Vyeboom GOF; $\chi^2 = 0.44$) modeling the effect of covariates on rodent capture data. At both sites, season and species had the highest support in explaining the variation in rodent capture data (Table 2), even though there was limited support from land use ($w = 0.25$) also affecting rodent capture rates (Table 2). At Ka-Ndengeza species and season had a significant ($\boldsymbol{\beta} = -1.34045$, $z = -4.44$, $p < 0.000$) effect on rodent capture rates with 26% (CI = 14.4%-47.1%; Fig. 4a) less rodent captures in the wet season compared to the dry season. In contrasting the species effect on the number of rodents captured, we fixed *Rattus rattus* as the reference species and compared other species to it. At Ka-Ndengeza only *Mastomys natalensis* were captured at significantly higher rates than *R. rattus*. (5.2 x more *M. natalensis* than *R. rattus*. $\beta = 1.65$, $z = 3.23$, $p < 0.001$; Fig. 4a). Similarly at Vyeboom, species and season had a significant effect on rodent capture rate ($\beta = -3.065$, $z = -8.259$, $p < 0.000$; Fig. 4b). Capture rates were 5% (CI = 2% - 10%) lower in the wet season compared to the dry season (Fig. 4b). At Vyeboom *R. rattus* dominated the capture rates and no species were captured at higher rates (Fig. 4b).

During dry season we captured 190 rodents representing 9 rodent species and 1 shrew from Vyeboom croplands (Table 1) whereas at Ka-Ndengeza crop lands 173 rodents were captured representing 6 rodent species (Table 1). At Vyeboom grazing areas 78 rodents where captured representing 7 rodent species (Table 1), while in the grazing lands of Ka-Ndengeza we captured 81 rodents representing 6 rodent species (Table 1). At Vyeboom settlement 128 rodents representing 8 species were captured (Table 1) and 87 rodents representing 5 rodent species captured at Ka-Ndengeza (Table 1).

On the other hand during wet season we captured in croplands of Vyeboom 20 rodents representing 1 rodent species (Table 1), while in Ka-Ndengeza crop lands we captured 13 rodents representing 3 rodent species (Table 1). We also captured 2 rodents representing 1 rodent species from Vyeboom grazing lands (Table 1), whereas in Ka-Ndengeza at the grazing land use we captured 11 rodents representing 4 rodent species (Table 1). Lastly 16 rodents representing 3 rodent species from settlements in Vyeboom were captured (Table 1), whereas in the settlement area of Ka-Ndengeza we captured 42 individuals representing 4 rodent species (Table 1).

At Vyeboom during the dry season there were a total of 10 rodents and 1 shrew species captured which is high compared to only 3 rodent species during wet season (Table 1). On the other hand the difference in the number of species captured in dry and wet season in Ka-Ndengeza area was 2, with dry season having a total of 9 rodent species compared to the 7 rodent species captured in wet season (Table 1).

Table 1: Trap success from Vyeboom and Ndengeza for the dry and wet season

Ndengeza	Dry Season									Wet Season								
	Agricultural			Natural			Settlement			Agricultural			Natural			Settlement		
Species	Tot captures	No Indv	RAI*	Tot captures	No Indv	RAI*	Tot captures	No Indv	RAI*	Tot captures	No Indv	RAI*	Tot captures	No Indv	RAI*	Tot captures	No Indv	RAI*
Aethomys namaquensis	3	3	0.02	8	4	0.09	3	3	0.04				5	5	0.45	1	1	0.02
Gerbilliscus leucogaster	8	6	0.05	12	3	0.14				4	3	0.31	3	3	0.27			
Lemniscomys rosalia	1	1	0.01															
Mastomys natalensis	155	69	0.90	31	16	0.36	60	26	0.74	6	2	0.46						
Mus minutoides	5	5	0.03	24	16	0.28	1	1	0.01				1	1	0.09	26	15	0.62
Rattus rattus	1	1	0.01				16	9	0.20							8	8	0.19
Elephantulus myurus				3	2	0.03												
Saccostomys campestris				9	5	0.10				3	3	0.23	2	2	0.18			
Rhabdomys pumilio							1	1	0.01							7	5	0.17

* Relative Abundance Index = Nr of individuals/Total number of captures for that specific landuse

Vyeboom	Dry Season									Wet Season								
	Agricultural			Natural			Settlement			Agricultural			Natural			Settlement		
Species	Tot captures	No Indv	RAI*	Tot captures	No Indv	RAI*	Tot captures	No Indv	RAI*	Tot captures	No Indv	RAI*	Tot captures	No Indv	RAI*	Tot captures	No Indv	RAI*
Aethomys namaquensis	5	4	0.03	17	9	0.22	6	5	0.05				2	2	1.00	7	4	0.44
Gerbilliscus leucogaster	41	23	0.22	11	6	0.14	1	1	0.01									
Lemniscomys rosalia	2	2	0.01	5	5	0.06	2	1	0.02									
Mastomys natalensis	4	4	0.02				12	5	0.09	20	9	1.00				4	4	0.25
Mus minutoides	6	6	0.03	12	8	0.15	4	4	0.03									
Graphiurus murinus				1	1	0.01												
Otomys irroratus	1	1	0.01															
Steatomys pratensis	49	26	0.26	30	17	0.38	1	1	0.01									
Rattus rattus	76	39	0.40	2	2	0.03	101	52	0.79									
Rhabdomys pumilio	4	4	0.02				1	1	0.01							5	4	0.31
Crocidura cyanea	2	1	0.01															

* Relative Abundance Index = Nr of individuals/Total number of captures for that specific landuse

Table 2: Model selection for variables effecting rodent capture data at Vyeboom and Ka-Ndengeza

	Vyeboom				Ka-Ndengeza			
Model	Df	Resid. Dev	dAIC	weight	Df	Resid. Dev	dAIC	weight
p+Season	64	65.07	0	0.75	54	69.67	0	0.75
Sp+L.use+Season	62	65.49	2.2	0.25	52	68.83	2.2	0.25
L.use+Season	72	73.93	14.9	0	60	67.33	17.2	0
Season	74	75.26	17	0	62	67.98	16.6	0
Sp	65	75.21	39.6	0	55	68.80	12.9	0
Sp+L.use	63	75.39	42.4	0	53	67.92	14.9	0
L.use	73	74.92	43	0	61	68.37	32.1	0

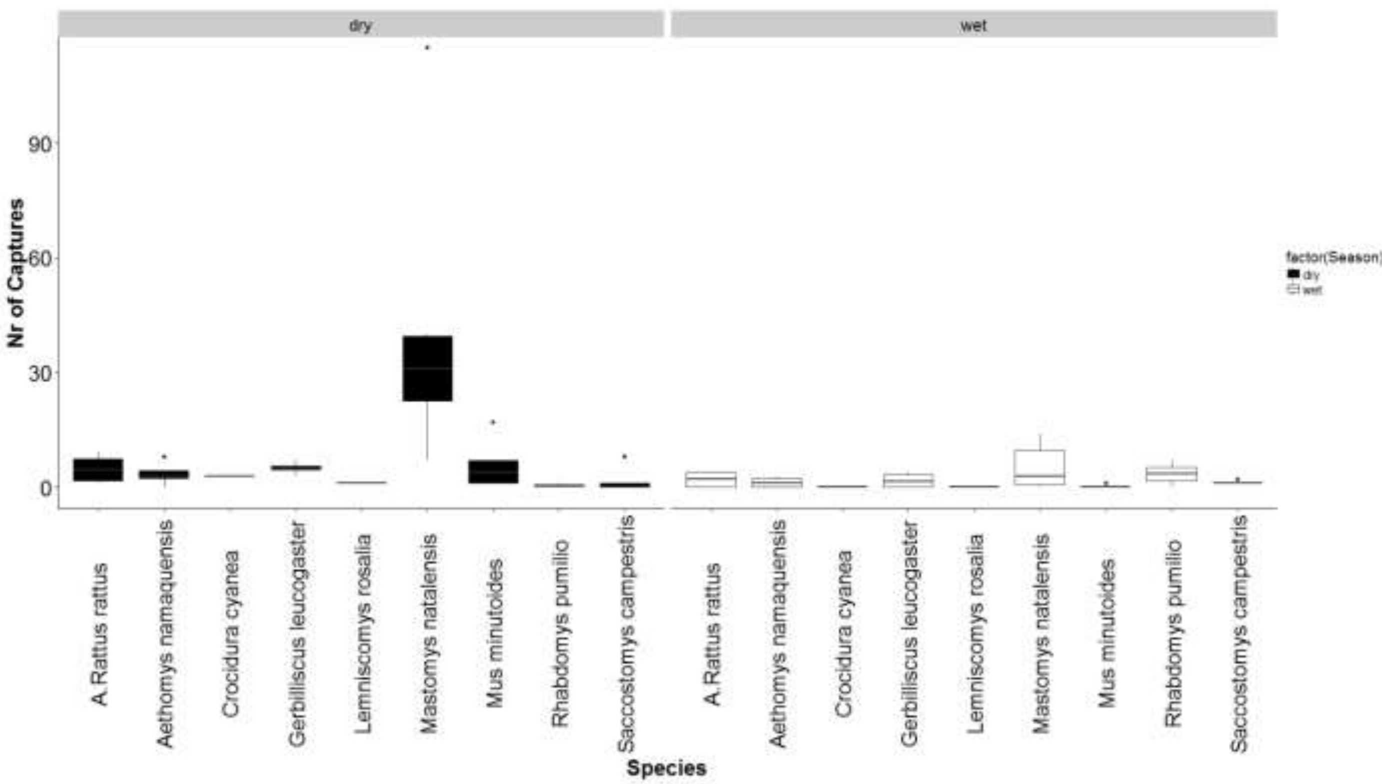

Figure 4a: Rodent capture rates at Ka-Ndengeza during the wet (09th to 12th February 2015) and dry (03rd to 15th June 2014) season

