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COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES

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Small Mammal Diversity and Farmers Knowledge, Attitude, and Practices along an Altitudinal Gradient in the Southern Part of Tigray.

By: Mebrahte Berhe

A thesis submitted to the Department of Biology in the partial fulfillment of the requirements for the Degree of Master of Science in Biology (Applied Pest Management)

Advisors:

Kiros Welegerima (PhD fellows, Associate Professor)

Getachew Mulalem (PhD)

Dawit Kidane (PhD, Associate Professor)

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Approved by the Examining Board:

Name Signature

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Chairman, Department Graduate Committee

_______________________ _______________

External Examiner

______________________ _______________

Internal Examiner

____________________ _______________

Research Advisor

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Abstract

Small mammals are divided into Volant and non-Volant species. Among the non-Volant mammals, rodents and shrews are the most common and widespread across all continents except Antarctica. They play vital ecological roles as bio indicators, model organisms, and, in some cases, agricultural pests. Diversity of small mammals across an altitudinal gradient and smallholder farmers' Knowledge, Attitudes, and Practices (KAP) regarding rodent pests were studied in south Tigray starting from June 2024- October 2025. This study aimed to assess the diversity of small mammals across varying altitudinal gradients and to evaluate the knowledge, attitudes, and practices (KAP) of smallholder farmers along these gradients. The study area was divided into four sites based on altitude, starting from 1500 – 2900 m.a.s.l, with an interval of ~500m. Both Sherman and snap traps were used to collect small mammals. The traps were baited with peanut butter and barley flour and then placed in a horizontal line transect with an average distance between traps of about 2m. Traps were set for three consecutive nights per elevation. In addition, KAP of smallholder farmers was assessed using semi-structured questionnaires. Fifty respondents were randomly selected from three kebeles across two districts, based on their altitudinal proximity to the rodent trapping sites. A total 138 individual small mammals (rodents and shrews) were captured. Of these 138 small mammals, 84 were males and 54 were females. Nine species of small mammals (eight rodent species and one shrew species) belonging to two families were recorded. The relative abundance of captured small mammals were *Stenocephalemys albipes* (70.2%), *Arvicanthis niloticus* (7.8%), *Mastomys awashensis* (7.25%), *Lophuromys simensis* (6.52%), *Mus mohamet* (4.35%) and *Rattus rattus* (1.4), *Acomys cahirinus* (0.72%), *Desmomys harringtoni* (0.72%), *Crocidura olivieri* (0.72%). Overall, *Stenocephalemys albipes* was the most abundant species in the study area. Diversity and distribution of small mammals were varied across altitude. The highest species diversity was recorded in 2000m (H=1.29) and the least in 2500m elevation (H=0.34). The highest number of individual rodent species was recorded at 2900 m.a.s.l (60.9%) and the least was at 2000m elevation (9.42%). There was variation in age and sex of small mammals but, age variation statistically not significant (ANOVA; *df* = 3, F=2.392, *p* = 0.071) unlike sex variation (ANOVA; *df* = 3, F=3.879, *p* = 0.01). Questionnaires from 50 farmers discovered that most were males (76%), aged 36-50, with no formal education (72%). Crop types varied significantly (p=0.000) between districts (Emba Alaje and Raya Azebo). All farmers (100%) recognized significant post and pre-harvest rodent losses, with damage reported in both fields and homes. The control methods relied on rodenticides, trapping, and cats, with limited satisfaction. This study shows different kinds and numbers of small mammals live at different elevations and reveals significant rodent-induced crop losses with limited effective management strategies among farmers. Targeted interventions considering both ecological and farmer's KAP are essential for sustainable pest management in this region.

Keywords: Small mammals, Altitude, Diversity, Rodents, Pests, KAP, Mount Mahbere Bekuru

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

Small mammals constitute approximately 43% of all known mammal species worldwide (Wilson and Reeder, 2005). They are broadly divided into two categories: volant species (such as bats) and non-volant species (which include rodents and insectivores) (Munian et al., 2020). Among the non-volant mammals, rodents and shrews are the most widespread and well-studied (Munian et al., 2020). Except for Antarctica, rodents and shrews are the most common animals on all continents (Arzamani et al., 2017). Their distribution and abundance are influenced by different environmental and ecological factors (Gebresilassie et al., 2004).

Ethiopia's highlands are home to a remarkable diversity of flora and fauna, including rare Afroalpine habitats on isolated mountains that support numerous highly specialized species (Yalden et al., 1976; Linder et al., 2012). Ethiopia's topography has distinctive altitudinal variations with the highest peak at Ras Dashen (4620 meter above sea level) and lowest altitude (126 meter below sea level) in the Afar depression (Zerihun et al., 2012; Ejigu, 2014).The complex geomorphology of the Ethiopian highlands, such as the presence of the Great Rift Valley and large rivers (e.g. the River Blue Nile), promoted diversification processes (Bryja et al., 2019). Other significant elements supporting the growth of Ethiopia's endemic biodiversity, which is particularly rich in animals and amphibians, include the existence of glaciers and the Afroalpine environment, which is the largest in space (Jacobs & Schloeder 2001, Lavrenchenko & Bekele 2017). As a result, the Ethiopian wild fauna are comprised of 326 mammals, 918 birds, 240 reptiles, 200 fish, 71 amphibians, and 1,225 arthropods (Chankallo, 2023). The Ethiopian rodent fauna also consists 104 species with 40 genera, 10 families (Bryja et al., 2019).

Small mammals are well known bio-indicators due to their; high reproductive rates, rapid turn-over and sensitive to habitat changes (Li et al., 2015). They are also used as model organisms in different experimental researches. For example, laboratory mouse (*Mus musculus*) is the most known model animals due to its small size, short generation time and used small area for breeding in relatively easy ways (Hedges, 2002). Small mammals have been the subject of anatomical, physiological, and ecological studies. However, some rodent species are considered the main causes of human food insecurity and public health problems (Jacob et al., 2010; Meheretu et al., 2014; Welegerima et al., 2020). Vertebrate pests, particularly rodents, caused large portion of damage and farmers frequently consider as one of the biggest threats to their crops (Sang et al., 2003; Tuan et al., 2003; Makundi et al., 2005).

According to Bekele et al. (2003), 10% of the 84 rodent species that are known to exist in Ethiopia are considered agricultural pests.The two genera that contain the most prevalent pest rodents in the country are *Mastomys* and *Arvicanthis* (Bekele et al., 2003).

Previous studies on small mammal diversity along altitudinal gradients in various regions of Africa and beyond have consistently demonstrated that altitude and habitat characteristics strongly influence species richness and composition. For example, Richard et al. (2022) reported that in Mount Rungwe Forest Nature Reserve Tanzania, increasing elevation is associated with a decline in tree abundance, shrub density, vegetation richness, and canopy cover. Similar surveys on Mt. Kenya documented strong elevational effects on non-volant small mammals, habitat structure and plant community changes with elevation drive marked turnover in species composition and a hump-shaped (mid-elevation) richness pattern (Musila et al., 2018). Aventine et al. (2003) observed a decrease in small mammal species richness with increasing altitude in Bwindi Impenetrable National Park, southwestern Uganda. A comparable pattern was documented on Mount Meru, Tanzania, where Stanley and Kihaule (2016) recorded the highest and lowest concentrations of *Lophuromys* species at 3,000 m and 1,950 m above sea level, respectively. Additionally, Mulungu et al. (2008) demonstrated that rodent diversity on Mount Kilimanjaro, Tanzania, is influenced by both habitat heterogeneity and altitudinal variation.

Prior studies in Ethiopia have also documented variations in small mammal diversity and distribution across altitudinal gradients. For instance, Kassa et al. (2023) reported that species composition, abundance, and diversity in the Simien Mountains National Park varied significantly with elevation. In the Chato protected area of western Ethiopia, Debelo & Bekele (2020) recorded the highest species abundance (89 individuals) at elevations of 975 – 2,230 m.a.s.l., with the lowest abundance (17 individuals) occurring above 2,230 m.a.s.l. Studies by Craig et al. (2020) in Simien Mountains National Park, conducted across altitudes of 2,900, 3,250, 3,600, and 4,000 meters above sea level, found the greatest species richness at mid-elevations (3,250 m). Mulualem et al.(2017), in their study on the diversity of rodents and their associated ectoparasites along an elevational gradient in Grakahsu forest, southern Tigray, reported the highest number of individual rodents at 2,000m elevation and the lowest at 3,000 m.a.s.l. The highest species diversity was observed at 2,600m, while the lowest diversity was recorded at 1,700m elevation. Similarly, Welegerima et al. (2024) found that the diversity and distribution of small mammals in Tigray varied according to vegetation type, with the greatest abundance recorded in the Afromontane, Ericaceous, and Afro alpine belts, respectively.

In Tanzania, Makundi et al. (2005) and in northern Ethiopia, Meheretu et al. (2010) identified rodents as the most prevalent crop pests, causing significant damage both in the field and during storage. Meheretu et al. (2012, 2013) further reported that three rodent species are considered as major pests in the region. Specifically, Meheretu et al. (2014) highlighted *M awashensis* and *A. niloticus* as the two most important crop pests in the Tigray highlands, responsible for substantial crop losses.

In Tigray, only a limited number of studies have been conducted on the ecology, diversity, and pest status of rodents in agricultural fields, primarily focusing on certain biomes such as, Dry Afromontane forest, protected areas including Grakahsu forest and Kafta Shiraro National Park (KNP), and the Tigray highlands in general. However, the small mammal communities of most Afromontane mountains in Tigray remain poorly documented, and the knowledge, attitudes, and practices (KAP) of smallholder farmers living near these areas regarding rodent pests have not been adequately addressed. Therefore, understanding the mechanisms influencing small mammal diversity across elevation gradients has become a key topic in bio geographical research. It is also essential for evaluating the possible effects of global climate change and the risks of extinction faced by at-risk species (Reiss et al. 2009; Fleishman 2010). Considering how organisms are distributed across highlands and mountains also provides important insight into montane ecosystems development and how to protect species diversity through conservation strategies (Stanley et al., 2014).

In addition to this, assessing the KAP of small holder farmers on rodent pests will enable us to understand its pest potential of rodents on agricultural crops and examine the control mechanism applied by the farmers. Having sufficient information on the species composition of small mammals are also important to strengthen of the existing wildlife conservation and management strategies of a particular protected area (Dolman et al., 2012). The peak of the study areas are characterized by typical evergreen Afromontane mosaic vegetation and are ecologically linked to surrounding mountain chains, including Mount Tsbet, the Hugumbrda-Gratkahsu forest, and parts of the Great Ethiopian Rift Valley. Although the study area is being part of the Ethiopian Afromontane mountain blocks, and is important for both ecological, local agricultural and irrigation practices, no studies have been conducted to investigate the diversity of small mammals or local farmers' knowledge, attitudes, and practices (KAP) regarding rodent pests in this region. So, it is essential to assess small mammal diversity along altitudinal gradients and evaluate farmers' KAP concerning rodent pest management around these sites.

1.2 Statement of the problem

Tigray region of northern Ethiopia is one of the least studied regions in the country and has largely been inaccessible for biological study over the past century because of localized internal and external war (Schulte to Bühne et al., 2024). While there are studies on the flora of southern Tigray in Hugumbirda-Gratkhassu forest by (Leul et al., 2010; Atsbha et al.,2019; Eyasu et al., 2020; Mengistu et al., 2022) and on fauna by (Yonas et al., 2011; Adam et al.,2015; Mulualem et al., 2017; Welegerima et al.,2024). several Afromontane mountain blocks in southern Tigray have yet to be studied. Additionally, the area has been the focus of a variety of human land uses, with agricultural expansion having especially negative impact on the Afromontane mosaic vegetation (Nyssen et al., 2005).

On the other hand, the highlands support a few remnants of Afromontane forest that are largely restricted to church yards and other sacred groves in a matrix of cropland and semiarid degraded savanna (Aerts et al., 2006). Moreover, the regional vegetation structure, such as Somali-Masai savanna, Sudanian savanna, and large vegetation belts connecting to these savannas separated by Afromontane mosaic vegetation types make up the Tigray region, a crucial area in terms of biogeography(Welegerima et al., 2024). Despite the region's distinctive biogeographical features, there is a serious lack of biota sampling, even for reasonably well-known animals like small mammals (see the sampling gap in Bryja et al., 2019).

In several Afroalpine ecosystems in Ethiopia, particularly in Tigray, biological diversity has dwindled dramatically in response to adverse human activities such as agricultural expansion, overgrazing, and settlement, which have caused significant habitat degradation resulting in several small mammal species being critically endangered before proper scientific information is documented (Tesema et al., 2022). Besides, knowledge, attitude and practices (KAP) of the small-holder farmers surrounding such Afromontane mosaic vegetation on rodent pests and their public healthy importance are limited.