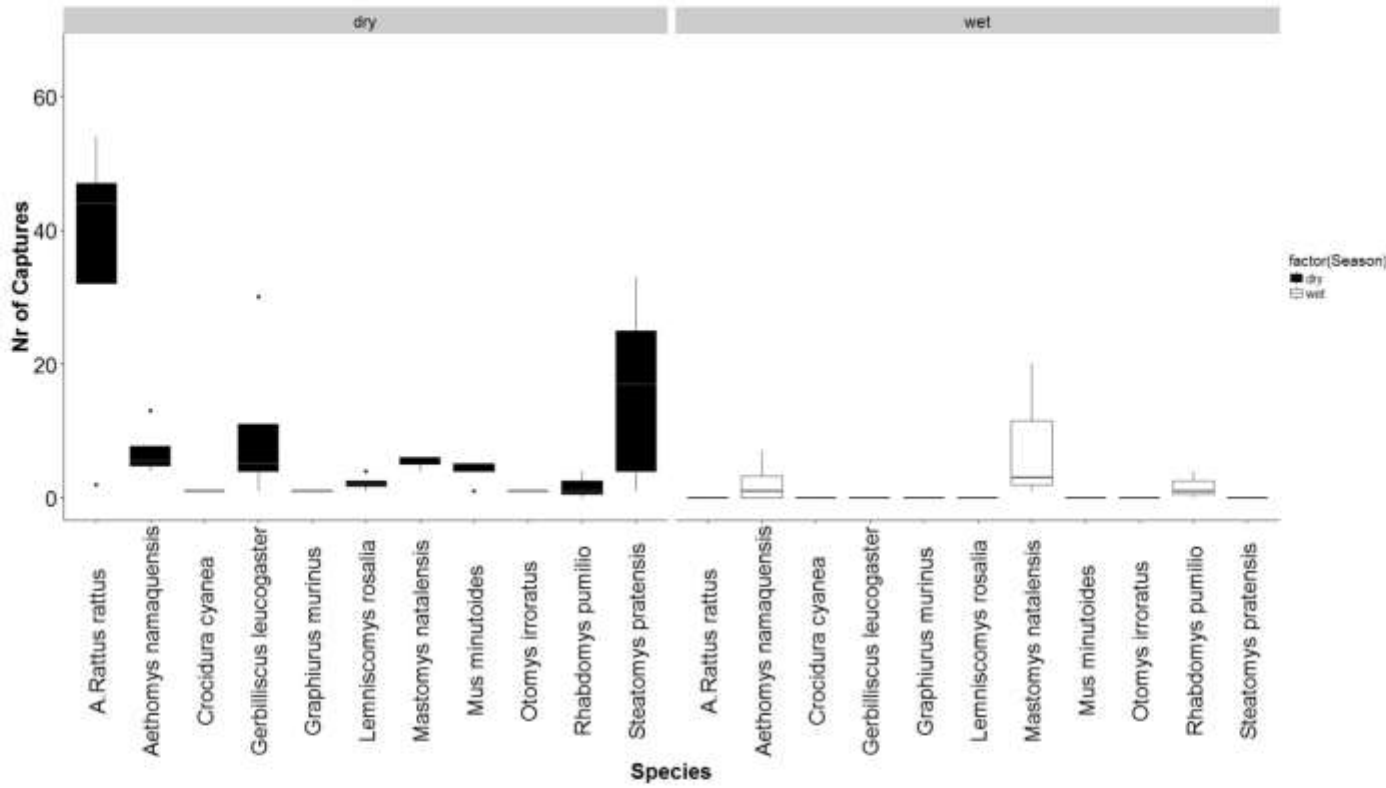

Figure 4b: Rodent capture rates at Vyeboom during the wet (03rd to 06th February 2015) and dry (08th to 25th April 2014) season

5.1. Species accumulation curves

5.1.1. Species observed at Vyeboom and Ka-Ndengeza villages during dry and wet seasons

At Vyeboom during dry season only the species accumulation graph representing the settlement land uses leveled off at 1400 trap night Fig 5(a). This result simply means that in this land use a reasonable number of individual samples have been taken and we can be confident that we did not under sample. On the other hand, crops and grazing land uses did not level off Fig 5(a).

In the wet season the graphs representing crops and grazing land uses leveled off immediately after 380 trap nights with only one species observed Fig 5(b), whereas the graph representing settlement land use leveled at the same number of trap nights (380) with 3 species observed Fig 5(b).

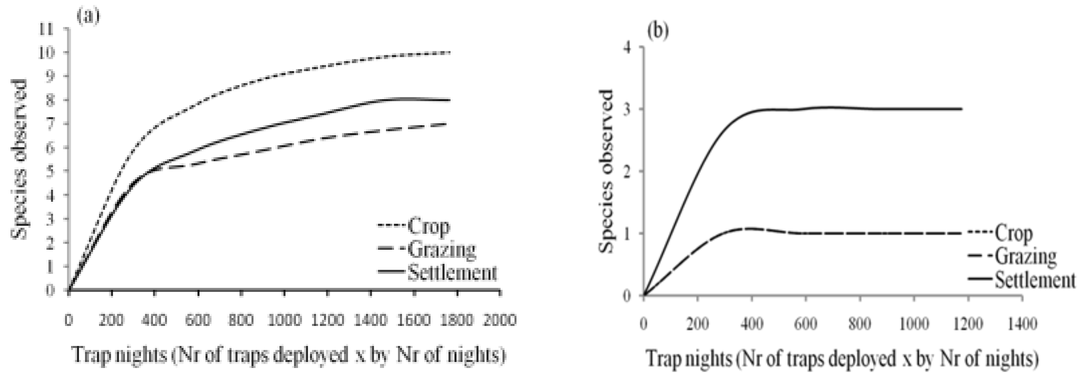

Figure 5: Vyeboom accumulation curves for dry (a) and wet (b) seasons showing species observed

The dry season of Ka-Ndengeza had only the species accumulation graph representing grazing land uses leveling off at 1000 trap nights Fig 6(a). This simply explains that a reasonable number of samples have been taken from this land use and all species have been covered in this study. On the other hand species accumulation graphs representing crop and settlement land use did not reach an asymptote Fig 6(a). Species were still adding up even on the last trap night.

Just like the different seasons, at Ka-Ndengeza during wet season species accumulation graphs representing crop and grazing land uses reached an asymptote at 1000 trap nights Fig 6(b). This shows adequate sample size to have been collected in this village and season. Only graph representing settlement land use did not level off in this wet season at Ka-Ndengeza Fig 6(b).

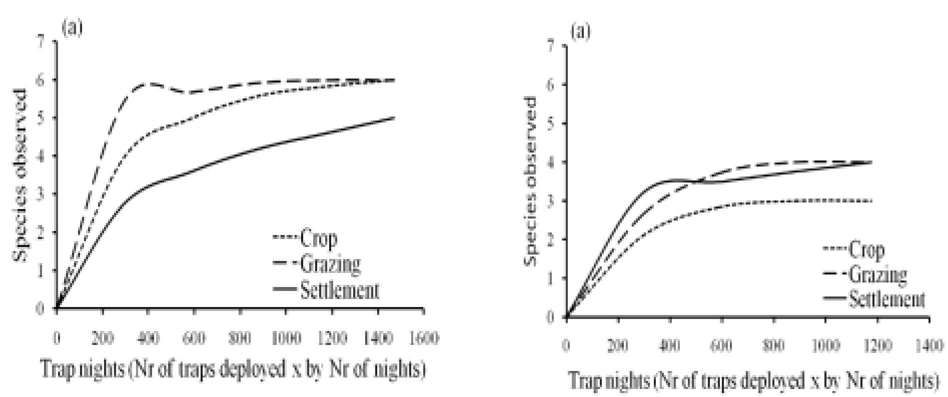

Figure 6: Ka-Ndengeza accumulation curves for dry (a) and wet (b) seasons showing number of species observed.

5.1.2. Species richness at Vyeboom and Ka-Ndengeza villages during both dry and wet seasons

At Vyeboom during dry season Fig 7(a), the settlement area had the highest number of species with 12 species followed by the crops growing area with a total of 10 species. The grazing area was the one found to have the least number of species captured (6 species) Fig 7(a).

During wet season at Vyeboom Fig 7(b), the settlement land use had 3 species which was found to be the highest number of species captured in this village in wet season. Whereas 1 species was captured in both crops growing and grazing land uses during wet season Fig 7(b).

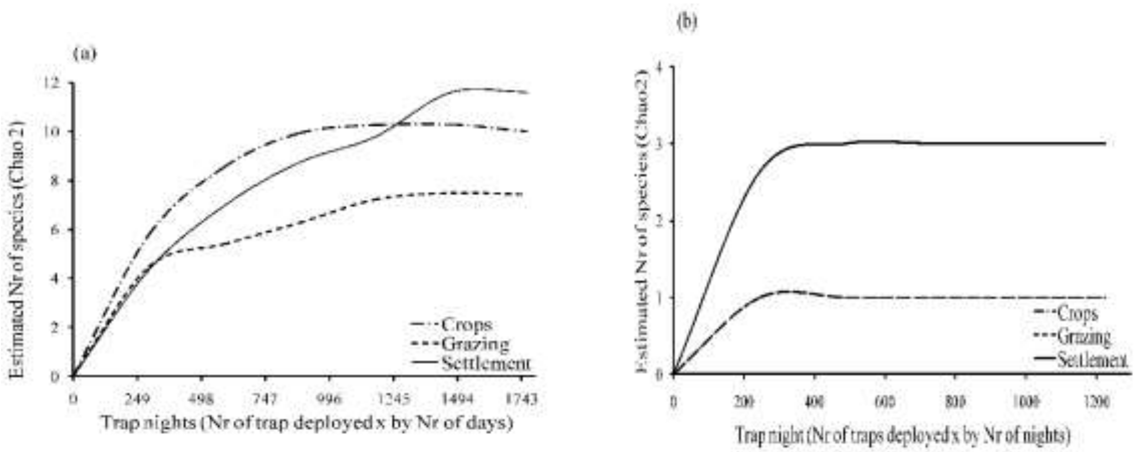

Figure 7: Vyeboom accumulation curves for dry (a) and wet (b) seasons showing estimated species richness (Chao2)

At Ka-Ndengeza the settlement land use had the highest number of species during dry season (7 species; Fig 8(a) followed by both crops growing and grazing land uses with equal number of species (6 species).

The wet season of Ka-Ndengeza village had equal number of species captured (4 species) for both settlement and grazing land uses Fig 8(b) which was also the highest number of species captured in the entire village for the wet season. Crops growing land use had the least number of species captured (3 species) Fig 8(b).

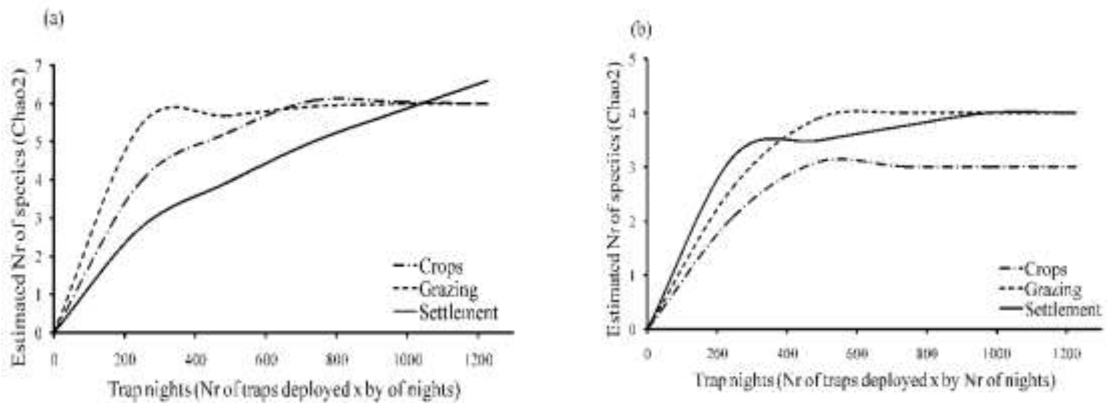

Figure 8: Ka-Ndengeza accumulation curves for dry (a) and wet (b) seasons showing estimated species richness (Chao2)

5.2. Rodent density

Despite the high diversity of rodents, only four rodent species were captured in adequate samples sizes to allow for robust density estimation. These included *M. natalensis*, *G. leucogaster*, *S. pratensis* and *R. rattus* (see Table 1). Similarly, there were strong seasonal effects on rodent captures, with almost no captures during the wet season (Table 1).

At Ndengeza, *M. natalensis* was the only rodent species with a sample size to allow for density estimation. There was high support for the model that included land use effect on density (AIC = 1682.012) compared to the constant model (AIC = 1749.143). The highest rodent densities were in the agriculture fields (Fig. 9), however, there was large variation even between cropping fields (Fig. 9; Rep1 [104 ± 17/ha] vs Rep2 [34 ± 8/ha]). Density of *M. natalensis* were similar between replicates in the settlement (Rep 1 [27 ± 8/ha] vs Rep2 [18 ±6/ha]; Fig 9). The lowest densities were attained at the grazing areas (Rep 1 [18 ±6/ha] vs Rep 2 [8 ±4/ha]; Fig 9).

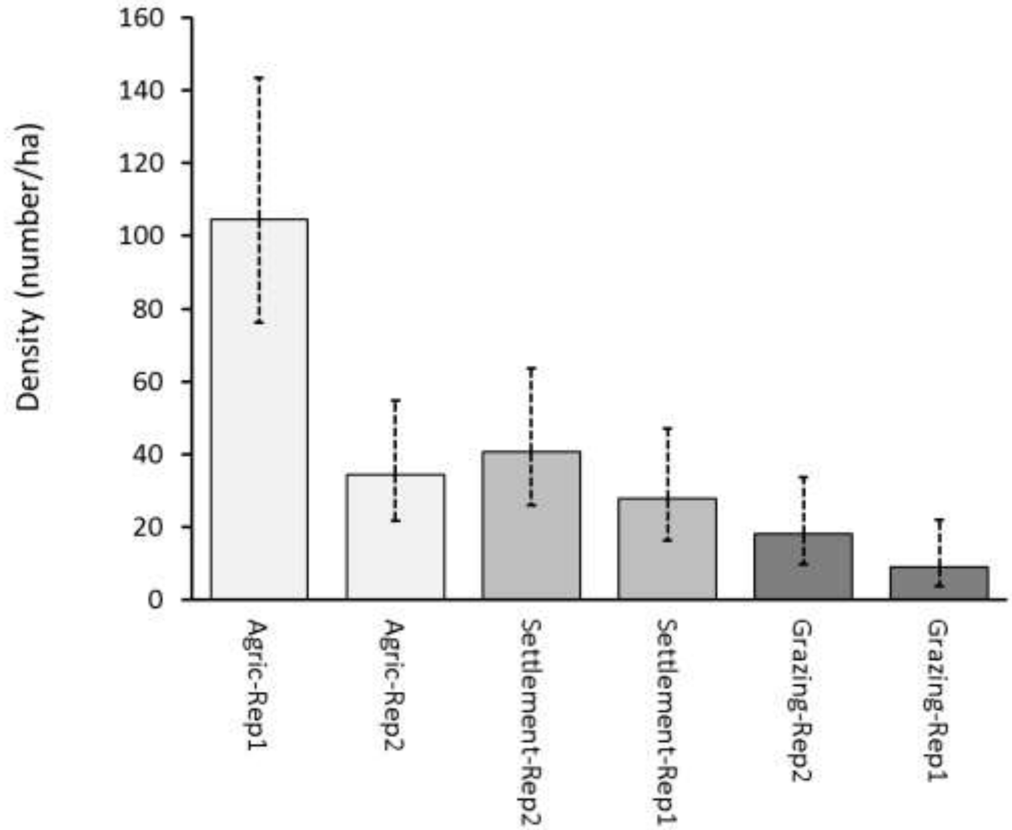

Figure 9: Density of *M. natalensis* at Ka-Ndengeza village during the dry season (2014) as estimated by spatially explicit capture recaptures models (Error bars represent Standard deviation)

At Vyeboom three species (*G. leucogaster, R. rattus and S. pratensis*) were captured at adequate sample sizes to allow for density estimation. The only support for land use effecting density was for *G. leucogaster* (*Gerbilliscus* Constant model AIC = 466.003 vs land use AIC = 457.90), but not for *R. rattus* (Constant model AIC = 1208.20 vs land use AIC = 1207.839), while for *S. pratensis* the constant model produced the most parsimonious model (Constant model AIC = 640.5vs land sue AIC = 644.145). *G. leucogaster* attained their highest densities (24 ± 8.7/ha) in the agricultural (crop growing) fields, while their lowest densities were attained in grazing areas (9 ± 4/ha; Fig 10). *Rattus rattus* was the most dominant species at Vyeboom in both agricultural (crop growing) areas (avg = 87.18 /ha) and settlements (128.57 /ha; Fig. 10).

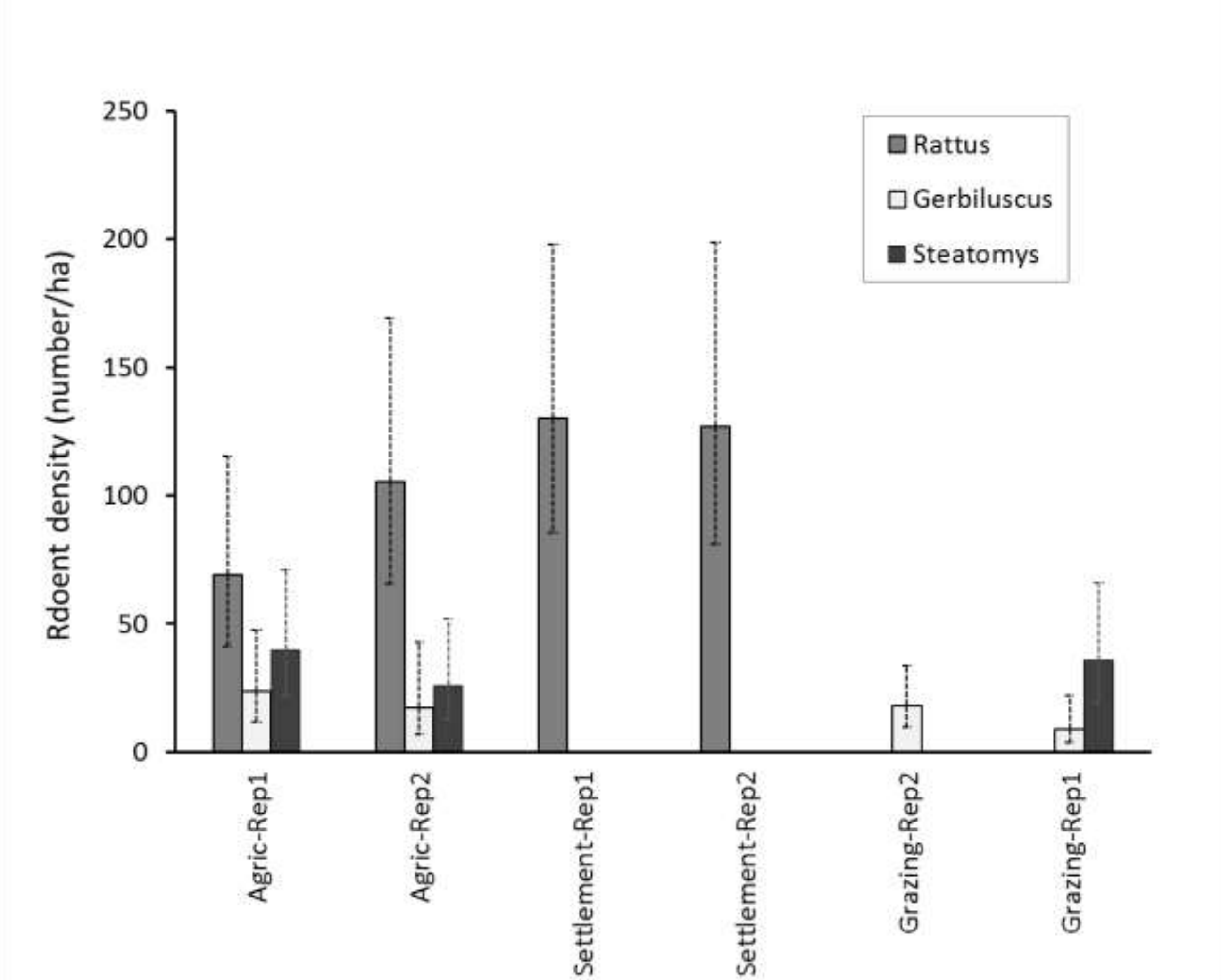

Figure 10: Rodent densities for *R. rattus*, *G. leucogaster* and *S. pratensis* in different land use types at Vyeboom village as estimated by spatially explicit capture recapture models