There are serious conservation concerns about the region's biodiversity because there are currently few protected areas (aside from Kafta-Sheraro National Park, Hugumbirda-Gratkhassu forest, Hirmi forest and Desa forest) but the human population and agricultural land use are expanding quickly. Currently, human-induced fire, firewood collection, overgrazing and farming expansion in the region are harming the Afromontane mosaic vegetation’s and national park such as Kafta Shiraro National Park (KSNP) in the north west Tigray (Temesgen et al., 2022). To the best of our knowledge, no research has yet been conducted in Mount Mahbere Bekuru to assess the diversity of small mammals along the altitudinal gradient, or to evaluate the knowledge, attitudes, and practices (KAP) of local farmers regarding rodent pests and their management. Therefore, the present study aims to fill this gap by providing valuable information on the diversity and distribution of small mammals in the area, as well as understandings into farmers’ KAP concerning rodent pest management.

1.3. Objectives of the study

1.3.1. General objective

To investigate the diversity of small mammals along altitudinal gradient and examine the knowledge, attitude and practices of smallholder farmers on rodent pests in Southern Tigray, Ethiopia.

1.3.2. Specific objectives

- To investigate the small mammal species community composition in the study area
- To investigate the diversity of small mammals along the altitudinal range
- To assess the small-holder farmers’ knowledge, attitude, and practices (KAP) on rodent pests residing near the study area across altitude in parallel with small mammal sampling.

1.4. Research Questions

The research questions encompass.

- How is the small mammal species community composition on study area differ?
- Is there any variation in species diversity and abundance of small mammals along an altitudinal range?
- Which species of small mammal is most abundant on the study area?
- What are the knowledge, attitude, and practice of small-holder farmers about rodents as pest animals across altitude?

1.5. Significance of the study

The overall significance of this assessment brings out new data on the small mammal community composition in the study area. This study bridges the gap between ecological research and practical agricultural challenges. The findings serve as a vital resource for agricultural extension workers, and conservationists aiming to develop sustainable solutions for both pest control and biodiversity conservation in the region. Besides, the result will bring the attention of researchers and conservationists to unexplored habitats for future conservation and study in the region. The study presents baseline data on diversity of small mammals to the concerned bodies that plan to set the forest as nature conservation area. Studying the environment associations of small mammals has an implication to develop an area wide nature conservation since small mammals are considered to be good indicators of ecosystem health. In addition to this, it fills our knowledge gap on diversity of small mammals of the forest and KAP information of the community on ecological role of small mammals and pest status of rodents.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Diversity of Ethiopian small mammals

The Ethiopian Highlands, a critical region within the Eastern Afromontane Biodiversity Highlands (EABH), supports a rich and diverse rodent fauna, many of which are endemic, reflecting the region's unique evolutionary history and biogeographic importance (Bryja et al., 2019). This remarkable diversity is shaped by complex topography, climatic conditions, and evolutionary processes (Billi, 2015). The montane ecosystems, isolated by geographical barriers like the Great Rift Valley, have led to allopatric diversification, making it a natural laboratory for studying speciation and adaptive radiation (Lyra et al., 2023).

In Ethiopia, about 104 species of rodents have been recorded (Brjya et al., 2019). In this monograph summarizing taxonomic and biogeographical knowledge of Ethiopian rodents, the Ethiopian rodent fauna currently represents 40 genera in 10 families, with a significant proportion being endemic to the Ethiopian Highlands (43 species = 41.3%), followed by those inhabiting the Somali-Masai (31 species) and Sudanian (13 species) savannas. Since the monograph, additional biodiversity assessments have been conducted in under-sampled regions such as, Tigray Highlands. However, the rodent fauna still remains understudied, with many regions in remote montane and fragmented habitats poorly sampled and significant taxonomic uncertainties persisting (Demos et al., 2014; Bryja et al., 2019 Studies are continuing to document many cryptic species. In Tigray, about 21 rodents and 2 shrew species with a number of cryptic species were recorded from the major vegetation types of Tigray (Welegerima et al., 2024).

2.2. Micro- habitat association and geographic distribution of small mammals

Abundance and diversity of food and microhabitat conditions such as vegetation characteristics, leaf litter depth, ground cover, canopy cover, and soil properties determine the presence and abundance of small mammals on a local scale (Leis et al., 2007). This is a result of small mammals choosing and adapting to various microhabitat conditions. The habitat-heterogeneity hypothesis states that an increase in habitat heterogeneity leads to an increase in species diversity (Cramer& Willig, 2002).The hypothesis emphasizes the impact of vegetation structure, composition, and types of habitat on rodent diversity and community assemblages (Stevens & Tello, 2011). According to the habitat heterogeneity hypothesis, additional microhabitats that offer more niches for coexisting species enable diverse ecosystems to support high species variety (Stein & Kreft, 2015). A diversified ecosystem is facilitated by microhabitats such as topography and soil features of the landscape, climate, vegetation, diseases, predation, and human habitat utilization (Men et al., 2015; Lim et al., 2018).

The abundance and community composition of small mammals depends on the vegetation structure and complexity of the habitat (Muck & Zeller, 2006; Glennon & Porter, 2007) with high vegetation diversity and dense ground cover supporting greater small mammal species diversity (Mulungu et al., 2008). Several studies were done related to micro habitat and distribution of small mammals in Africa. For example, Mulungu et al. (2008) pointed out that different vegetation types have different species diversity, capture probabilities, and population sizes. Species cohabitation, which is influenced by characteristics unique to each species such nesting, food availability, and risk of predation, determines the assembly of rodent communities (Cramer & Willig, 2002). A prior study conducted in the Serengeti ecosystems by Shilereyo et al., (2023) revealed that species diversity varied with land use and habitat type. They reported that species diversity was highest in the park, middling in the agricultural land, and the lowest in the pastoral land. Climate, habitat heterogeneity, species area effect, and the mid domain effect linked to altitudinal gradients all have an impact on biological communities (Caceres et al., 2011).

According to Cramer & Willig (2002), high ground cover and dense shrubs, which provide niches for a variety of species, fallow was the most varied environment. Fallows act as a transitional area between montane forests and agricultural fields, offering other rodents a place to live, alternate food sources, and defense against predators (Cramer & Willig, 2002; Makundi et al., 2010). According to Mulungu et al. (2008), the mountain's disturbed and intact forested sections had the greatest number of species, with six or seven, while the highest altitude moorland had the fewest species, with only two or four. There have been reports of relatively low species diversity and richness in habitats with short and sparse grass on the slopes of Mount Elgon (Clausnitzer & Kityo, 2001). In comparison to disrupted and intact forests, living circumstances and the abundance of rodents and shrews are likely poorer in moorland areas (Canova & Fasola, 2000). The study shows that the composition and diversity of the rodent and shrew communities in the disturbed forest were very different from those in the intact forest. The variation in community composition implies that the modification of the native forest in the mountains causes a rise in the diversity of rodent species. Mulungu et al. (2008) reported that there was no significant variance in species composition in places with closely related vegetation, but there was a significant variation when two or more locations had different vegetation types. Datiko et al. (2007) reported that the distribution of species varied from habitat to habitat in a forest and farmland study in Arbamich, Ethiopia. Most rodent species were captured more from natural habitats than farmlands during the study period. The higher preferences of natural habitat than farmlands by most rodents might be due to homogeneity of agricultural habitats and heterogeneity of natural habitats, the place where the species occurred in high abundance was also a place where there is enough cover as well as adequate food (Datiko et al., 2007). Kassa et al. (2023) found highest species richness in the forest habitat and lowest in the giant Lobella domination areas.

Ethiopia is a geomorphologically very diverse country, which is reflected in the diversity of ecosystems and vegetation types. The most conspicuous feature of Ethiopian geomorphology is the large area of mountains (Bryja et al., 2019). Ethiopia's diverse topography, land use practice, and climatic variations have shaped a heterogeneous habitat with remarkable levels of endemism (Billi, 2015). For example, high altitude grassland and moorland habitats in Ethiopia are home to endemic mouse, *Tachyoryctes macrocephalus* (Yalden, 1988; Alemayehu, 2014). Ethiopian ecosystems such as, the Afroalpine ecosystem, montane forests, bush land habitats and human-modified and agricultural landscapes are home to unique fauna and flora. The Afroalpine ecosystem on isolated mountains providing critical habitats for many highly specialized species (Yalden et al.,1976). This ecosystem is characterized by a mosaic structure, predominantly composed of open grasslands and moorlands, occasionally interspersed with shrub lands of tree heaths (Erica) (e.g. Fetene et al., 2006; Asefa et al., 2020).

Ethiopian Afroalpine ecosystem is home to diverse rodent genera, including narrow-headed rats (*Stenocephalemys*), brush furred rats (*Lophuromys*), grass rats (A*rvicanthis*), African vlei rats (*Otomys*), and African root-rats (*Tachyoryctes*) (Šumbera et al., 2018; Bryja et al. 2019; Mizerovská et al., 2020, 2023). The Ethiopian montane forests are a tropical moist broadleaf forest ecoregion in Ethiopia. It covers the southwestern and southeastern portions of the Highlands. Small mammals found in Ethiopian montane forests include species of *Arvicanthis niloticus, Desmomys harringtoni, Mastomys awashnesis*, *Stenocephalemys albipes*, *Lophuromys simensis*, *Crocidura olivieri* (Bryja et al., 2019; Welegerima et al., 2024). Bushland habitats composed of shrublands, scattered trees, and dry grasses; characterized by *Acacia* and *Commiphora* species, also support a variety of small mammals adaptations such as the genera *Mastomys*, *Arvicanthis*, *Stenocephalemys* and various shrew species (Ayechw et al., 2024).

Anthropogenic defaunation causes reduction in small mammal biodiversity but increases the density of opportunistic species that can occur as pests in agriculture and are carriers of infectious diseases (Dirzo et al., 2014; McCauley et al., 2015). However, due to their unique behaviors such as, high reproductive rate and seasonal breeding rodents like, *Mastomys awashensis* and *Arvicanthis niloticus* exhibit seasonal reproduction timed with rainfall and crop development stages, allowing rapid population growth when resources are abundant, especially during milky, fruiting, and harvest stages of crops. This reproductive strategy enables them to quickly exploit the resource-rich but temporally unstable agricultural habitats (Meheretu et al., 2015). They also use habitat structure like stone bunds, terraces, and remnant vegetation patches for shelter and nesting. Although stone bund density has a minor effect on survival, these structures provide cover that supports persistence in disturbed landscapes (Meheretu et al., 2015). Small mammal species common to this habitat includes *Mastomys natalensis, Arvicanthis niloticus, Lophuromys flavopunctatus, Acomys cahirinus, Mus musculus,* are abundant in agricultural areas, drier cultivated areas and around human settlements, adaptable to various habitats including disturbed areas (Yalden et al., 1996).

Northern Ethiopia particularly Tigray region consists five types of natural vegetation's including, Afromontane mosaic vegetation, Afroalpine vegetation, Ericaceous belt habitats, Somali-Masai savanna vegetation and Sudanian savanna vegetation (Lillesø et al., 2011). The diversity and distribution of small mammals varied depending on the vegetation type, with highest number of small mammals recorded in the Afromontane, Ericaceous belt and Afroalpine in the region (Welegerima et al., 2024). Mulualem et al. (2017) also reported that diversity of rodents was influenced by habitat and altitude with the highest species of rodents in bush land habitat and the least in grassland habitat.

2.3. Ecological role of rodents

Small mammals are well-known bio-indicators of high reproductive rates, rapid turn-over, and sensitive to habitat changes (Li et al*.,* 2015). For example, rodents are sensitive to changes in plant communities, while insectivores are more sensitive to changes in forest litter and moisture (Li et al., 2015). Burrowing rodents also act as ecosystem engineers, reshaping subterranean landscapes through their tunnel networks (Akin et al., 2024). These excavations improve soil aeration by breaking up compacted layers and introducing oxygen-rich air pockets (Davidson et al., 2013). By aerating soil, rodents indirectly support plant growth and ecosystem vitality, fostering conditions for diverse vegetation and microbial communities. Additionally, they contribute in accelerating organic matter decomposition. Rodents' habit of hoarding plant residues in burrows accelerates decomposition by concentrating organic matter in nutrient-rich microsites (Kramer et al., 2012). Stored plant materials decompose faster underground due to stable moisture and temperature conditions, releasing essential nutrients like nitrogen and phosphorus (Lavelle et al., 2006; Kramer et al., 2012). This nutrient cycling enhances soil fertility, boosting crop yields and wild plant productivity. Additionally, enriched soil supports thriving microbial and invertebrate populations, which drive biodiversity and ecosystem resilience (Bardgett & van der Putten, 2014).

As primary consumers, rodents occupy a critical position in food webs, serving as a vital energy source for predators such as raptors, owls, snakes, and carnivorous mammals (Gosselin et al., 2006). By supporting apex predators, rodents indirectly preserve biodiversity and ecological balance. Rodents, particularly mice (*Mus* spp.), play a dual role in ecosystem regulation through their consumption of insects and weed seeds (Batzli, 1977). Their insectivorous behavior helps suppress insect populations, while herbivorous seed predation limits weed dispersal and germination. These activities collectively function as a natural pest control mechanism, maintaining ecological balance by regulating insect populations through reducing potential agricultural pests (e.g., crop-damaging larvae) and mitigating nuisance insects in residential areas, Suppressing weed spread by destroying weed seeds before germination and preventing invasive species colonization (Brown & Heske, 1990).

2.4. Influence of altitude on diversity and distribution of small mammals.

The distribution and diversity of small mammal communities are significantly influenced by altitudinal gradients, which are often linked to ecological and climatic changes that support unique vegetation and animal life (Caceres et al., 2011; Bantihun & Bekele, 2015). Several fundamental factors contribute to the impact of altitude on biological communities, including the species-area effect, climate, habitat heterogeneity, and the mid-domain effect (Rowe et al., 2015). Mountains often serve as crucial refuge for many small mammal species, particularly during unfavorable climatic periods, such as when surrounding areas become arid, leading to the isolation of forest species in high-altitude forest patches (Clausnitzer & Kityo, 2001; Stanley et al., 2005). Conversely, some savanna species may seek refuge in moorland grasslands above the forest boundary if lower elevations are dominated by extensive rainforests. These isolation mechanisms, driven by varying altitudinal conditions, result in distinct distribution patterns for small mammals across mountain ranges.

The altitudinal gradient on mountains is characterized by the formation of diverse vegetation zones, typically including disturbed forest, intact forest, and moorland grasslands. These distinct zones, along with other environmental factors, influence the presence and abundance of small mammals. Species abundances are generally highest at the centers of their distributions and gradually decline towards their boundaries (Betz et al., 2020).

Mid-elevation areas are frequently identified as having optimal environmental conditions for small mammals. These zones often benefit from conducive climatic conditions, abundant and diverse vegetation, higher canopy cover, and richer microhabitats (Manhou & Jing, 2018). Studies consistently show that species abundance and richness peak at mid-elevations (Betz et al., 2020; Ssuuna et al., 2020). This phenomenon is often attributed to the peak humidity and rainfall typically found at mid-elevations, which create a climate favorable for small mammal survival (Li et al., 2003). In contrast, higher elevation characterized by lower temperatures, often dropping below freezing, higher humidity, and potentially strong winds and frost. Primary productivity can be limited by these harsh conditions and compacted soils. Environments often present significant challenges. Previous research in areas like the Mount Rungwe Forest Nature Reserve (MRFNR) indicates a decrease in the abundance of trees, shrubs, vegetation richness, and canopy cover as elevation increases (Richard et al., 2022). While higher elevations may exhibit a greater percentage of ground cover due to more grass and herbs, this often results in lower canopy cover, which is crucial for reducing predation risk and contributing to microhabitat variety (Carey & Wilson, 2001).

Consequently, the small area, sharp rocks, and extreme weather at higher elevations make the environment less suitable for many small mammal species, leading to lower capture rates (Novillo & Ojeda, 2014; Richard et al., 2022). The species-area association also contributes to lower abundance at high elevations, as smaller, steeper, and more rugged terrain limits the area available for species, impacting primary producer growth and subsequently consumers (Li et al., 2003; Connor and McCoy, 2017). Although the flora at higher elevations may be abundant, it often exhibits less diversity and richness due to the dominance of shrubs, herbs, and grasses, underscoring the critical role of vegetation characteristics in microhabitat selection for small mammals (Madden et al., 2019). Kassa et al. (2023) reported the mid-elevational peak and decline at higher altitudes in Seimien Mountains National Park Ethiopia. Mulalem et al. (2017) in Tigray also reported as altitude increase species richness decreases. While general trends suggest higher diversity at mid-elevations, the distribution patterns of individual small mammal species often vary along altitudinal gradients, reflecting their unique requirements and tolerance levels (Richard et al., 2022). For example, a positive productivity-diversity relationship between producers and consumers (Ramírez-Bautista & Williams, 2019; Kamenišťák et al., 2020) suggests that food availability plays a key role.

Low elevation typically characterized by warmer temperatures and potentially lowers rainfall, leading to drier conditions in many areas. Research in mountainous regions, such as the Eastern Tatras Mountains of Slovakia, has also revealed that generalist species may colonize various parts of the altitudinal gradient, while specialist species are confined to specific habitats whose presence is limited by altitude (Kamenišťák et al., 2020). This study reported a significant decline in small mammal species richness with rising elevation, from ten species below 1000 ma.s.l. to four or six species at higher elevations. These results highlight that changes in community composition and species richness not only reflect environmental conditions and biological limits but also the combination of adjacent habitats and available resources (Kamenišťák et al., 2020).

In the Urucum Mountains of western Brazil, altitude was found to have a strict influence on the small-mammal community, with vegetation being a critical factor affecting individual species (Caceres et al., 2011). The mid-domain, species-area, and climate hypotheses are believed to complement the explanation for these altitudinal changes in community composition (Caceres et al., 2011). Ultimately, while altitude itself is not the sole determinant of small mammal abundance and distribution, vegetation structure and types remain paramount (Clausnitzer & Kityo, 2001). Variations in individual species patterns along altitudinal gradients have been consistently noted across different mountainous areas, such as Mount Meru, where *Lophuromys* sp. showed highest concentrations at 3000 m.a.s.l. compared to 1950 m.a.s.l., potentially due to increased herb density at higher altitudes (Bantihun & Bekele, 2015; Stanley & Kihaule, 2016).

2.5. Rodent as pests

Large portion of damage is caused in crops by vertebrate pests, particularly rodents, which farmers frequently consider as one of the biggest threats to their crops (Sang et al., 2003; Tuan et al., 2003; Makundi et al., 2005). Due to their high cost to agriculture, rodent pests have a significant impact on both worldwide agricultural production and farmers' livelihoods (Singleton et al., 2005, 2010). They cause huge economic losses in agricultural crops, primarily root crops and cereals in the field, and consume and contaminate stored grains (Meheretu et al., 2010; Mulungu et al., 2015; Jones et al., 2017). According to Lund (2015), rats and mice eat food, physically harm packaging and storage materials, and contaminate products with their hair, urine, and feces. They are responsible of destroying food supplies that could provide a year's worth of food for 280 million people (Meerburg et al., 2009). Food contaminated with rodent hair or droppings can cause serious issues for exporting nations, even leading to the rejection of entire shipments (Lund, 2015).

The food security and income of small-holder farmers in developing countries are greatly affected by rodent damage (Lund, 2015; Htwe et al., 2016). Such a country level damage can have a major effect on the economy of any country and all available consumers (Gebhardt et al., 2011). Rodents cause serious problems to human communities in Africa as a result of their involvement in the spread of diseases (Katakweba et al. 2012) and losses of crops through direct consumption (Bekele et al. 2003; Mulungu et al. 2003;) and spoilage (Mdangi et al. 2013). For example, Taylor (1968) reported 20% damage to maize crop after the outbreak of rodents in western Kenya. Earlier reports (Taylor, 1968) on economic losses due to rodents in Kenya indicated 20–30% damage to maize crops, and a 34–100% loss during rodent outbreaks. In Tanzania, rodents are estimated to cause on average 15% yield loss (Makundi et al. 1991).

Additionally, Ethiopia consistently faces rodent pest issues with a variety of agricultural products (Makundi et al., 2005). Of the total rodent species known to exist in Ethiopia, dozens of the species are significant agricultural pests (Bekele et al., 2003). Recently, Gadisa and Hundera (2015) reported the existence of four rodent pest species, namely *Rattus rattus*, *Mastomys natalensis, Arvicanthis dembeensis* and *Lemniscomys barbarus* in Sekoru district, Southwest, Ethiopia. In Northern Ethiopia, surveyed farmers estimated 9–44% pre-harvest yield losses in annual production of cereal crops due to rodent attacks (Meheretu et al. 2010), while Central Ethiopia showed 26.4% loss of yield in maize (Bekele et al. 2003). Post-harvest losses are mostly caused by inefficient harvesting and inefficient use of technology in post-harvest tasks such threshing, washing, drying, and storing (Abrehet, 2018; Satheesh and Fanta, 2018). Traditional postharvest handling of cereal grains in developing countries like Ethiopia is causing considerable postharvest loss, which has a direct impact on food security and resulting in losses related to nutrition and finances (Hodges & Bernard, 2014). According to Befikadu (2018) postharvest losses in Ethiopian value chains of particular cereal crops are estimated to be between 10 and 50 percent on average. According to estimates from the Food and Agricultural

Organization, Ethiopia lost 9.9% of its wheat after harvest (FAO, 2018). Conversely, a survey conducted in 2017 by Dessalegn et al. (2017) found that the average wheat loss in four regions of Ethiopia (Amhara, Tigray, Oromia, and Southern Nations Nationalities and Peoples region) was 17.1%.

Ethiopia ranks third in terms of stored grain losses, after Egypt and Tanzania according to the current report (Mulungu, 2017). It is economically beneficial to control rodent population to reduce rodent linked losses (Skonhoft et al., 2006; Brown et al., 2013). Appropriate rodent control strategy, such as Integrated Pest Management (IPM) can help to reduce the loss of yield caused by rodent pests and produce more food to feed the population of a country. The socioeconomic circumstances and farming culture of a specific region are another crucial aspect (; Mulungu et al., 2003; Sang et al., 2003; Sudarmaji et al., 2003; Tuan et al., 2003; Makundi et al., 2005).

CHAPTER THREE

3. MATERIAL AND METHODS

3.1. Description of the study area

The study was conducted in some selected sites of southern Tigray Raya Azebo and Emba Alaje districts namely Babur Hadid, Zibandas, Qala Alela, and Mount Mahber Bekuru based on altitudinal gradient). The distance of the study area districts from Mekelle is 127 and 120 km respectively. Small mammal samplings and KAP assessment was performed in the above mentioned four sites where they have altitudes of 1500, 2000,2500, and 2900 m.a.s.l , respectively (Table 1). The distance of Babur Hadid, Zibandas, and Qala-Alela from Mehoni is 17, 7 and 12 kms, respectively. Mount Mahbere Bekru is the fourth study site which is located at the highest altitude and it is under Emba Alaje district. Although it belongs to Emba Alaje district it is near to Mehoni topographically and its air distance is about 9 km far.

Babur Hadid**,** a low-altitude site located in Kara Kebele of the Raya Azebo district, has emerged as a vibrant investment area. It is home to active mechanized irrigation projects, including prominent farms such as Desta Berhe Farms and the Haleka Mogos farming area. These initiatives have significantly boosted agricultural productivity, with a wide variety of fruits and vegetables cultivated throughout the site. In addition to its agricultural output, Babur Hadid plays a vital socio-economic role by providing temporary employment opportunities for many young people in the region.

Zibandas is a site located north of Mehoni in Tsgea kebele which is the base of mount Mahbere Bekru where there are some agricultural activities and scattered houses of small holder farmers. This site is periodically protected by the local farmers. However, the surrounding of this site experienced disturbances from agricultural activities such as burning for agricultural expansion, overgrazing, cutting of large trees and honey bee production.