5.3. Dietary results

A total of 65 stomachs were collected during dry season only from both Vyeboom and Ka-Ndengeza in all three different land uses (crops, grazing and settlement). The percentage volume of stomach contents ranges between 0% and 70% with the average of 30% corn from Vyeboom

0% and 45% with the average of 15% corn from Ka-Ndengeza followed by 0% and 35% with the average of 12% of insects in Vyeboom and 0% and 25% with the average of 5% insects in Ka-Ndengeza (Fig. 11). Stomachs of species from both villages seems to be mainly dominated by corn and insects, however seeds and vegetation have been found on stomachs collected from Vyeboom only whereas none of the stomachs from Ka-Ndengeza contained any seeds or vegetation (Fig. 11).

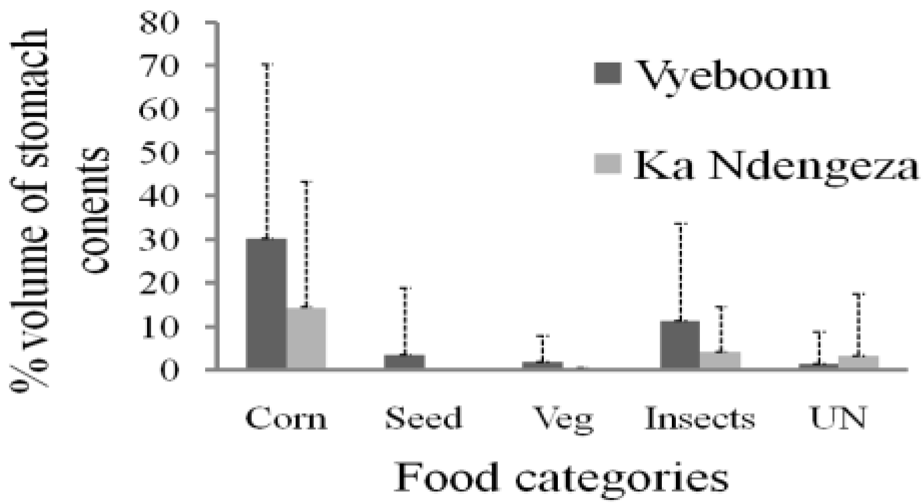

Figure 11: Percentage volume of stomach contents of rodent species at Vyeboom and Ka-Ndengeza in dry season

Mastomys natalensis was trapped in all three land uses. In the crop lands the stomach contents of *M. natalensis* was found to be highly dominated by corn at over 30% corn followed by 16% insects, a little bit of vegtation and no seeds. On the other hand, the stomachs of rodents captured in the grazing areas contained food from all categories (corn (23%), seeds(12%), vegetation(5%) and insects10%) except unidentified materials. Lastly stomach contents of rodents captured from settlement areas were dominated by 35% corn, 10% insects, 3% vegetation 2% unidentified materials and 1% seeds. (Fig 12).

G. leucogaster was only trapped in crop and grazzing land uses with none from the settlement land use. The diet of *G. leucogastor* in croplands was dominated by 43% corn, 2.5% insects, 2% vegetation and 0.5% seeds. Where as the stomach contents of rodents from grazing land use was dominated by 22% seeds and 1% corn. (Fig. 13).

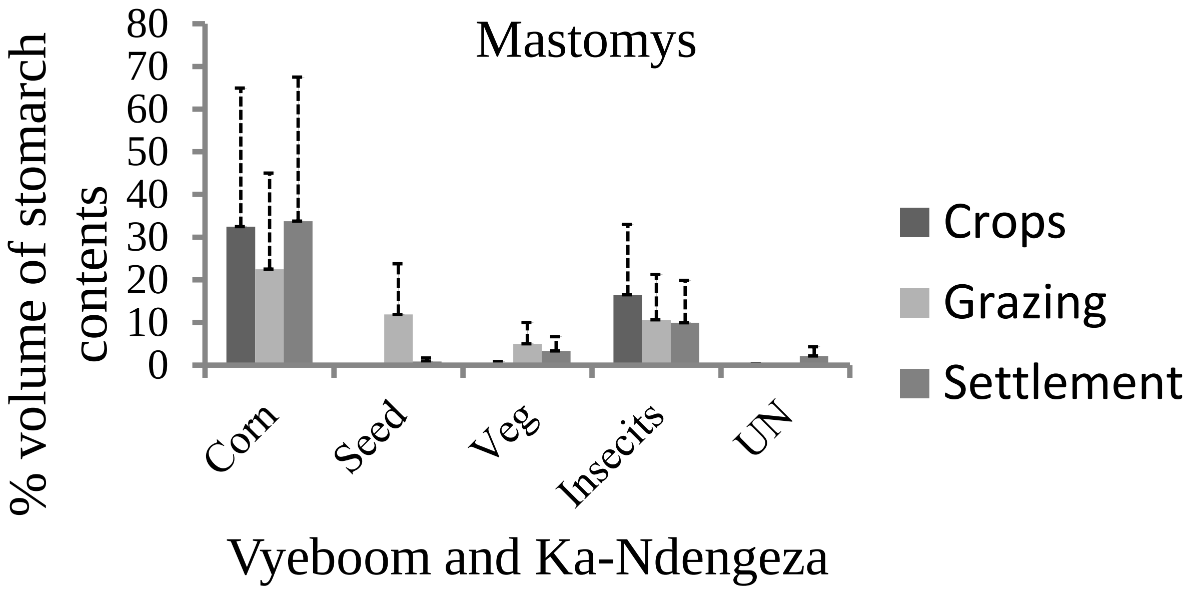

Figure 12: Percentage volume of the diet of *M. natalensis* at Vyeboom and Ka-Ndengeza during dry season

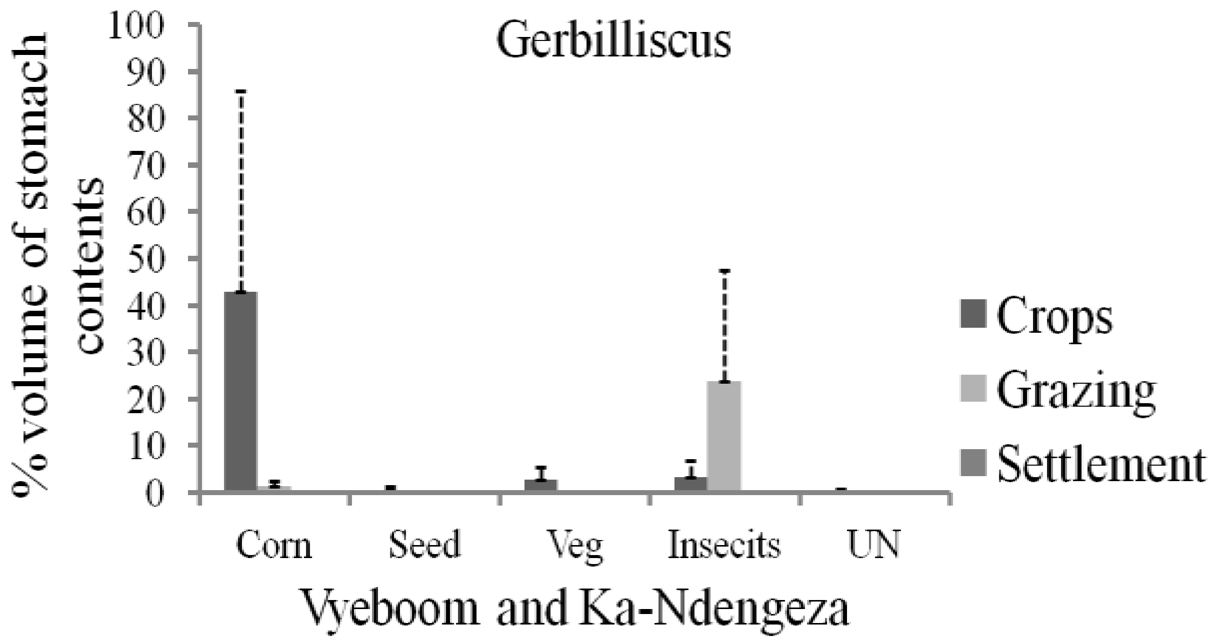

Figure 13: Percentage volume of the diet of *G. leucogaster* at Vyeboom and Ka-Ndengeza during dry season

5.4. Impact of rodents in the livelihood of community members

5.4.1. Community member's opinion on whether rodents are a problem?

In both villages, the respondents of the selected group overwhelmingly reported that rodents are problem and they cause problems to various aspects of their livelihood (100% response in both villages).

5.4.2. Indicators of rodent problems in the land uses of Vyeboom and Ka-Ndengeza

Rodent droppings was chosen as the most common sign of presence of rodents in the crop and settlement land uses of both Vyeboom and Ka-Ndengeza (Fig. 14). Other signs include visual observation, burrows, cutting of seedlings, noise, run ways, damage to stores, damage to grain and nests in their order of having more respondents from the highest to the lowest (Fig. 14).