Qala Alela is the third site located between Zibandas and Mahbere Bekuru. The area is covered with dense forest and no farmers live there. Relatively it is undisturbed area. Only small mammal sampling was conducted at this site, while KAP sampling was not performed due to the absence of a surrounding community. Mahbere Bekuru is found in Ayiba kebele, Emba Alaje. The remnant patches of natural forest in the area are classified as Dry Afromontane Forests, characterized by dominant tree species such as *Juniperus procera*, *Olea europaea* subsp. *cuspidata*, and *Acacia abyssinica*. (Hishe, 2019). The massif forest is within the domain of the northern highlands of Ethiopia, in the western escarpment of the rift valley. The topography includes hilly areas, flat lands, mountains, and valleys (Hishe, 2019)

Table 1: Description of the trapping sites

Site	Site description	Altitude	GPS
Babur Hadid	The area is part of the Somali-Masai savanna vegetation types. It is an investment area for variety of crops such as sorghum and maize, as well as in plantations of bananas, mangoes, avocados, tomatoes, and papayas. This location was the lowest and warmest compared to the other three sampling sites. Plants common to this area was *Acacia abyssinica, Acacia etbaica, Balanites aegyptiaca* and *Opuntia ficus-indica.*	1500	12º41' 03.61"N 39º43'53.30"E
Zibandas	The area is protected by the local community for rehabilitation, beekeeping and grass collection purposes for their livestock. Plants such as *Aloe* species, *Dodonaea angustifolia*, *Acacia abyssinica, Acacia etbaica Schweinf, Balanites aegyptiaca* , *Carissa spinarum*, *Grewia* sp., *Olea europaea subsp. Cuspidate* , *Opuntia ficus-indica* among the dominant ones. Surrounding this site, there was a honeybee production area established by a nearby community, where the members shared their earnings evenly. The specific sampling site was not directly impacted however, there were disturbances from human and animal activities in the vicinity, including overgrazing, logging for construction, and burning for agricultural expansion.	2000	12º51'01.24"N 39º37'57.24"E

Qala Alela	This sampling location was a highland region populated with dense forests, featuring large trees such as *Olea europaea subsp. cuspidata, Acacia abyssinica, Calpurnia aurea*, *Spathodea campanulata*, *Acacia etbaica, Balanites aegyptiaca* , *Carissa spinarum*, *Grewia* sp., *Myrsine africana*, *Opuntia ficus-indica* , *Rhus glutinosa , Rhus natalensis , Rubus steudneri , Rosa abyssinica , Senecio hadiensis ,Podocarpus falcatus* and *Grewia mollis* and various local plant species.	2500	12º50'58.56'N 39º36'05.08E
Mahbere Bekuru	Mount Mhabere Bokuru is part of the dry evergreen Afromontane mosaic vegetation. Situated at the highest elevation, this site remains undisturbed by human or animal activity. Dominant plant species include *Juniperus procera*, *Olea europaea* subsp. *cuspidata, Acacia abyssinica*, and *Erica arborea*. Apart from the monks residing within the monastery, there is no nearby community living in proximity to the church.	2900	12º51'36.79"N 39º35'57.86"E

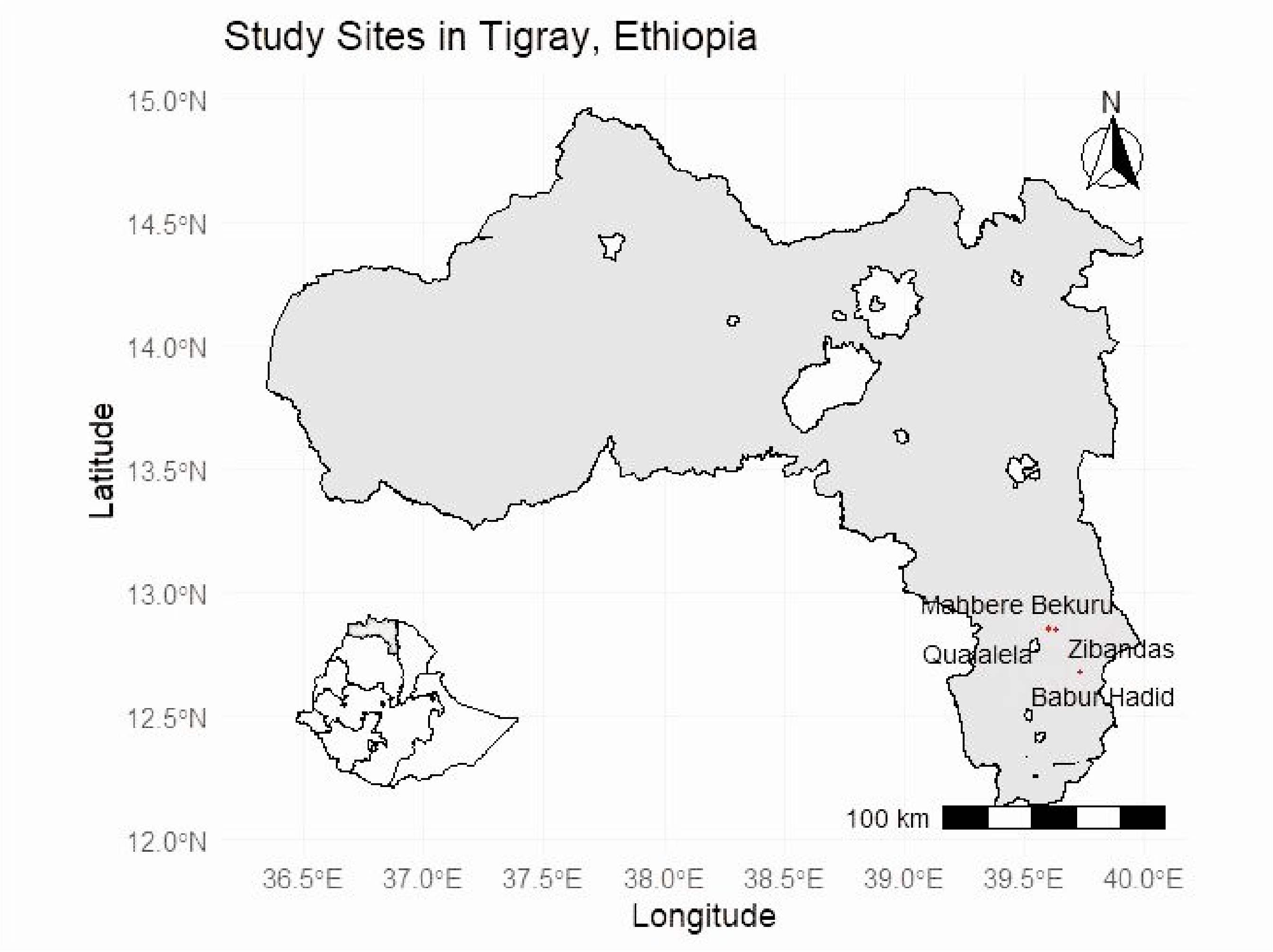

Fig. 1: Location of the study area (Mount Mahbere Bekuru) in the southern part of Tigray

Fig. 2: Location of sampling sites

3.1.1. Agro-ecological condition

The study area encompasses two distinct agro-climatic zones: The highland (referred to as "dega") and the lowland (termed "kola"), with a predominant presence of the highland zone. The area has 20 and 30 ºC minimum and maximum temperature respectively (Kidane et al., 2016). Conversely, the average minimum temperatures are significantly lower, with December and January registering averages of 5.47 °C and 6.88 °C, respectively (Hishe, 2019). The highest rainfall distribution occurs between July and August, coinciding with the main rainy season. Additionally, there is a secondary, albeit less intense, rainfall period observed in March, April, and May. The mean annual rainfall for the study area is approximately 630 mm, as documented by the National Meteorological Services Agency (NMSA) over the period from 1998 to 2017 (Hishe, 2019).

3.2. Sampling design

The study area was divided into four different altitudinal gradients (1500 – 2900 m.a.s.l) and then a representative permanent one line transect was established based on altitude. Following the establishment of the line transect trap stations were set at two meter intervals along one horizontal transect. The trap stations were marked using colored plastic tags or strings, depending on the density and height of the vegetation type present in each line.

3.3. Small mammal sampling

Small mammals (rodents and shrews) were trapped using Sherman live traps (23 × 9.5 × 8 cm; H.B. Sherman Traps Inc.) and snap traps. A total of fifty traps (25 Sherman and 25 snap traps) were placed at each altitude. Large Victor rat trap (17.5 × 8.5 cm; Wood stream Corporation) and the small snap trap (9.5 × 4.5 cm; manufactured in the Czech Republic) were used in combination with Sherman. Trapping sites were selected along altitudinal gradient starting at 1,500 m.a.s.l with a sampling interval of ~500 m i.e., 1500, 2000, 2,500, 2,900 m.a.s.l (see Table 1). At each elevation, one line transect with 50 traps were deployed. In each line, three trap types Sherman trap, large victor rat trap and small snap trap were set alternately, one after the other, in lines up to 100 m long in each transect. Traps were baited with peanut butter and barley flour and then placed in a horizontal line transect with an average distance between traps of about 2 m. The traps were set for three consecutive nights per elevation. Captures were checked each morning and also rebaited the tarps. In order to facilitate the daily control and trap recovery, each trap was marked by a piece of surveyor's flag attached at proximity (i.e., 1-2 m) to the vegetation. A unique code was assigned to each trap line. Captured rodents were handled in accordance with the guidelines of the American Society of Mammologists for the use of wild animals in research (Gannon et al., 2007).

3.3.1. Species and sex identification

Each captured animal was identified to the species level in the field using basic morphological traits and body measurements, following the guidelines outlined in *Mammals of Africa, Volume III* (Happold, 2013). Tissue samples including liver, spleen, kidney, and heart was collected and preserved in 96% ethanol. These samples were stored at the Rodent Research Unit Laboratory, Department of Biology, Mekelle University. Representative specimens were later sent to the Institute of Vertebrate Biology at the Czech Academy of Sciences, Czech Republic, where genetic analyses were conducted to confirm species identification. Sex and age of small mammals were differentiated by observing their external reproductive organs, presence of scrotum covering testicles in adult males and of the vagina in females, Nevertheless, juvenile males have their testes inside the body (abdominal) while the adult tests are scrotal visible, juvenile males and females differentiation was done by observing the distance between the anus and the genitals, which is greater in males than in females (Herbreteau et al., 2011). Juvenile females have the vagina which is not perforated while adult females have a perforated vagina.

3.3.2. Data recording

Additional data including weight, sex, reproductive status, ear length, tail length and hind foot length were recorded in accordance with the methodologies outlined by Herbreteau et al. (2011) and Aplin et al. (2003). Habitat descriptions, along with photographs and videos of the small mammals, were documented at each sampling site. GPS coordinates were recorded at every altitude to support spatial analysis.

3.4. Assessment of KAP of the community

Data were collected using semi-structured questionnaires to assess farmers' KAP of rodents as crop pests, their beliefs, and the actions taken to mitigate rodent-induced crop losses. Fifty respondents were randomly selected from three villages across the two study districts. Given the scattered nature of houses in the communities, households nearest to the study sites were selected based on altitude. Ten respondents were selected out of the total thirty individuals near Mount Mahbere Bekuru from Arera Emba Alaje. From Zbandas village in Raya Azebo district, thirty respondents were chosen out of one hundred twelve residents and ten respondents were added out of forty workers from Babur Hadid surrounding the private Desta Berhe farms.

The survey was originally prepared in English and then translated into Tigrigna, the local language, to ensure clarity and comprehension for the farmers. The questionnaire was pretested and refined. The questionnaire comprised four sections. The first section collected demographic and farming background. The second section focused on general knowledge about rodent pests and the pre-harvest crop damage they cause. The third section addressed post-harvest crop losses attributed to rodent pests. In the final section, farmers were asked to evaluate the management techniques they employed to mitigate crop losses caused by rodents.

3.5. Data analysis

Before data analysis data was arranged, organized, and entered into Microsoft Excel. Rodent species diversity and richness were compared among the altitudinal gradients. Species diversity for each site (elevation) was calculated and compared using the Shannon index of diversity (Shannon and Weaver, 1949; Hutcheson, 1970; Kwak and Peterson, 2007). The Shannon index of diversity was calculated as

$$H' = -\sum_{i=1}^{s} \left(\frac{ni}{N} \right) \times \ln \left(\frac{ni}{N} \right)$$

Where H'= index of species diversity, ni is the number of individuals in a species, S is the total number of species, also called species richness, N is the total number of individuals. These ecological and biodiversity indices, such as the species diversity, species richness and evenness parameters were calculated using the software PAST (Hammer et al., 2001). In addition to PAST and for further statistical analysis SPSS version 16 was also used. One Way ANOVA was used to calculate the variation of species across altitude. To compare the variation in specie abundance in each specific elevation one sample t-test was used. We employ “trap-night” to accurately quantify the sampling effort. The effectiveness of each method is articulated through “trap success”. Trap success is a measure used in wild life ecology and rodent population studies to indicate the efficiency of traps in capturing rodents and calculated using the following formula:

Trap success (%) = (Number of rodents captured/Number of trap nights)*100, Where Number of rodents captured= Total individual rodent caught; Trap nights=Number of traps deployed*Number of nights set.

Rodent dominance was analyzed using Simpson’s Index of Dominance (D)

$D = \Sigma\, n\,(n-1)/N\,(N-1)$ where N= the total number of individuals of all species, n= the total number of individuals of particular species. To describe how common or rare each rodent species relative to others metric relative abundance (pi) was used and calculated using the formula: pi = ni/N, where, ni= number of individuals of specie i, N=Total number of individuals of all species.

Cross table and frequency distribution was employed for data analysis of respondents using SPSS software and presented in the form of tables and figures. To determine statistical significance among the responses, a chi-square test was conducted at the 0.05 significance level. All statistical analysis was conducted using SPSS version16, PAST and Microsoft Excel software’s.