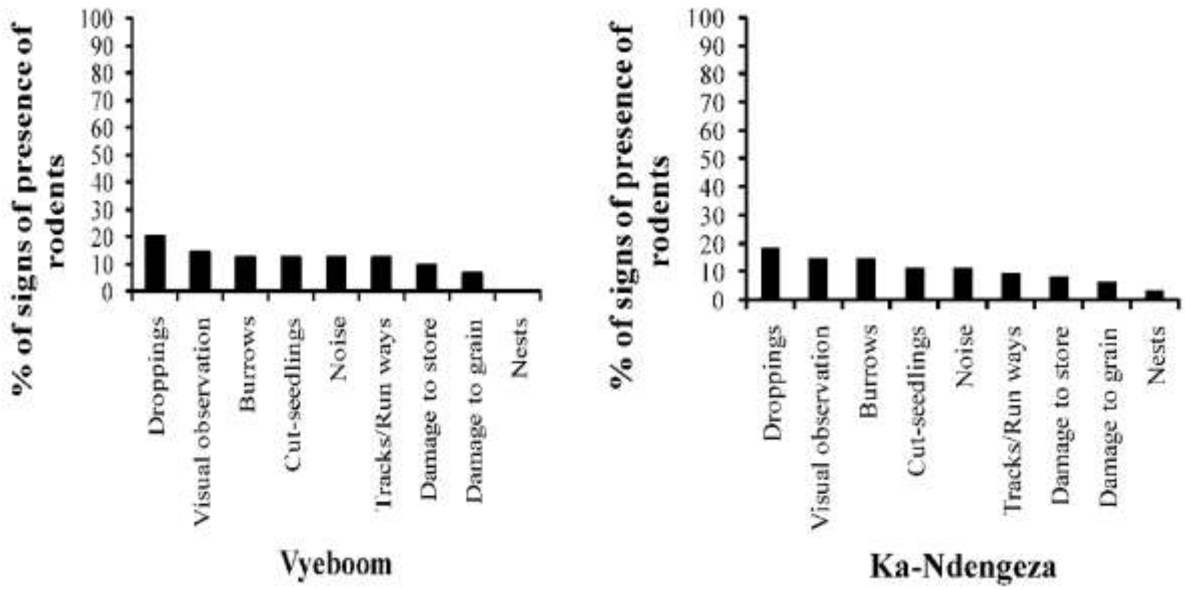

Figure 14: Graph showing how community members notice the presence of rodents in their surrounding and fields

5.4.3. Community member's opinion on area highly affected by rodent damage

The Vyeboom community believes that the greatest problem caused by rodents was found to be on household damage (40%) followed by the loss of grains (35%) (Fig. 15). Diseases and food contaminations were thought to be the least important problems (Fig. 15). In contrast the Ka-Ndengeza community believes that rodents cause more than anything diseases followed by food contamination, grain damage with the house hold experiencing least rodent problems (Fig. 15).

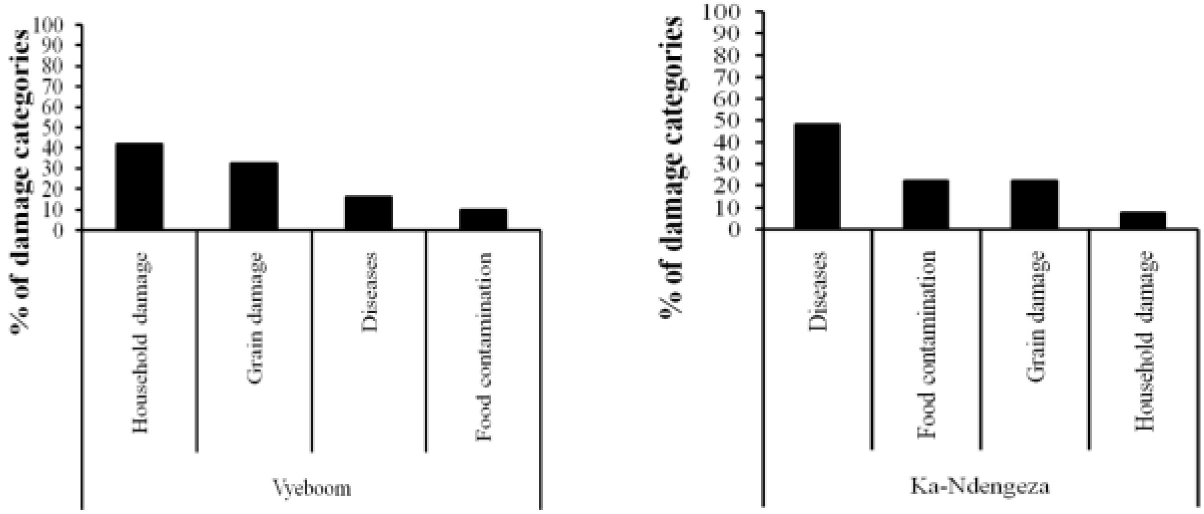

Figure 15: Graph showing human perception as to what part of their socio-economic categories experiences high rodent impact

5.4.4. How large is problem – grain

Large number of respondents considered rodents as serious source of damage to their belongings. The community members from Vyeboom think that 46% (Fig. 16). of their personal items are damaged by the rodents whereas the community members from Ka-Ndengeza believe that the total damage by the rodents is approximately 68% (Fig. 16)

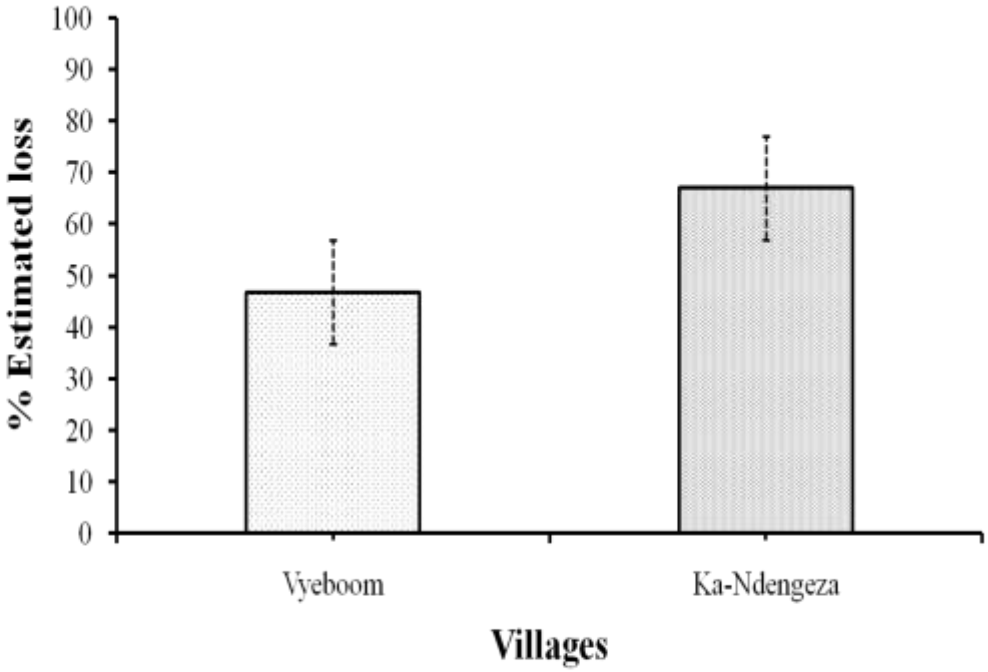

Figure 16: The graph showing the magnitude of the rodent problem to the grains

5.4.5. Rodent control

Over 55% of the respondents at Vyeboom believe in sealing their storage houses in order to prevent rodents from damaging their crops as a controlling measure, whereas 25% uses poison to control the damage (Fig. 17). Fifteen percent of the respondents use cats and 5% uses snap traps due to affordability (Fig. 17).

Community members from Ka-Ndengeza rely on sealing their storage houses (57%) for harvested crops and the use of poison (45%) for both harvested and field crops to control rodent damage (Fig. 17).

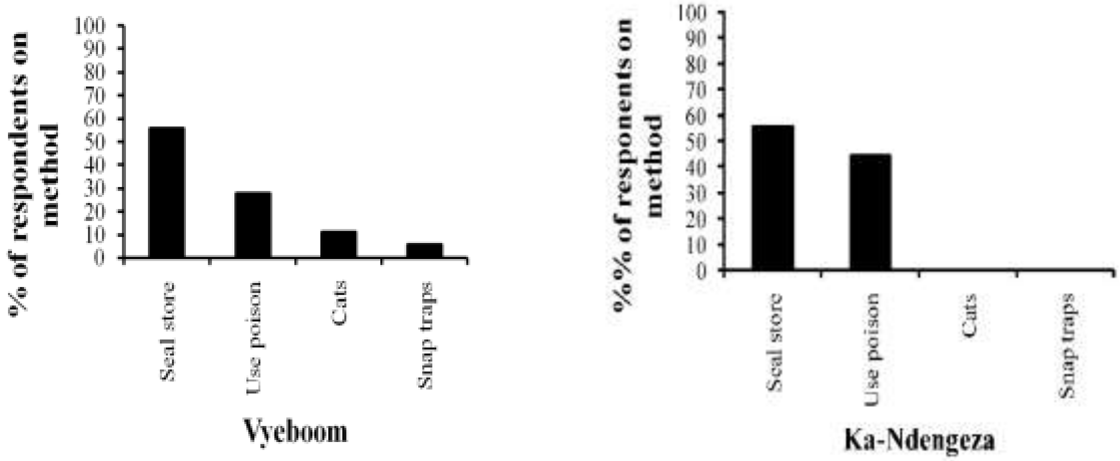

Figure 17: The graph showing the methods preferred by community members in controlling rodent damage

CHAPTER SIX: DISCUSSION, CONCLUSION AND RECOMMENDATION

6.1. Species diversity and capture rates

The species accumulation graph for settlement land use at Vyeboom started leveling off after the 1400th trap nights for dry season whereas in wet season species accumulation graphs for all land uses leveled off at 400th trap nights. According to Aplin *et al.* (2003) the trapping effort was adequate for number of traps. This suggests that dry season required additional trapping nights for crop and grazing land uses to reach asymptote. However, there was enough sampling during wet season at both sites and concurs with other studies (Parmenter *et al.*, 2003).

At Ka-Ndengeza during dry season, only graph representing grazing land use leveled off at 1000 trap nights, whereas crop and settlement never leveled off. Only crop and settlement land uses require more trapping in order for their graphs to reach asymptote. During wet season crop and grazing land uses reached asymptote whereas settlement needed more trap nights to level off.

The dry season had higher capture rate and diversity than the wet season. High capture rates in the dry season can be due to several reasons. When wet seasons come to an end, rodents move outside houses because of more food outside. And also at the beginning of the rainy season, rodents remain inside because of lack of food sources (Belmain, 2006). Another thing is that rodent start breeding during the wet season when the population is low (Leirs *et al.*, 1994). In both study sites the dry season had high number of captures compared to the wet season because the dry season comes during and after harvest when there is more food whereas the wet season comes after winter when there is less food available. Also Vyeboom study site had higher number of rodent compared to Ka-Ndengeza study site. This is basically because Vyeboom is wet compared to Ka-Ndengeza which is drier and the absence of *G. leucogaster* in Vyeboom and its presence in Ka-Ndengeza support this statement based on Hoffman and Zeller (2005) who reported that Gerbil occurs in drier areas like Nama Karoo.

The current study also showed great variation in species composition in term of richness and capture rate between the two villages and three land uses. For example, Ka-Ndengeza was dominated by *M. natalensis* whereas Vyeboom is dominated by *R. rattus* this because Ka-

Ndengeza is more disturbed compared to Vyeboom due to cattle grazing (Makundi *et al.,* 2007). At Vyeboom the settlement areas were dominated by *R. rattus* whereas at Ka-Ndengeza the settlement was dominated by *M. natalensis.* The same applies for crop growing land use in both villages and according to (Makundi *et al*., 2007) Ka-Ndengeza is more disturbed than Vyeboom. The grazing land use at Vyeboom was dominated by *S. pratensis* whilst at Ka-Ndengeza grazing was dominated by *M. natalensis*. However, according to Monadjem (1999), the grazing land use of Vyeboom is recovering and revegetated and less disturbed compared to Ka-Ndengeza. That is why Vyeboom is dominated by *S. pratensis* which is associated with recovering areas (Monadjem, 1999).

Rodent capture rates were influenced by seasons because during wet seasons, species and to a lesser extent land uses. For example, rodents stay in the house following stored food whereas during wet seasons they move outside because of more food outside (Belmain, 2006). And also different species favour different conditions therefore, with different land uses differing in terms of disturbance, rodent will respond differently others will dominate disturbed land use whereas others dominate less disturbed area (Makundi *et al.,* 2007). This then concurs with the previous studies (Makundi *et al.,* 2007; Hieronimo *et al.,* 2014).

During both dry and wet season there was a great variation in terms of species observed, species composition and species richness in both villages and different land uses, which could be attributed by the availability of food (Hieronimo *et al.,* 2014).

6.2. Rodent density

The two study sites had different number of species with sample size to allow density estimation. There were three species in area of high rainfall (Vyeboom) and one in the area of low rainfall (Ka-Ndengeza) and this confirms that rainfall have effect on rodent density and population dynamics concurring with the study by (Massawe *et al.,* 2006;Makundi *et al.,* 2007 and Massawe *et al.,* 2011). Another covariance with high effect to the density of rodents was seasons resulting to very low density during wet season because rodents stay in the houses in this seasons and high density during dry season concurring with (Belmain, 2006 and Makundi *et al.,* 2007) At Ka-Ndengeza there was also a high density variation in different land uses with *M. natalensis* having an adequate sampling size to allow for density estimation in this area and mostly in the crops growing areas and also there was a high variation even between cropping fields concurring with previous studies by (Makundi *et al.,* 2007: Hieronimo *et al.,* 2014).

Vyeboom had three rodent species with sample sizes to allow density estimation; however the three rodent species dominated different land uses because of species adaptability to human disturbance supporting the study by (Makundi *et al.,* 2007). At Vyeboom the sample size of *M. natalensis* did not allow density estimation giving us an impression that Ka-Ndengeza is more disturbed than Vyeboom because confirming reports that *M. natalensis* quickly colonize disturbed areas (Makundi *et al.*, 2007).

6.3. Diet

The rodents from Vyeboom feed from all food categories (corn, seeds, vegetation, insects and unidentified materials) whereas rodents from Ka-Ndengeza only feed on corn, insects and unidentified materials avoiding vegetation and seeds in the process.

6.3.1. *M. natalensis* diet

Mastomys natalensis was captured in all three land uses (crop growing, grazing and settlement) confirming what was also reported by Makundi *et al.,* (2007) where it was mentioned that this species can tolerate different kinds of habitats making it an expert in colonizing disturbed areas. Even though this species fed in all food categories, the stomach content had high proportion of corn, seeds and insects in all three land uses (crops growing, grazing and settlement) confirming that is an omnivorous species (Skinner and Smithers, 1990; Monadjem, 1997).

6.3.2. *G. leucogaster* diet

The *G. leucogaster* had high proportion of two food categories in all the stomach contents (corn and insects) and a little proportion of vegetation leading us to a conclusion that this species is an omnivorous animal confirming that which was also concluded by (Monadjem, 1997; Hoffman and Zeller, 2005).

6.4. Questionnaire discussion

All respondents 100% from two study sites have acknowledged that rodents are a serious problem to their livelihood confirming (Makundi *et al.*, 2005: and Gadisa and Birhane, 2016). The two sites also reported that they are seeing rodent droppings, rodent movements and barrows among others as a proof of presence of rodents in their surrounding similar to what was reported by (Eisen *et al.*, 2013).

Just like in Belmain and Nala, (2002) it was also discovered in this study that respondents from different villages (Vyeboom and Ka-Ndengeza) have different view when it comes to what part or land use is highly affected by rodents. However the respondents from both study sites believe that rodents cause a serious damage to the grain concurring with Gadisa and Birhane (2016). The current study have 46% respondents from Vyeboom and 68% respondents from Ka-Ndengeza agreeing with the study conducted in Tanzania and Ethiopia where they considered rodents a pest causing a serious damage in agriculture(Makundi *et al.*, 2005).

Majority of respondents in both villages have put their trusts heavily on sealing their storage and excessive use of poison with Vyeboom respondents extending their trust to the use of domestic cats and snap traps. This is in contrast with that which was reported by Eisen *et al.*, (2013) where they uncovers that different methods are used to protect crops in storage and their fields from rodents.

6.5. Importance of study for EBRM

The EBRM is a rodent management action which relies on the understanding of the behavior and the ecology of the pest species. The current study shows that different pest species to respond differently to different villages and different land uses. For example, *M. natalensis* dominated Ka-Ndengeza cropping land use which had low species richness (6 species) compared to Vyeboom cropping land use which had high species richness (10 species) and was dominated by *R. rattus*. According to Makundi *et al.*, 2007 *M. natalensis* mostly colonize areas which are recovering from disturbance, however the current study have proven that this species avoid competition as it was mostly captured in area with low species richness and this concur with the previous studies by Massawe *et al.*, (2011). Acquiring an understanding like this will help when putting EBRM in action or planning and implementation of environmental friendly management strategies for the pest rodent species

6.6. Conclusion

The current study shows that in both villages the dry season had higher number of captures and richness compared to the wet season. However at Vyeboom during dry season, the cropping land uses had higher richness of species followed by settlement with grazing land uses with the least number of species. This disagrees with one of our hypothesis where we had thought that there will be equal richness between different land uses. On the other hand at Ka-Ndengeza crops and grazing land uses had equal number of species and settlement had the least number of species. Even though this does not agree with the hypothesis it was close enough with a different of one species in settlement land uses

During wet season at Vyeboom, settlement land use had the highest number of species with crops and grazing land uses having equal number of species. On the other hand at Ka-Ndengeza settlement and grazing land uses had high but equal number of species with cropping land uses having least number of species. Lastly, the current study shows that the community members believe that rodents are major agricultural pests and this agrees with the hypothesis of the current study.

6.7. Recommendations

The current study only covers one part of the season leaving the whole season unattended. The follow up study should add more trapping sessions. For example, if trapping can be done in the beginning, middle and end of season. It will also be a good idea to add more trap nights in order to be sure enough trapping was done. By so doing the study will be more accurate and give actual ecology of different species which will help in the implementation of EBRM.

REFERENCES

AKAIKE, H., 1974. A new look at the statistical model identification. *Institute of Electrical and Electronics Engineers Transactions on Automatic Control*, 19(6), pp. 716-723.

APLIN, K.P, BROWN, P.R, JACOBS, J, KREBS, C.J, AND SINGLETON, G.R., 2003.Field methods for rodent studies in Asia and Indo-Pacific. *Australian Centre for International Agricultural Research, Canberra.*

ASSOGBADJO, A.E, CODJIA, J.T.C, SINSIN, B, EKUE, M.R.M, AND MENSAH, G.A., 2005. Importance of rodents as a human food source in Benin. *Belgian Journal of Zoology*., 135 (supplement): pp. 11-15

AVENANT, N.L., 2000. Small mammal community characteristics as indicators of ecological disturbance in the Willem Pretorius Nature Reserve, Free State, South Africa. *South African Journal of Wildlife Research*, *30*(1), pp. 26-33.

AVENANT, N.L, AND CAVALLINI, P., 2007. Correlating rodent community structure with ecological integrity, Tussen-die-Riviere Nature Reserves, Free State Province, South Africa. *Integrative Zoology*, *2*(4), pp. 212-219.

AVENANT, N.L., WATSON, J.P, AND SCHULZE, E., 2008.Correlating small mammal community characteristics and habitat and habitat integrity in the Caledon Nature Reserve, South Africa. *Mammalia* 72(3), pp. 186-191.