CHAPTER FOUR

4. RESULTS

4.1. Species composition and elevational distribution of small mammals

Over the course of 600 trap nights, we captured a total of 138 small mammals, achieving a trap success rate of 22.8% for rodents and 0.2% for shrews. The captured individuals comprised eight morphologically and (or) genetically distinct rodent species and one shrew species, distributed across four different altitudinal zones throughout the study (Tables 2 and 4; Fig. 3). Of these, 137 were rodents, and one was a shrew species. All eight rodent species belonged to the family Muridae, while the single shrew species (*Crocidura olivieri*) belonged to the family Soricidae. The number of small mammal captured varied with trap success from the lowest of 13 (8.7%) individuals at 2000m, to the highest of 84 (28%) individuals at 2900 m.a.s.l. (see Table 3). The most widely distributed species was *Stenocephalemys albipes* (found in all altitudes except 1500 m), followed by *Arvicanthis niloticus, Mastomys awashensis, Lophuromys simensis*, *Mus mohamet* (Table 2; Fig. 3). The least distributed species were *Acomys cahirinus, Crocidura olivieri, Rattus rattus* and *Desmomys haringtoni.* The first two species were recorded from 2000 m elevation and *Desmomys haringtoni* and *Rattus rattus* were found only in 2500 and 1500 m elevations respectively. *Stenocephalemys albipes, Lophuromys simensis* and *Mus mahomet* were distributed from 2000 – 2900 m.a.s.l.

Table 2: List of small mammals recorded across altitudinal gradient in the study area. The species was captured in that particular site (√), and not captured in that particular site (x).

Family	Species	Elevation (m.a.s.l.)			
		1500m	**2000m**	**2500m**	**2900m**
Muridae	*Arvicanthis niloticus*	√	√	x	x
	Desmomys harringtoni	x	x	√	x
	Mus mahomet	x	√	x	√
	Mastomys awashensis	√	√	x	x
	Stenocephalemys albipes	x	√	√	√
	Rattus rattus	√	x	x	x
	Acomys cahirinus	x	√	x	x
	Lophuromys simensis	x	x	√	√
Soricidae	*Crocidura olivieri*	x	√	x	x

Table 3: Trap success of rodents trapped along altitude

Elevation	**Captured individuals**	**Trap night**	**Trap success (%)**
1500	14	150	9.3
2000	13	150	8.7
2500	27	150	18
2900	84	150	56

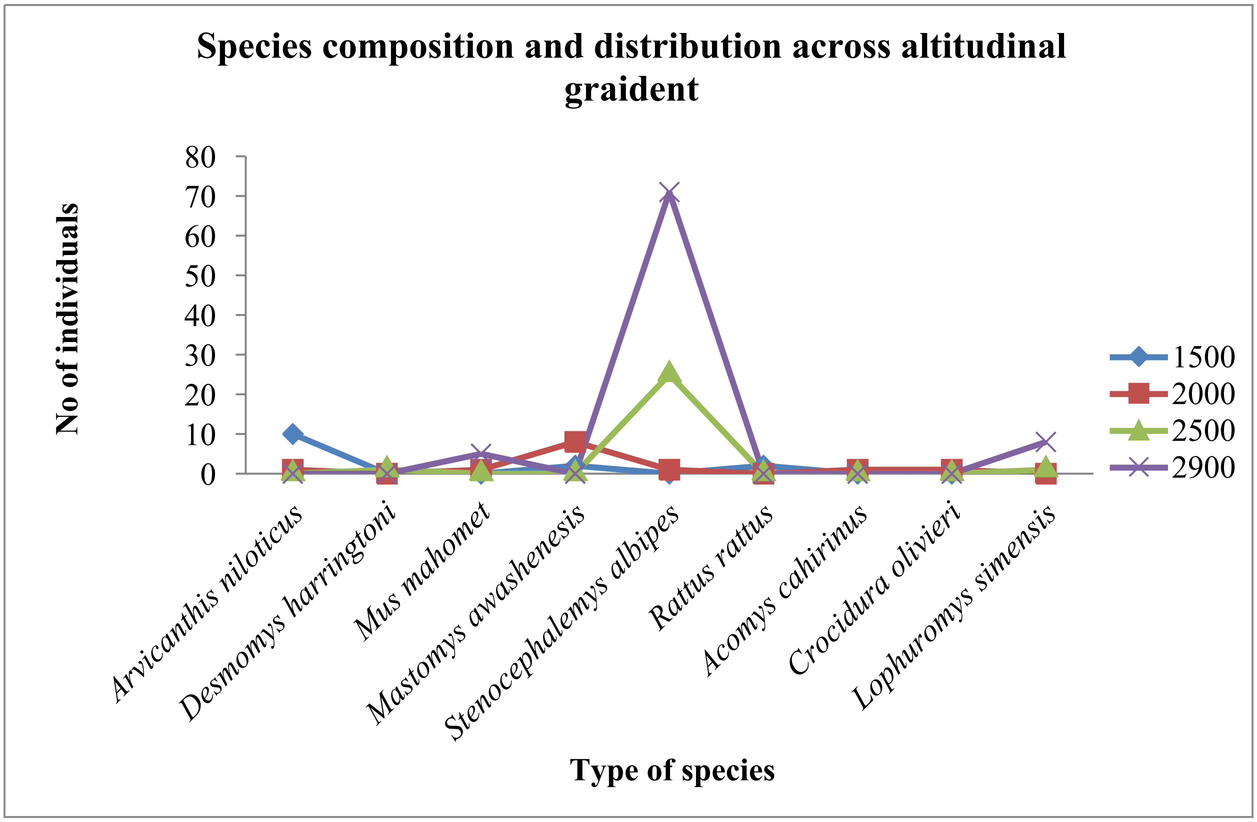

Fig. 3: Distribution of small mammals across altitude

4.1.1. Species diversity (richness and abundance)

The number of individual small mammal’s species captured and their relative abundance varied across altitudinal gradients. Particularly, *Stenocephalemys albipes* was the most abundant species with 97 individuals, representing 70.3% of all captures, predominantly found at the higher elevations of 2500m and 2900 m.a.s.l. (Table 4). In this elevation *Lophuromys simensis* was the second abundant species next to *Stenocephalemys albipes* (Table 4). *Arvicanthis niloticus* and *Mastomys awashensis* were also relatively common, with 11 (7.97%) and 10 (7.25%) individuals respectively, mainly captured and most abundant at the lower elevations (1500 and 2000 m.a.s.l.). The rest species, such as *Mus mahomet*, *Rattus rattus*, *Desmomys harringtoni*, *Acomys cahirinus*, and *Crocidura olivieri* were accounts lower number of individuals and lower relative abundances (see Table 3). The most abundant rodent species from 1500 – 2900 m were *Arvicanthis niloticus*, *Mastomys awashensis*, *Stenocephalemys albipes* (dominant in both 2500 and 2900 m), respectively.

Throughout the study across altitudinal gradient nine small mammal species were recoded. Of those three rodent species (*Stenocephalemys albipes, Lophuromys simensis, Mus mahomet)* were recorded from 2900 m and other three species (*Stenocephalemys albipes, Lophuromys simensis, Desmomys harringtoni*) from 2500 m. In the lower altitude, three species were recorded at 1500 m and six species at 2000 m. The highest species richness was recorded from 2000 m consisting six species, where five of them were rodents and one shrew species.

Table 4: Small mammal's species composition and their relative abundance across altitude

	Elevation					
Species	**1500**	**2000**	**2500**	**2900**	**Total**	**Relative abundance (%)**
Arvicanthis niloticus	10	1	0	0	11	7.97
Desmomys harringtoni	0	0	1	0	1	0.72
Mus mahomet	0	1	0	5	6	4.35
Mastomys awashenesis	2	8	0	0	10	7.25
Stenocephalemys albipes	0	1	25	71	97	70.3
Rattus rattus	2	0	0	0	2	1.4
Acomys cahirinus	0	1	0	0	1	0.72
Crocidura olivieri	0	1	0	0	1	0.72
Lophuromys simensis	0	0	1	8	9	6.52
Total #rodent individuals	14	12	27	84	137	_
Total # shrew individuals	0	1	0	0	1	_
Total # rodent species	3	5	3	3	8	_
Total # shrew species	0	1	0	0	1	_

The results for altitudinal diversity of small mammals indicated in table 5. The highest species diversity of small mammals was recorded at an elevation of 2000 m which is the mid elevation of the study gradient (Shannon index, H' = 1.285). The lowest species diversity was shown (H' = 0.3154) in 2500 m. Evenness was highest at 1500 m (EH = 0.74) and the lowest at 2500 m.a.s.l. (EH = 0.457), species dominance were highest in 2000 m (D = 0.5917) and the lowest in 2500 m.a.s.l. (D = 0.1399) .

Table 5: Species diversity induces of small mammals across altitude (S = Species richness, H'= Shannon diversity index, D = Simpsons diversity index, EH = Evenness).

Elevation	S	H'	D	EH
1500	3	0.7963	0.449	0.7391
2000	6	1.285	0.5917	0.6026
2500	3	0.3154	0.1399	0.4569
2900	3	0.534	0.273	0.5686
Total	9	1.122	0.4878	0.3414

Although the highest number of individuals was recorded at the highest altitude(2900m) the variation in abundance of small mammals among the four altitudes was statistically insignificant (ANOVA, df = 3, F = .799, p = 0.504). In addition the abundance of small mammals of each elevation didn't show significant differences at $p > 0.05$ (Table 6).

Table 6: Total species abundance, mean (±SD) and *p*-value of one sample t-test of each study altitude

Elevation	**Number of capture**	**Species mean**	***p*- value**
1500	14	1.556 ± 3.280	0.193
2000	13	1.444 ± 2.501	0.123
2500	27	3.000 ± 8.261	0.308
2900	84	9.333 ± 23.308	0.264

4.2. Population structure

The population structure (age and sex) of small mammals varied among the captured species. Of the total 138 individual small mammals captured 107 (77.4%) were adults, 16 (11.5%) were sub-adults and the rest 16 (11.5%) were juveniles (Table 7). Sub-adult and juvenile individuals were recorded in species such as *Stenocephalemys albipes*, *Mastomys awashensis*, and *Lophuromys simensis*, whereas all individuals of *Acomys cahirinus*, *Rattus rattus*, *Mus mahomet*, and *Crocidura olivieri* were adults. Despite these differences, statistical analysis revealed that variation in age structure among species across altitudinal gradient was not significant (ANOVA; df = 3, F=2.392, $p = 0.071$).

On the other hand, the sex structure of the investigated small mammal species across the altitudinal gradient consist a total of 84 male and 54 females (Table 7). Unlike the age structure, there is significant difference among species in sex structure (ANOVA; df = 3, F = 3.879, p = 0.01). Overall adult male small mammal species dominates the population structure consisting 62 individuals (44.93%, Table 7).

Table 7: Age and sex variation of captured small mammals (Age: Adult, Sub adult, Juvenile; Sex: M-male, F-Female).

	Adults		**Sub adults**		**Juveniles**	
Species	**M**	**F**	**M**	**F**	**M**	**F**
Stenocephalemys albipes	49	26	10	1	7	4
Lophuromys simensis	4	2	1	-	1	1
Mastomys awashnesis	1	4	2	-	-	3
Desmomys haringtoni	-	-	1	-	-	-
Arvicanthis niliticus	5	5	-	1	-	-
Mus mahomet	3	3	-	-	-	-
Crocidura olivieri	-	1	-	-	-	-
Rattus rattus	-	2	-	-	-	-
Acomys cahirinus	-	1	-	-	-	-
Total	62	44	14	2	8	8
Relative abundance (%)	44.93	31.9	10.2	1.45	5.8	5.8

4.3. Assessment of KAP of the small-holder farmers

4.3.1. Socio –demographic features of smallholder farmers

Among the 50 respondents selected to complete the semi-structured questionnaire, 38 were male (76%) and 12 were female (24%). The majority of participants were between 36 and 50 years old, on average. Over half of the respondents (72%) had no formal education, while the remaining 28% had attained a primary level of education. Most farmers in the study area cultivated fields ranging from 0.5 to 1 hectare in size. Farming was the primary occupation for 86% of the respondents, while the remaining 14% were engaged in other occupations, such as daily labor (see table 8).

Table 8: The socio-demographic characteristics of the study participants

Character	No .of respondents	Percent (%)
Gender		
Male	38	76.0
Female	12	26.0
Age		
Under 20 years	2	4.0
21-35 years	11	22.0
36-50 years	20	40.0
Over 50 years	17	34.0
Educational level		
None	36	72
Primary	14	28
Secondary	0	0
Collage	0	0
Source of livelihood		
Farmer	43	84
Daily laborer	7	16
Animal husbandry	0	0
Total area cultivated		
1 ha	15	70
0.5 ha	35	30
2 ha	0	0

4.3.2. Respondent’s crop and pest knowledge on pre-harvest loss

A statistically significant difference ($X^2 = 18$, df = 1, $p = 0.000$) in the types of crops and fruits cultivated was observed between the two study districts at the 0.005 level of significance. In Emba Alaje district, respondents listed the cereals such as, barley, wheat, and maize as the primary crops grown, all of which are vulnerable to rodent pests. Among the crops, barley was found to be the most susceptible crop to rodent damage compared to wheat and maize as reported by 95% of respondents. Conversely, in Raya Azebo district, maize, teff, and sorghum were reported as the most commonly produced crops and 86 % of respondents indicated that maize was the most susceptible cereal to rodent pests. Within Raya Azebo, particularly in the third kebele (Kara) onion, papaya, tomato and watermelon were notable fruits cultivated, especially in irrigated areas. Of these tomato and watermelon were highly susceptible to rodent pest damage.

All respondents from both districts recognized rodents as a significant problem and had observed pre-harvest crop losses. In addition, majority of respondents (88%) identified rodents as causing significant damage both in crop fields and homestead. According to the responses of the respondents (70%), replied pest infestations caused more than 15% loss in crop yields. In Emba Alaje, 40% of the farmers attributed these losses solely to rodents, while 60% reported that losses resulted from a combination of rodents, insects, and birds. In Raya Azebo district 65% of the respondents replied that majority of the crop loss in their field caused by birds and insects and the rest 35% of the famers said by rodents. The farmers in both districts primarily relied on visual inspections to detect rodent presence, looking for signs such as droppings, cut stems, and runway in the fields. In addition we asked the farmers if they know the differences between the rodent pests found in field and around house. Accordingly, half of the farmers (50%) observed morphological difference between the rats found in crop fields and those in homesteads, while 26% believed they were the same, and 24% were unsure. Regarding rodent activity, 54% of respondents reported that rodent activity in crop fields was similar during both day and night, whereas 42% noted that rodent activity was higher at night.

There was a variation in rodent population observation among the crop growing stages. Accordingly, 92% of the respondents reported that rodent population was highest during the harvesting stage; with the respondents (82%) observed an estimated average number of 21 to 50 rodent pests per crop field. Farmers also indicated that rodent-related losses varied across different crop growth stages, including the shooting, milky, and harvesting stages (Table 9). In Emba Alaje district, the average estimated annual pre-harvest losses were reported as 12.7% for barley, 8.9% for wheat, and 8.1% for maize. In Raya Azebo district, respondents reported annual losses of 10.9% for maize, 7% for sorghum, 6% for teff, 12.5% for tomato, and 9.3% for watermelon (see Table 9).

Table 9: Respondents ranking susceptible crops to rodent pests and their annual pre-harvest loss at different stages

District (Villages)	Crop/ fruit Type	Estimated loss per 100kg	Loss in %	No of respondents	In percent (%)
Emba Alaje (Arera)	Maize				
	Shooting stage	2	2	4	40
		3	3	4	40
		2.5	2.5	1	10
		1	1	1	10
	Milky stage	2	2	6	60
		3	3	4	40
	Harvesting stage	3	3	7	70
		4	4	3	30
	Barley				
	Shooting stage	5	5	7	70
		6	6	3	30
	Milky stage	3	3	4	40
		4.5	4.5	4	40
		5	5	2	20
	Harvesting stage	4	4	5	50
		2	2	3	30
		3	3	2	20
	Wheat				
	Shooting stage	3	3	2	20
		4	4	4	40
		5	5	3	30
		2.5	2.5	1	10
	Milky stage	2	2	6	60
		3	3	4	40
	Harvesting stage	4	4	1	10

		2	2	1	10
		3	3	7	70
		2	2	1	10
Raya azebo (Zibandas Babur Hadid)	Maize				
	Shooting stage	2	2	18	60
		3	3	7	23.3
		4	4	3	10
		2.5	2.5	2	6.7
	Milky stage	3.5	3.5	1	3.3
		2	2	17	56.7
		3	3	7	23.3
		4	4	4	13.3
		5	5	1	3.3
	Harvesting stage	3	3	10	33.3
		4	4	7	23.3
		5	5	8	26.7
		6	6	5	16.7
	Teff				
	Shooting stage	2	2	2	6.7
		3	3	16	53.3
		4	4	8	26.7
	Milky stage	3	3	4	13.3
	Harvesting stage	0	0	30	100
	Sorghum				
	Shooting stage	3	3	21	70
		1	1	9	30
	Milky stage	2	2	4	13.3
		1	1	18	60.0
		3	3	8	26.7
	Harvesting stage	2	2	2	6.7

	3	3	22	73.3
	4	4	6	20.0
Tomato				
Shooting stage	1	1	3	30
	0	0	7	70
Milky stage	0	0	10	100
Harvesting stage	6	6	1	10
	12	12	2	20
	16	16	5	50
	14	14	2	20
Watermelon				
Shooting stage	0	0	10	100
Milky stage	0	0	10	100
Harvesting stage	4	4	1	10
	11	11	6	60
	13	13	3	30

4.3.3. Respondent's knowledge on post-harvest loss by rodent pests

Most farmers harvested their crops by hand, with an average annual yield exceeding seven quintal per hacter. They used a combination of traditional and modern storage materials to preserve their products. In Emba Alaje district, farmers utilized a variety of crop storage methods, including woven polythene sacks, clay pots, and barrels crafted from cattle dung mixed with straw. In contrast, respondents from Raya Azebo primarily relied on polythene sacks and underground pits for storing their harvests. The susceptibility of these storage methods to rodent infestation varied with woven polythene sacks being particularly vulnerable, whereas clay pots and underground pits proved more effective in preventing rodent access.

According to the respondents of all villages, the primary cause of post-harvest loss was pest infestation (with rodents responsible for the greatest damage (98%), followed by insects (2%). Most respondents (76%) estimated that the average number of rodents found in storage areas ranged from 11 to 20. On the other hand, 96% the respondents noted that rodent populations were observed higher after harvest and during storing the harvested crops than any time before harvesting. The highest rodent activity in storage was during night time and this was reported by 84% of the respondents. While 16% the respondents observed higher rodent activity during the day. Furthermore, 92% of the farmers explained that the extent of rodent damage in storage varied from year to year. Interviews revealed that 68% of farmers lost between 21 and 30 kg of stored crops due to rodent pests (see fig. 4). Rodents also caused significant damage to household items such as clothes and storage materials, as reported by 76% of respondents. Additionally, 74% mentioned losing 1 to 10 kg of food items to rodent damage. Beyond crop loss rodents affect the living status of the farmers. Accordingly, 80% of the respondents reported that rodents disturbed their sleep. In addition, 22% of the farmers said that, rodents had bitten their family members, while 76% reported no such incidents. Approximately 62% of farmers reported frequent contamination of food and storage materials by rat urine and feces within their homes. Additionally, 70% noted occasional encounters with rat ectoparasites. All respondents stated that they avoided consuming food that had been touched by rats, citing concerns about contamination (58%), fear of disease transmission (26%), and general discomfort (16%).

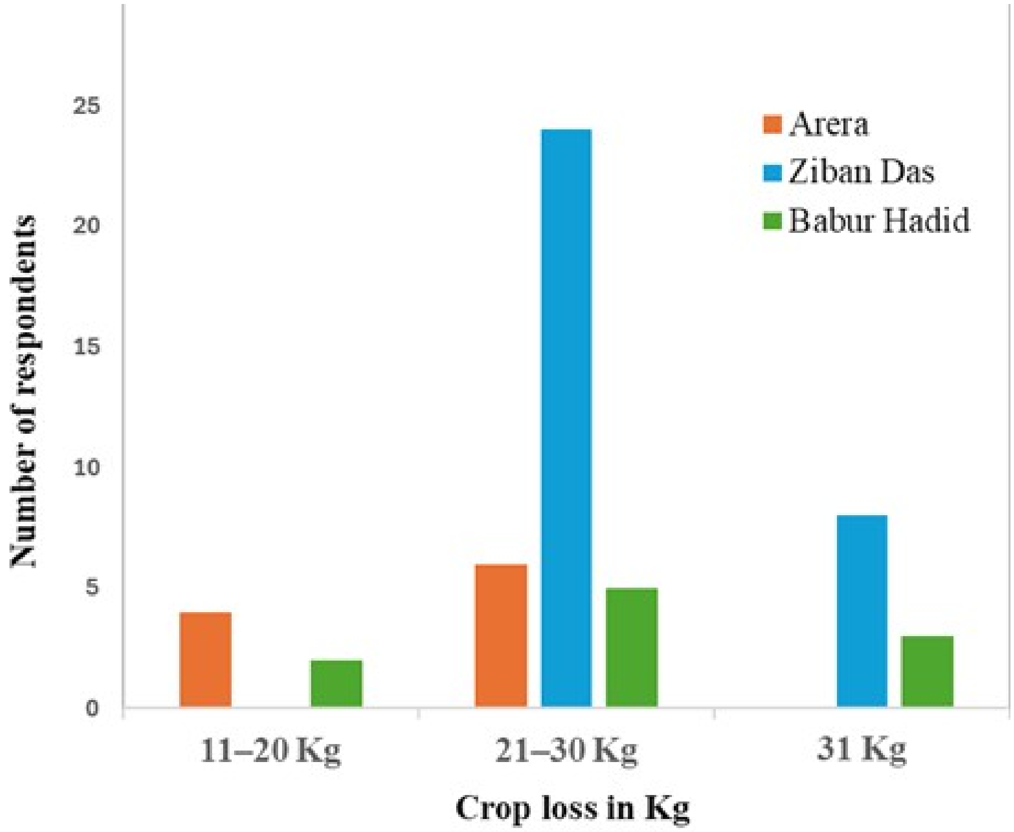

Fig. 4: Estimated damage to stored crops in storage

4.3.4. Farmers' actions to control rodents in the field and storage

According to the farmers' management practice in crop field in both districts, 44% of the respondents indicated low levels of action, 26% medium, and 30% described their efforts as high. They were also responsible for rodent control activities at individual level in their crop fields rather than in collectively at the group or village level. Rodent control was performed only when their crops are in the field from sowing to harvesting time. In the field, rodenticides are the preferred controlling action with 42% of the respondents practiced, followed by closing burrows and field sanitation (26%), trapping (18%), and 4% of the respondents applied all of the above control actions. While 10% of the respondents replied that they never take any control action (Table 10). The commonly used rodenticide by the farmers was Zinc phosphide (Zn_3P_2). It is the only rodenticide used by the farmers in the study areas, and it is considered highly effective rodenticide by 92% of the users.

On the other hand, 80% of the respondents rated the overall level of rodent control activity in storage is high, 14% considered it medium, and the rest reported low level of control efforts. When rodent damage is high in storage areas, most farmers (42%) respond by using cats, 34 % use rodenticides, 16% relies on trapping and 8% the respondents use all control actions in combination (Table 10). Prevention of rodents in the crop storage areas or materials is very crucial. Hence, the farmers mention that underground storage methods are viewed as the most effective and this was rated by 80% of the respondents. Twenty percent of the respondents considered that clay pots are effective way of storage but they used less frequently. While woven polythene sacs are not effective at all and easily damaged by rodents. On the other hand all respondents explained that there is no any practice on using poison plants to control rats. Among the control mechanisms using cats are widely regarded as highly effective for rodent control and accounts about 94%. In addition, 98% of the respondents reported that cats serve as repellents in storage areas, where the average number of cats in the communities (villages) ranged between 5 and 20 (Table 10).

Table 10: Farmer's action to rodent pests in storage and field

Character	**Number of respondents**	**Percentage (%)**
When damage high what you do in storage?		

Trapping	8	16
Rodenticide	17	34
Searching for cat	21	42
Searching for cat trapping, rodenticide, cat	4	8
When damage high in field what you do?		
Trapping	9	18
Rodenticide	21	42
Close burrows	13	26
Trapping, rodenticide, close burrows	2	4
Did nothing	5	10
What type of rodenticide did use in storage & field?		
Zinc phosphide	50	100
How effective is the rodenticide in both storage and field?		
Highly	46	92
Medium	4	8
Which storage material is effective?		
Clay pot	10	20
Underground	40	80
Woven polythene sac	0	0
Do you use poison plants to kill rats?		
Yes	0	0

No	50	100
How effective using cats?		
Low	2	4
Medium	1	2
High	47	94
Are cats effective as repellants?		
Yes	49	98
No	1	2
Number of cats estimated in community		
5-10	22	44
11-20	22	44
> 21	6	12

4.3.5. Farmers' perceptions on rodent pests and practices regarding rodent control

Farmers' perceptions of rodents as pests in all villages showed no significant difference among respondents across the surveyed villages (p = 0.61). However, the farmers expressed a uniformly negative perception of rodent populations, failing to differentiate between species based on their ecological importance. Instead, they identified rodents based on observable characteristics such as color, tail length, and body size, without knowledge of specific species or their ecological roles. This lack of differentiation suggests a generalized fear of rodents, which may hinder effective pest management strategies. The majority of respondents (72%) of them were uncertain whether rodents can transmit diseases or not, while 26% believed that rodents are capable of disease transmission (Fig. 5).