AVENANT, N.L., 2011. The potential utility and other small mammals as indicators of ecosystem integrity of South African grassland. *Wildlife Research*, 38(7), pp. 626-639.

BEKELE, A., LEIRS, H, AND VERHAGEN, R., 2005. Composition of rodent's and damage on maize farms at Ziway, Ethiopia. *Australian Centre for International Agricultural Research, Monograph Series, 96,* pp. 262-263.

BELMAIN, S.R., 2006. Rats and human health in Africa: *In proceedings of an international workshop on rodent-borne diseases and the RatZooMan research project* pp. 3-6.

BELMAIN, S.R., MEYER, A.N., TIMBRINE, R, AND PENICELA, L., 2003. Managing rodent pests in households and food stores through intensive trapping. *Australia Centre for International Agricultural, Research Monograph Series*, *96,* pp. 440-445.

BELMAIN, S.R. AND NALA, R., 2002. Assessment of the impact of rodents on rural household food security and the development of ecologically-based rodent management strategies in Zambezia Province, Mozambique. *Natural Resource Institute. Final Technical Report.*

BOT.ES, A., MCGEOCH, M.A., ROBERTSON, H.G., VN NIEKERRK, A., DAVIDS, H.P., CHOWN, S.L., 2006. Ants, altitude and change in the Northern Cape Floristic Region. *Journal of Biogeography*, 33(1), pp. 71-90.

BUCKLE, A., CHALTON, J., MAYER, A, AND PRESCOTT, C., 2010. Anticoagulant resistance in the Norway rat and guidelines for the management of rat infestations in the United Kingdom.

BURNHAM, K.P, AND ANDERSON, D.R., 2002. Model Selection and Multimodel Inference: a practical information-theoretic approach. *Springer, New York.*

BURNHAM, K., ANDERSON, D, AND HUYVAERT, K., 2011. AIC model selection and multi-model inference in behavioral ecology: some background, observations, and comparisons. *Behavioral Ecology and Sociobiology* 65(1), pp. 23-35.

CAPIZZI, D, AND MORTELLITI, B., 2013. Rating the rat: Global patterns and research priorities in impacts and management of rodent pests. *Mammal Review,* 44(2), pp. 148-162.

CARLTON, M.D, AND MUSSER, G.G., 2013. Mammal species of the world: a Taxonomic and geographic Reference, *The Johns Hopkins University Press*, pp. 745-753.

CHAO, A., HWANG, W.H., CHEN, Y.C, AND KUO, C.Y., 2000. Estimating the number of shared species in two communities. *Statistica sinica*, pp. 227-246.

CHITTY, D., 1954. The study of the brown rat and its control by poison. *Control of rats and mice, 1*, pp. 160-305.

COLWELL, R.K., MAO, C.X, AND CHANG, J., 2004. Interpolating, extrapolating and comparing incidence-based species accumulation curves. *Ecology* 85(10), pp. 2717-2727

COWAN, D.P., QUY, R.J. AND LAMBERT, M.S., 2003. Ecological perspectives on the management of commensal rodents. *Australian Centre of International Agricultural Research, Monograph series, 96*, pp. 433-439.

DAVIS, D.E. AND CHRISTIAN, J.J., 1958. Population consequences of a sustained yield program for Norway rats. *Ecology, 39*(2), pp. 217-222.

DOUANGBOUPHA, B., BROWN, P.R., KHAMPHOUKEO, K., APLIN, K.P. AND SINGLETON, G.R., 2009. Population dynamics of rodent pest species in upland farming system of Lao PDR. *Kasetsart Journal of Natural Sciences, 43*, pp. 125-131.

EFFORD, M.G., 2004. Density estimation in live-trapping studies. *Oikos*, 106(3), pp. 598-610.

EFFORD, M.G., 2012. Spatially explicit capture-recapture models. R package version 2.3.2.

EFFORD, M.G. AND FEWSTER, R.M., 2013. Estimating population size by spatially explicit capture–recapture. *Oikos*, 122(6) pp. 918-928.

EISEN, R.J.,ENSCORE, R.E.,ATIKU, L.A.,ZIELINSKI-GUTIERREZ, E.,MPANGA, J.T.,KAJIK, E.,ANDAMA, VMUNGUJAKISA, C.,TIBO, EMACMILLAN, KJEFF N. BORCHERT, JN, AND KENNETH L. GAG, K.L., 2013. Evidence that rodent control strategies ought to be improved to enhance food security and reduce the risk of rodent-borne illness within subsistence farming villages in the plague-endemic West Nile Region, Uganda. *International Journal of Pest Management*; 59(4), pp. 259–270.

GADISA, T. and BIRHANE, A., 2016. Farmers perceptions of rodents as crop pests: Knowledge, attitude and practices of farmers about rodent pest management in Southwest Ethiopia. *Journal of Agricultural Extension and Rural Development, 8*(3), pp.39-46.

GOTELLIN.J, AND COLWELL, R.K., 2001.Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters,* 4(4), pp. 379-391.

HANSON, L, AND NILSON, B., 1975.Biocontrol of rodents. Ecological bulletins, No: 19, Swedish Natural Science Research Council. 306p.

HIEROMINO, P., KIMARO, D.N., KIHUPI, N.I., GULINK,H., MULUNGU, L.S., MSANYA, BM., LEIRS,H. AND DECKERS, J.A., 2014. Land use determinants of small mammals' abundance and distribution in a plague endemic area of Lushoto District, Tanzania. *Tanzania journal of health research*, 16(3)

HIJMANS, R.J., CAMERON, S.E., PARRA, J.L., JONES, P.G, AND JARVIS, A., 2005. Very high resolution interpolated climate surfaces for global. *International Journal of Climatology*, 25: 1965-1978.

HOFFMAN, A, AND ZELLER, U., 2005. Influence of Variation in land use intensity on species diversity and abundance of small mammals in the Nama Karoo, Namibia. Berg. *J. Zool.,* 135 (supplement): 91-96.

HUDUK, A.T., 1999. Rangeland mismanagement in South Africa: failure to apply ecological knowledge. *Human Ecology, 27*(1), pp. 55-78.`

HUGGINS, R.M., 1991. Some practical aspects of a conditional likelihood approach to capture experiments. Biometrics, 47, 725-732.

KITZINGER, J., 1994. The methodology of Focus Group: the importance of interaction between research participants. *Sociology of Health and Illness Vol. 16 No. 1 1994 ISSN 0141-9889.*

KLEIBER, C, and ZEILEIS, A., 2008.Applied Econometrics with R. New York: Springer-Verlag. ISBN 978-0-387-77316-2. URL http://CRAN.R-project.org/package=AER

LEIRS, H., 2003.Management of rodents in crops: the Pied Piper and his orchestra. *Australian Centre of International Agricultural Research Monograph Series, 96,* pp. 183-190.

MAKUNDI, R.H., OGUGE, N.O, AND MWANJABE, P.S., 1999. Rodent pests management in East Africa – an ecological approach in Ecologically Based Rodent Management. ACIAR Canberra, pp. 460-476

MAKUNDI, R.H., BEKELE, A., LEIRS, H., MASSAWE, A.W., RWAMUGIRA, W, AND MULUNGU, L.S., 2005 Farmer's perceptions of rodents as crop pests : Knowledge, attitudes and practices in rodent pest management in Tanzania and Ethiopia. Belg. J. Zool., 135 (supplement): 153-157.

MAKUNDI, R.H., MASSAWE, A.W, AND MULUNGU, L.S., 2007.Reproduction and population dynamics of Mastomys natalensis Smith, 1834 in an agricultural landscape in the Western Usambara Mountains, Tanzania. *Integrative Zoology*, 2(4), pp.233-238.

MAKUNDI, R.H, AND MASSAWE, A.W., 2011. Ecologically –based rodent management in Africa: Potential and Challenges. *Wildlife Research*, 38 (7): 588-595.

MASSAWE, A.W., MULUNGU, L.S., MAKUNDI, R.H., DLAMINI, N., EISEB, S.J., KIRSTEN, F., MAHLABA, T.A., MALEBANE, T., VON MALTITZ, E., MONADJEM, A. AND TAYLOR, P., 2011. Spatial and temporal population dynamics of rodents in three geographically different regions in Africa: implications for ecologically based rodent management. *African Zoology, 46(2),* pp. 393-405.

MDANGI, M., MULUNGU, L.S., MASSAWE, A.W., EISEB, S., TUTJAVI, V., KIRSTEN, F., MAHLABA, T., MALEBANE, P., MALTITZ, E.V., MOMADJEM, A., DLAMINI, N., MAKUNDI, R.H., BELMAIN, S.R., 2013. Assessment of rodent damage to stored maize (*Zea mays L.)* on small holder farms in Tanzania. *International Journal of Pest Management,* 59(1): 55-62.

MEERBURG, B. G., SINGLETON, G. R, AND KIJLSTRA, A., 2009.Rodent-borne diseases and their risks for public health. Critical Reviews in Microbiology 35: 221–270.

MONADJEM, A., 1997. Stomach contents of 19 species of small mammals from Swaziland: short communications. *African Zoology, 32(1)*, pp. 23-26.

MONADJEM, A., 1999. Population dynamics of Mus minutoides and Steatomys pratensis (Muridae: Rodentia) in a subtropical grassland in Swaziland. *African Journal of Ecology*, 37(2), pp.202-210.

MONADJEM, A., AND PERRIN. M., 2002. Population and fluctuations and community structure of small mammals in a Swaziland grassland over a three-year period. *African Zoology*, 38(1): 127-137.

MULUNGU, L. S., MLYASHIMBI, E.C.M., NGOWO, V., MDANGI, M., KATAKWEBA, A.S., TESHA, P., MROSSO, F.P., MCHOMVU, M., KILONZO, B.S., AND BELMAIN, S.R., 2014. Food preferences of the multi-mammate mouse, *Mastomys natalensis*, in irrigated rice habitats in Tanzania. International Journal of Pest Management 60:1-8.