The respondents expressed that controlling rats, especially in the field, is challenging due to the rodents' aggressive behavior, high reproduction rate, and extensively wide farming areas. Additionally, half of the farmers (50%) were concerned that using rodenticides could have harmful side effects on non-target organisms, including plants and animals. They were generally dissatisfied with the effectiveness of both rodenticides and trapping methods, believing these actions provide only temporary relief rather than permanent control. Almost all farmers (96%) widely practiced the use of cats as an effective rodent management strategy (Fig.6), particularly for storage areas, where cats also serve as natural repellents. They also believed that snakes were the potential predator of rodents next to cats and noted that the presence of rats in homes occasionally attracts snakes, which come to feed on them. Thus, rats are perceived not only as pests damaging crops but also as indirect threats by attracting dangerous animals like snakes.

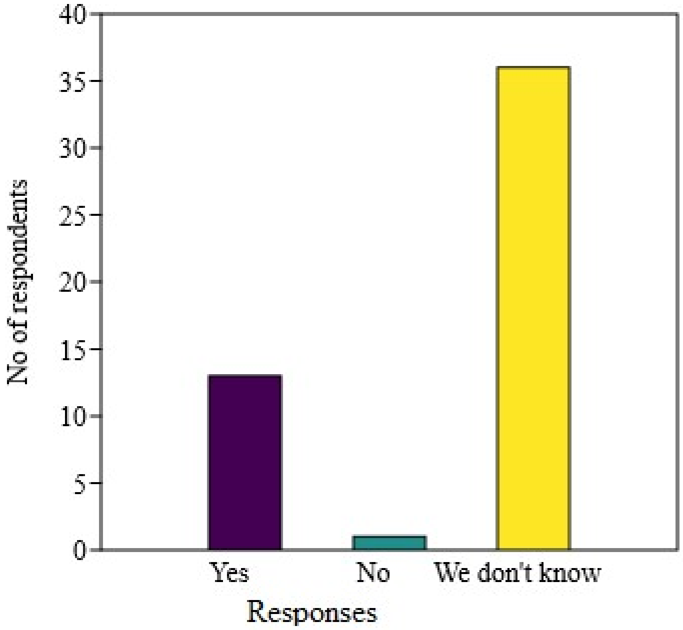

Fig. 5: Response of farmers whether rats transfer disease or not

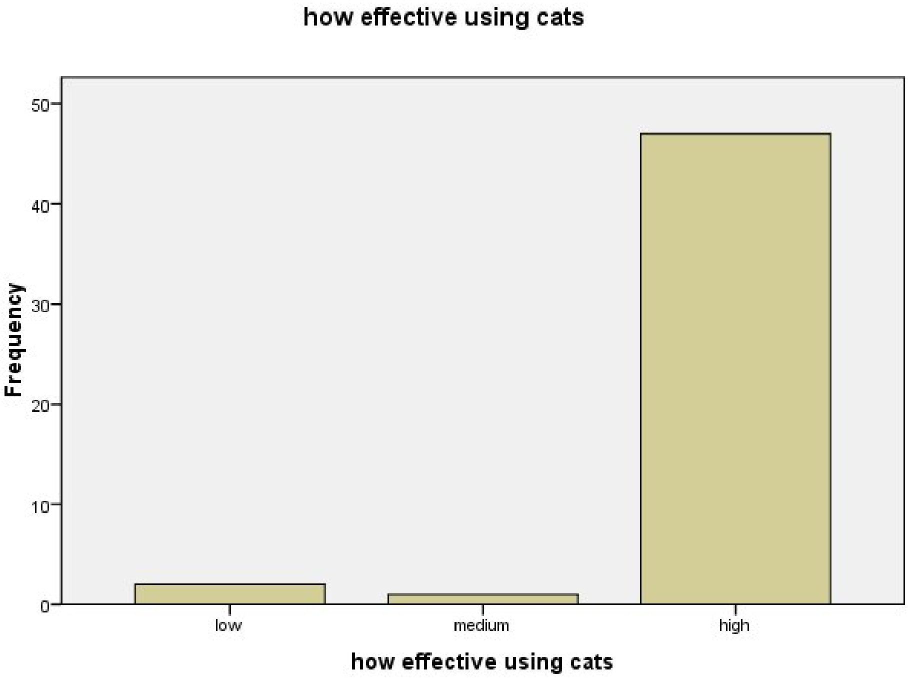

Fig. 6: Response of farmers on effectiveness of cats for rodent control

Regarding storage practices, all farmers use a variety of traditional storage materials such as Ayibet, Lokota, Godo, Shirfa, Gutera, and Ayno (Etro) (see Fig.7).. Respondents from Emba Alaje district preferred using clay pots for crop storage, considering them more effective than sacks or animal product-based containers. In Raya Azebo district, underground pits were reported as an effective storage method, especially when the annual yield was high. For smaller yields, farmers tended to use sacks and traditional animal product storage materials. Notably, all of respondents reported that they had not been visited by extension workers regarding rodent pests and their management. However, all expressed willingness and interest in receiving training on rodent management techniques. Rodents represent a substantial threat to the livelihoods of local farmers in the study area, affecting both field crops and stored products.

Fig.7: Traditional and modern storage materials used by local farmers of southern Tigray A-*ayibet*, B-*ayibet* & sack, C-Sack, D - *Shirfa*, E - *Godo*, and F - *Gutera*.

CHAPTER FIVE

5. DISCUSSION

5.1. Species composition of small mammals

A total of nine small mammal species, eight rodents and one shrew were recorded in this study along an elevation gradient from 1500 m.a.s.l. to 2900 m.a.s.l., indicating a higher abundance and species richness than those found in earlier studies in the Hugumbirda-Grakahsu State Forest, Southern Tigray, which had an almost identical altitudinal gradient from 1700 to 3000 m.a.s.l. In the Hugumbirda-Grakahsu State Forest, seven rodent species *Acomys sp. Arvicanthis niloticus , Mastomys awashnesis, Gerbilliscus robustus, Praomys sp., Mus setulosus* and *Gerbillus sp*. were identified (Mulualem et al., 2017). Only two species recorded in the current investigation were similar to Hugumburda-Grakahsu forest. Unlike the current study, which identified certain rodent species restricted to a single elevation, all species reported in the Hugumbirda-Grakahsu State Forest were observed across all four elevation zones.

According to Welegerima et al. (2024) twenty three species of small mammals were documented in Tigray and all the nine small mammal species found in this study are among those that have been previously reported in other Tigray area sites. Of these nine small mammals recorded in the present study, four species *Stenocephalemys albipes, Desmomys harringtoni, Mus Mahomet ,*and *Lophuromys simensis* are endemic rodents to Ethiopian highlands. The current study is also similar to the findings of Kassa et al. (2024), which noted that eight rodent species and one shrew species were identified in the Semen Mountains National Park.

5.1.1. Diversity and distribution of small mammals across altitude

A prior study conducted in Tigray indicated that *Stenocephalemys albipes* was located at altitudes between 1500 and 3820 meters above sea level, particularly thriving in higher elevations and montane forests, including Mount Tsibet and Hagereselam (Welegerima et al. 2024). Similarly, we identified *Stenocephalemys albipes* across an elevational range from 2000 to 2900 meters above sea level noting an increase in their population with rising altitude; however, in this study the species was not observed at 1500 meters elevation. Welegerima et al. (2024) also reported that *Desmomys harringtoni* and *Lophuromys simensis* from Mount Tsibet and Hugumbrda-Grakahsu forest, with elevation ranges of 2000 -3820 meters above sea level and 2404 – 3657 meters above sea level, respectively, while *Mus* *mahomet* was captured from various locations throughout Tigray within an altitudinal range of 1700 - 3800 meters above sea level. In the current research, *Desmomys harringtoni* were captured at an elevation of 2500 m, whereas *Lophuromys simensis* were captured at altitudes ranging from 2500 to 2900 m,a.s.l., and *Mus mahomet* were identified at elevations of 2000 and 2900 m.a.s.l. Conversely, in our investigation, *Mastomys awashnesis* and *Arvicanthis niloticus* were found in altitudes of 1500 and 2000 m,a.s.l., specifically in crop fields, irrigated areas, and bush land habitats, which aligns with the aforemontene mosaic vegetation studies in Tigray. These species pose a significant threat to agriculture, particularly in crop fields within the region (Meheretu et al. 2014). *Rattus rattus* recognized as an invasive species (Bryja et al., 2019), was captured only in an irrigated crop field at an elevation of 1500 m.a.s.l. The capture of this species is related to the presence of farmers' residence and a camp around the field where daily workers prepared their own food.

Other Previous findings in Semien Mountains National Park reported that *Stenocephalemys albipes, Desmomys harringtoni, Mus mahomet,* and *Lophuromys simensis* were captured in an altitudinal range from 2000 – 3300 m.a.s.l. (Craig et al., 2020). Similarly all the four species were captured in the present study with the exception of *Desmomys harringtoni* which was recorded in 2500 m.a.s.l. elevation and absent in 2900 m elevation in the current study. But, the reverse is true in Semien Mountains National Park the species was observed in 3000 m and absent in 2500 m.a.s.l. *Stenocephalemys albipes* and *Lophuromys simensis* were recorded across an altitudinal range of 2800 – 4000 m.a.s.l., with peak population densities observed at mid-elevations between 2800 and 3200 m.a.s.l. (Kassa et al. 2024). Consistent with our findings both the above species predominantly occur between 2500 and 2900 m.a.s.l. while *Desmomys harringtoni* was documented at an elevation of 3200 m.a.s.l. (Kassa et al., 2024). In contrast, our study recorded the species at a lower altitude of 2500 m.a.s.l., suggesting a broader elevational distribution than previously reported.

The highest species diversity was recorded in 2000 m elevation (mid elevation) in this study. Similarly, in Mount Kilimanjaro and Mount Meru (which is the second highest mountain in Tanzania next to Kilimanjaro) the highest species diversity of small mammals was recorded in 3000 m elevation, and the lowest in 1950 m elevation (Stanley et al., 2014;2016). Mulungu et al. (2008) also indicated diversity and distribution was highest in 3000 m elevation.

In the present study, small mammal abundance was highest in Mahbere Bekuru, located at the uppermost elevation. This elevated abundance may be attributed to extensive forest cover and minimal human disturbance. Previous research has shown that vegetation diversity and density, reduced anthropogenic pressure, and the presence of varied microhabitats enhance both the diversity and abundance of small mammals (Girma et al., 2012; Horncastle et al., 2019; Richard et al., 2020).

The most abundant species recorded in Mount Mahbere Bekuru was *Stenocephalemys albipes*, with a total of 97 individuals captured. In the current study the highest species richness were recorded in 2000 m elevation. This finding aligns with global montane studies that report peak species richness of non-volant small mammals at mid-elevations (Goodman & Rasolonandrasana, 2001; McCain, 2004; Rickart et al., 2011; Stanley et al., 2014; Stanley & Kihaule, 2016). Among the captured individuals, adult males comprised the largest proportion (44.93%). Although variations in sex and age composition were observed among the captured rodents, these differences were not statistically significant in age structure and significant in sex structure.

5.2. Socio-demographic characteristics of respondents and agricultural context

In this study male respondents participated in the survey was more than that of females which were 76%, and 24% respectively. Similar result of previous study by Gadisa & Birhane (2016) reported more males (92.92%) participated in the study than females (7.08%) in the farmers' perception of rodents as pests in Southwest Ethiopia. Likewise, Ayinde & Adeola (2020) reported that 58.3% males and 41.7% females were participated in the survey of peoples' perception of rodents as pest in Ibadan, South-western Nigeria. The higher proportion of male respondents in this study may reflect greater involvement of males in farming activities. It also indicates that males were more willing to participate in surveys, as observed in similar studies. These findings highlight a potential gender bias in survey participation.

In this study majority of the respondents were without formal education (72% uneducated) and none of them were college graduates. This is consistent with the study of Gadisa & Birhane (2016) where more than half (55%) of the study participants had not completed the first cycle of primary education (Grade 1 to 4) and none of them were college graduates. On the other hand, the present study is different from the study of Ayinde & Adeola (2020) in Ibadan, South-western Nigeria,where the majority of respondents (89.2%) were in their tertiary level of education and none of the respondents were uneducated or with primary education. The current study indicated forty percent (40%) of the respondents were within the age range of 36 – 50 years old. While Gadisa & Birhane, (2016) reported in their findings that 37.08%

of the study participants were within the age range of 31 to 40 years. Farming was the primary occupation for 86% of the respondents. This is similar with findings of Khanam & Mushtaq, (2021) where they reported that Farming was the major occupation of 42% of the respondents, the rest of them were involved in other occupations along with farming. In the present study farmers had farmland (0.5-1hacter). This is different from the study of Gadisa & Birhane (2016) where farmers had farmlands ranging from 0.5 - 2.5 hectare.