MULUNGU, L.S., NGOWO, V.D., MAKUNDI, R.H., MASSAWE, A.W, AND LEIRS, H., 2010.Winning the fight against Rodent Pests: Recent Development in Tanzania. Journal of Biological Sciences, 10:333-340.

MWANJABE, P.S., 1990. Outbreak of Mastomys natalensis in Tanzania. *African Small Mammal Newsletter*, 11(1).

MWANJABE, P.S, AND LEIRS, H., 1997.An early warning systems for IPM Based rodent control in smallholder farming system in Tanzania Belgian. *Journal of Zoology 127 pp.* 49-58.

MWANJABE, P.S., 1998. Final report of rodent control operations. Internal report. Tanzania. *Ministry of Agriculture and Cooperatives.*

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 Biodeterioration & Biodegradation, 49(2),* pp. 133-137

NEWBERY, C.H., 1999. A key to the Soricidae, Macroscelididae, Gliridae and Muridae of Gauteng, North West Province, Mpumalanga and the Northern Province, South Africa. Koedoe 42, 51-55.

OLI, M.K., 2003. Population cycles of small rodents are caused by specialist predators: or are they? TREE, 18(3): 105-107

PARMENTER, R.R., YATES, T.L., ANDERSON, D.R., BURNHUM, K.P., FRANKLIN, A.B., FRIGGENS, M.T., LUBOW, B.C., MILLER, M., OLSON, G.S, AND PARMENTER, C.A., 2003. Small-mammal density estimation: a field comparison of grid based vs. web-based density estimators. *Ecological monographs*, *73*(1), pp.1-26.

PELZ, H.J., 2001. Extensive distribution and high frequency of resistance to anticoagulant rodenticides in rat populations from North Western Germany. *Advances in Vertabrate Pest Management, 2,* pp. 433-439

SALO, P., BANK, P.B., DICKMAN, C.R, AND KORPIMAKI, E., 2010. Predator manipulation experiment: Impacts on population of terrestrial vertebrate prey. *Ecological Monograph*,(80):531-546.

SCHILLER, J.C.F., 2006.Rodents in agriculture in the Lao PDR – a problem with an unknown future. In ecologically based management of rodent pests. Lao Journal of Agriculture and Forestry, Australian Centre for International Agricultural Research.

SKINNER.J.D. AND SMITHERS, R.H.N., 1990.The mammals of the Southern African Sub-region. *University of Pretoria,* Pretoria

SKINNER, J.D, AND CHIMIMBA, C.T., 2005.The mammals of Southern Africa Sub-region.3rd edition. Cambridge University Press.

SINGH, S.J, AND DUDLEY, N., 2012. The economics of ecosystems and biodiversity: Chapter 5 Ecosystem services in rural areas and natural resources management. Institute of social ecology, Vienna; Equilibrium Research.

SINGLETON, G.R., 1997. Integrated management of rodents: a Southeast Asian and Australian perspective. Belgian Journal of Zoology, 127, 157-169.

SINGLETON, G.R., 2003.Impacts of rodents on rice production in Asia. IRRI Discussion Paper Series No.45, 30 pp, Los Banos, Philippines.

SINGLETON, G.R., LEIRS, H., HINDS, L.A, AND ZHANG, Z., 1999. Ecologically-based management of rodent pests-re-evaluating our approach to an old problem. *Ecologically-based management of rodent pest. 1st ed. Canberra: Australian Centre for International Agricultural Research*.

SINGLETON, G.R., HINDS, L.A., KREBS, C.J., SPRATT, D.M., 2003. Rats, mice and peoples: rodent biology and management. ACIAR Monograph No. 96, 564p, 262-263, 301-303, 389-394.

SINGLETON, G.R., BROWN, P.R., JACOBS, J., 2004. Ecologically-based rodent management: its effectiveness in cropping system in South-East Asia. Commonwealth Scientific and Industrial Research Organization (CSIRO).

STENSETH, N.C., LEIRS, H., SKONHOFT, A., DAVIES, S.A., PECH, R.P., ANDREASSEN, H.P., SINGLETON, G.R., LIMA, M., MACHANGU, R.S., MAKUNDI, R.H. AND ZHANG, Z., 2003. Mice, rats and people: the bio-economics of agricultural rodent pests. *Frontiers in Ecology and the Environment, 1(7),* pp. 367-375.

SUDARMAJI., SINGLETON, G.R., HERAWATI, N.A., DJATIHARTI, A, AND RAHMINI., 2003. Farmer's perceptions and practices in rat management in West Java, Indonesia. In 'Rats, Mice and People: Rodent Biology and Management'. (Eds Singleton, G.R., Hinds, L.A., Krebs, C.J., Spratt, D.M).pp. 389-394.

TAYLOR, K.D., 1968. An outbreak of rats in agricultural areas of Kenya in 1962.*East African Agricultural and Forestry Journal* 34, pp. 66-77.

TATLOR, P.J., MONADJEM, A., EISEB, S.J., MULUNGU, L.S., MASSAWE, A.W., THEMB'A, A.M., KIRSTEN, F., VON MALTITZ, E., MALEBANA, P. AND MAKUNDI, R.H.

2012. Experimental treatment-control studies of ecologically based rodent management in Africa: balancing conservation and pest management. *Wildlife Research, 39(1),* pp. 51-61.

TEAM, R.C., 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2013.

TURCHIN, P, AND BATZLI, G.O., 2001.Availability of food and the population dynamics of arvicoline rodents. *Ecology,* 82(6), 1521-1534.

VENABLES, W.N, & RIPLEY, B.D., 2002. Modern Applied Statistics with S. Fourth Edition. Springer, New York. ISBN 0-387-95457-0

VER HOEF, J.M, AND BOVENG, P.L., 2007. Quasi-Posson vs. negative binomial regression: How should we model over dispersed count data? Ecology 88: 2766-2772.

WAGGONER, B., 2000. Introduction to the Rodentia. *University of California Museum of Paleontology.*

WARD, D.J., 2008.An ecological assessment of secondary poisoning risk in the Australian Sugarcane Industry. A thesis submitted for the degree of Doctor of Philosophy of the Queensland University of Technology.

WICKHAM, H., 2009.Elegant Graphics for Data Analysis. Springer-Verlag New York, ggplot2.

WITTMER, H. AND GUNDIMEDA, H. eds., 2012. The economics of ecosystems and biodiversity in local and regional policy and management. *Routledge.*

WOOD, B.J. AND FEE, C.G., 2003. A critical review of the development of rat control in Malaysian agriculture since the 1969s. *Crop protection*, 22(3), pp.445-461.

ZHANG, Z.B., HINDS, L., SINGLETON, G, AND WANG, Z.W., 1996.Rodent biology and management. Abstracts of papers presented at the International Conference of Rodent Biology and Management held at Beijing, China. 14

APENDICES

APENDIX A

1. Are rats a problem in your community? How do you know they are a problem?
2. What kinds of problems do rats cause for you? (try not to prompt different sectors, but some issues may be unfamiliar, like health/disease).

- Crops, which crops, damaged when, estimate of loss?
- Post-harvest, when, what, how, estimate of loss?
- Household, e.g. damage of personal possessions, cooked food, stored water, damage to building
- Livestock, e.g. feed contamination, disease, attack of chickens/eggs
- Human health, e.g. zoonosis, dysentery, unknown fevers, rat bites

3. How do you asses rat damage in your field crops?
4. How do you asses rat damage in your food store
5. How do you describe the occurrence of rat damage in your field crops

- What is the estimated yield loss per crops grown?

6. How do you describe the occurrence of rat damage in your food store?

- What is the estimated loss during a typical storage period?

7. How do you protect your stores from rat damage?
8. What is the other non-crop damage caused that you or other members of your household have experienced over the last year?

- What are the implications?

- What do you do when you notice such damage?

➢ Answer either yes, no or maybe for questions 9-25

9. Planting almost at the same time (within a span of two weeks) can reduce rat populations.
10. Rodent management must be done continuously in order to be effective.
11. Cleaning on farms and surroundings areas can reduce rat populations.
12. Using rodenticides reduces the severity of observed damage.
13. Trapping rats reduces the severity of rat damage.
14. Hunting rats reduces the severity of observed damage.
15. Individual rat control action is best to control rat damage because the farmer has some options of when and where to conduct rat control.
16. Community rat control is best to control rat damage because it is done at the same time.
17. Rats are too clever to be successfully controlled.
18. Community rat control at anytime of the cropping season is most effective in reducing rat population.
19. Community rat control at a specific stage of the crop is most effective in reducing rat population.
20. Rattex (name of common anticoagulant) is an effective and safe poison to use.
21. Two-step (name of common acute poison) is an effective and safe poison to use.
22. Do you believe that

Item	**Yes**	**No**	**Don't know**	**Why?**

1. Controlling rats is important?				
2. Rats can be controlled?				
3. Rats control must be done during the crop growing season?				
4. Rats have to controlled after harvest or in the fallow season?				
5. Chemicals used to control rats are safe (for humans, other animals and the environment)?				
6. By controlling rats, a farmer can increase his or her crop yields?				
7. Rats can cause severe yield losses?				
8. Rats can only be controlled if different farmers work together at the same time?				
9. Reducing rat damage is important to my family's livelihood?				
10. Rats are controlled effectively in my community?				

23. Do you believe that rats carry diseases that make people or livestock sick?

24. Do you know somebody who got sick due to rats?

25. Do you know someone who has been bitten by rats?

26. What methods do you use to control rats in the field and around your household

27. At which stage of crop growth do you control rats?

- What method will you continue to use in the future?
- Why would you use the method you chose?
- What is the single most effective method of controlling rats?
- Why do you think this is so?
- Do you think cats, birds and snakes are effective in controlling rats?
- Should they be encouraged?
- Would you promote/tolerate others promoting the use of owls in your community?

28. What is your decision based on when it comes to your choice of control method?

29. How important is it to you to spend less time and money controlling rats

30. How true is the following statement? by using recommendations from the rodent project you have spent less time and money controlling rats.

31. Will you work with other farmers to control rats in the future?