5.2.1. Crop vulnerabilities and rodent- related losses

There was significant variation on cultivated crops between the two districts of the study sites ($\chi^{2}=18$, df= 1, *p* = 0.000). Barley, wheat and maize were cultivated in Emba Alaje distrct while sorghum, teff, maize, tomato and watermelon were cultivated in Raya Azebo district (Zibandas and Babur Hadid). This is consistent with the study of Taffesse et al. (2012) who reported that Ethiopia's crop agriculture is complex, involving substantial variation in crops grown across the country's different regions and ecologies. In Emba Alaje district barley, wheat, maize experienced pre-harvest loss of 12.7%, 9%, 7%, respectively, while in Raya Azebo, maize, teff, tomato, watermelon faced losses up to 15% losses. The 15% losses in irrigated fruits highlight how agro ecological zones shape pest exposer. In the present study barley crops were highly susceptibility to rodent pests (12.7%, loss annually) in Emba Alaje district. This aligns with study conducted in Farta district, South Gondar, Ethiopia, that reported a significant damage of barely from rodent pests, with an estimated annual yield loss of 21.7% (Wendifraw et al., 2021).While in previous study in South west Ethiopia 82.08% of farmers ranked maize as the first crop susceptible to rodent depredation and barley was ranked second by 62.29% of the study participants (Gadisa & Birhane, 2016).

In Raya Azebo, irrigated fruits face elevated risks due to water-attracted pest populations. They estimated 21 - 50 rodents per field and 21 - 30 kg annual storage losses per household that illustrate the severe impact on food availability. This is consistent with global estimates that post- harvest losses threaten 20 - 30% of smallholder yields (Singleton, 2001). In the present study farmers indicated that rodent-related losses varied across different crop growth stages, including the shooting, milky, and harvesting stages with highest rodent population during harvesting stage. This finding aligns with previous studies in Australia, where rodent pests caused significant damage to cereal crops such as wheat, particularly during the later stages of crop development (Ngaomei & Singh, 2016). Similarly in central Ethiopia, rodent damage in the maize field was critical after the seedling stage while in Tanzania damage in the seedling stage showed a significant impact on the potential yield since farmers cannot replant seeds after the rainy season advanced (Bekele et al., 2003; Mulungu et al., 2003). This is similar with the study in Pakistan by Khanam & Mushtaq (2021) which found that the harvesting stage was considered the most critical stage to rodent damage due to high rodent population.

5.2.2. Storage practices and pest control challenges

The impact of rodents on stored crops extended beyond mere consumption, including contamination through feces and urine, damage to storage materials, and the facilitation of secondary pest infestations (e.g., weevils). Farmers in both districts use different traditional storage containers to store their crops. Those storage materials constructed in different forms of storage structures made of locally available materials such as bamboo split, wooden walls, animal products and mud. In Emb Alje district, traditional storage materials such as clay pots, *Gutera*, *Shirfa*, *Lokota*, *Ayibet*, and *Godo* were commonly used by farmers. However, respondents indicated that, with the exception of clay pots, these materials were largely ineffective in controlling rodent infestations. This observation is consistent with findings by Duguma (2020), who reported that the majority of Ethiopian farmers rely on traditional storage structures that offer limited protection against storage insect pests, rodents, and mold contamination.

Farmers in Raya Azebo district use the underground pit to store maize and sorghum crops only. A FAO (2017) study in fourteen districts from Oromo, Amhara, SNNP and Tigray region reported storing grains like sorghum and maize in underground storage is a common practice. According to farmers responses in this study, underground pit storage is cheap and most effective against rodent pests. Similarly previous study by Mulu & Belayneh (2016) in Jigjiga and Awubarre districts of Fafen Zone, Ethiopia found that underground pit storages are considered as cheap and cost effective for storing grain for consumption.

5.2.3. Perception-action gaps in pest management

The respondents ranked rodents as number one pest, probably because they are least able to control them compared to the other pests. Similar studies conducted in Indonesia by Sudarmaji et al. (2003) and Tuan et al. (2003) in Vietnam reported that farmers perceived rodents as the most important pests in their crops. Prior study by Makundi et al. (2005) & Meheretu et al. (2010) reported rodents as the important pests and need to be controlled in Tanzania and Ethiopia.

In the present study rodent control activity by farmers were too low (44% in fields) due to farmers reliance on individual measures (e.g. cats, traps) rather than community based integrated pest management (IPM) programs which mirrors structural deficiencies observed in Ethiopian extension services (Abate, 2020). In the current study farmers reported that rodenticide, trapping, hunting and domestic cat were the most practiced method to manage rodent damage both in the field and storage. In similar study Makundi et al. (2005) reported that trapping, hunting and rodenticides are the most practiced techniques for rodent control in Ethiopia and Tanzania. In the current study, majority of the farmers used rodenticide (Zink phosphide) to control rodents both in the field and storage. This is consistent with the study in northern Ethiopia, ~ 93% of surveyed cereal farmers reported the use of zinc phosphide rodenticide in rainfed crop fields to manage rodent pests (Meheretu et al. 2010), in Tanzania and Ethiopia (68.7%) by Makundi et al. (2005), in Laos (34.2%) by Brown & Khamphoukeo (2007), and in Myanmar (31.1%) by Brown et al. (2008). However the farmers from both districts have no enough knowledge on how and when to apply the chemical to ensure effective rodent control method and to reduce the damage on non-target organisms.

According to farmers report, government intervention (role of agricultural experts) and their contribution in giving training and assistance regarding rodent control technique were very low and the supply of rodenticides was also limited. In similar study (Makundi et al., 2005) reported that in Tanzania, government intervention in the form of free supplies of rodenticides, distribution and supervision of bait application is done only during outbreaks of rodents but not for routine rodent control. This is also aligned with the findings of Khanam & Mushtaq (2021) in Pakistan where 77% of the respondents indicated that they lacked assistance in managing rodents. As a result poor awareness of rodenticide application is likely to result in weak efficacy of action and treatment failure, leading to apathy and widespread acceptance of rodent pests in fields and storage areas.

In this study, farmers had negative point of view on all rodent species and perceived a great threat on their crops and house settlements from rodent damage. The respondents cultural believe indicated that they need to have smooth relationship with rodents by calling them with polite and sweet words (such as '**መርዓት**', meaning 'bride'), even though they caused huge damage on their crops. They prefer not to tell or report the aggressiveness and dangerous action of rodents to others; because they believe reporting will increase the damage. This indicates how much rodents are threats to farmers. Meheretu et al. (2010) also reported that in several regions in Ethiopia, people fear calling rats by the name 'rats', rather they tend to call it 'bride' and 'queen'. This is based on the belief that if one calls a rat by the name 'rat', the rat will increase in number in the fields or storage and avenge by attacking crops out of lack of respect. It is a sign of the severity of the problem and the attitude of farmers who do not know how to deal with it.

Farmer's inability to differentiate rodent species (by physical traits) exacerbates control challenges, as species-specific reproductive strategies require tailored interventions. Fear of snakes as indirect pests further complicates risk perceptions, suggesting rodent pest management programs must address both biological and cultural factors.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

This study documented the species composition, abundance, and altitudinal distribution of small mammals, as well as the knowledge, attitudes, and practices of smallholder farmers regarding rodent pests in the study areas. A total of nine small mammal species (eight rodents and one shrew) were recorded across four altitudinal zones (1500 – 2900 m.a.s.l.), showing variation in abundance and distribution with altitude. *Stenocephalemys albipes* was the most dominant and widely distributed species, particularly at higher elevations (2500 – 2900 m.a.s.l.), while *Arvicanthis niloticus* and *Mastomys awashensis* were common in the lower altitudes (1500 – 2000 m.a.s.l.). Species richness peaked at 2000 m, representing mid-elevation diversity typical of montane ecosystems. The socioeconomic survey revealed that most farmers had no formal education (72%). Farming was the main occupation for 86% of respondents, with small landholdings (0.5 – 1 ha). Crops cultivated varied between districts, with barley, wheat, and maize dominant in Emba Alaje, and maize, teff, sorghum, tomato, and watermelon in Raya Azebo. Rodents were universally recognized as major agricultural pests, causing significant pre-harvest and post-harvest losses. Average pre-harvest losses reached up to 12.7% for barley and 12.5% for tomato, while post-harvest losses were estimated between 21–30 kg of stored crops per household annually. Farmers reported limited rodent control actions, mainly relying on individual measures such as cats, rodenticides (zinc phosphide), and trapping. However, most lacked training on the safe and effective use of rodenticides, posing risks to non-target organisms. Although farmers viewed cats as effective biological control agents, the overall management of rodents was fragmented, reactive, and lacked coordinated community-based action.

Cultural beliefs and poor awareness about rodent ecology hindered effective management. Many farmers could not differentiate between rodent species and expressed generalized fear and negative attitudes toward all rodents. Additionally, extension services and government support for rodent management were minimal, leaving farmers without technical guidance or adequate supply of control materials.

6.2 Recommendations

- Expand monitoring of small mammal populations along elevational gradients to understand seasonal dynamics, habitat preferences, and population fluctuations.
- Promote long-term ecological studies to evaluate how environmental changes, land use, and agricultural intensification affect small mammal communities.
- The presence of rodent pests in the study area causes a significant threat to smallholder farmers. To mitigate these challenges, introducing integrated pest management (IPM) strategies for effective rodent control is crucial.
- Provide regular training and awareness programs for farmers on safe and effective rodent control, storage management, and environmental impacts of chemicals.
- Enhance the role of agricultural extension services in pest education, awareness raising, and continuous technical support for rural farmers.

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APPENDICES

Appendix 1: Results of Genetically identified small mammal species

ID	*Species*	*CYTB-barcoding*	Sex¶	Age	Locality	Country	Sample in alcohol	Elevation	Collectors
KW90¶	*Mus sp.*¶	*Mus mahomet*¶	F	Adult	Mahbere Bekuru	Ethiopia	LSKH¶	2900	GM,KW,MB, BG,MH¶
KW96	*S.albibes*	*Stenocephalemys albipes "ap3"*¶	M	Adult	Mahbere bekuru	Ethiopia	LSKH¶	2900	GM,KW,MB, BG,MH¶
KW97	*S. albibes*	*Stenocephalemys albipes "ap3"*	F	Adult	Mahbere bekuru	Ethiopia	LSKH	2900	GM,KW,MB, BG,MH
KW112	*Lophuromys sp.*	*Lophuromys simensis "North-I"*	M	Adult	Mahbere Bekuru	Ethiopia	LSKH	2900	GM,KW,MB, BG,MH
KW115	*Lophuromys sp.*	*Lophuromys simensis "North-I"*	M	Adult	Mahbere Bekuru	Ethiopia	LSKH	2900	GM,KW,MB, BG,MH
KW123	*Mus sp.*	*Mus mahomet*	F	Adult	Mahbere Bekuru	Ethiopia	LSKH	2900	GM,KW,MB, BG,MH
KW125	*S.albibes*	*Stenocephalemys albipes "ap3"*	F	Adult	Mahbere Bekuru	Ethiopia	LSKH	2900	GM,KW,MB, BG,MH
KW127	*S.albibes*	*Stenocephalemys albipes "ap3"*	M	Adult	Mahbere Bekuru	Ethiopia	LSKH	2900	GM,KW,MB, BG,MH
KW128	*S.albibes*	*Stenocephalemys albipes "ap3"*	M	Adult	Mabere Bekuru	Ethiopia	LSKH	2900	GM,KW,MB, BG,MH
KW136	*S.albibes*	*Stenocephalemys albipes "ap3"*	M	Adult	Mahbere Bekuru	Ethiopia	LSKH	2900	GM,KW,MB, BG,MH
KW137	*S.albibes*	*Stenocephalemys albipes "ap3"*	M	Adult	Mahbere Bekuru	Ethiopia	LSKH	2900	GM,KW,MB, BG,MH
KW138	*S.albibes*	*Stenocephalemys albipes "ap3"*	F	Adult	Mahbere Bekuru	Ethiopia	LSKH	2900	GM,KW,MB, BG,MH
KW145	*Lophuromys sp.*	*Lophuromys simensis "North-I"*	M	Sub adult	Mahbere Bekuru	Ethiopia	LSKH¶	2900	GM,KW,MB, BG,MH
KW154	*S.albibes*	*Stenocephalemys albipes "ap3"*¶	M	Adult	Mahbere Bekuru	Ethiopia	LSKH	2900	GM,KW,MB, BG,MH
KW162	*Mus sp.*	*Mus mahomet*	F	Adult	MahbereBekuru	Ethiopia	LSKH	2900	GM,KW,MB, BG,MH

Appendix 2: Photos during fieldwork

Appendeix 3. The researcher during interview with particiapnts in the study sites