Addis Ababa University

College of Natural and Computational Sciences

Department of Zoological Sciences

Studies on the Ecology and Conservation Status of Non-volant Small Mammals in Wenchi Montane Forests, Oromia Regional State, Ethiopia

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A Dissertation Submitted to The School of Graduate Studies of Addis Ababa University in Partial Fulfilment of The Requirements for The Degree of Doctor of Philosophy in Zoology (Ecological and Systematic Zoology Stream)

Advisor: **Afework Bekele (Prof.)**

Addis Ababa University
Addis Ababa, Ethiopia
February, 2024

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Ecological and Systematic Zoology Stream

This is to certify that the thesis prepared by Kabeta Legese, entitled "***Studies on the Ecology and Conservation Status of Non-volant Small Mammals in Wenchi Montane Forests, Oromia Regional State, Ethiopia***'' and submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy in Zoological Sciences (Ecological and Systematic Zoology Stream) complies with the rules and regulations of the University, and meets the accepted standards with respect to originality and quality.

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ACKNOWLEDGEMENTS

My sincere thanks and appreciations go to my advisor **Prof. Afework Bekele**. It is his unreserved and endless moral and academic support, critics and fatherly advice when it matters, and empowering encouragement are few of the many things that enabled me to complete this study. His financial backings and material support are also worth mentioning. Dear Prof.! I have no words to describe your massive importance during the hard times in my academic career. I will always remain thankful to you. I also regard myself as a lucky man to be nurtured by you, and have a taste of your huge and accumulated experiences and knowledge in wildlife ecology and conservation. It is really an honour and a great privilege to call myself as one of your academic products.

Next, my heartfelt gratitude goes to my field assistant, the late **Malela Shiferaw**, for his friendly interactions, an amazing commitment and unreserved hard work that he puts on despite the challenging environmental conditions of Wenchi highlands throughout the field works. He was an inspiring young man that pushed me to the limit during my field work. He also made the field works very entertaining and easily achievable. Dear brother, you always have a big thank you from me though I learned lately that you are no more here!

I acknowledge the reception, hospitality and help of **Wakuma Ango** and other village administrators for their cooperation and coordination which were also amazing and instrumental for the success of this study. My study participants were also crucial and praiseworthy for providing their knowledge, perceptions and management options that they employ to contain rodent damage and outbreaks as well as resource utilizations, conservation activities and challenges, and other required information in the study area. It is only by their willingness and the information they have provided that turned to a meaningful product.

It is noteworthy to appreciate my mother university, Wolkite University, and Addis Ababa University for this golden opportunity that they have put on the table for me. The faith and efforts that these two institutions have put in place to enable me to realise my dream were priceless and immense. Beyond their intellectual investment, the financial and material support that these institutions presented were the main key factors that brought this work to the end.

In this regard, I am very thankful to the Department of Biology, Wolkite University, and Department of Zoological Sciences, Addis Ababa University. The cooperative nature and friendly approaches of **Dr Bezawork Afework** is something that I am indebted to acknowledge. I am also grateful for the animal diversity thematic research project for financial support. My special thanks also go to Ketema Amberbir for his field guidebook provision and species identification support.

My heartfelt thanks go to my classmates − **Beselam Shiferaw**, **Bewketu Takele, Adane Tsegaye** and **Seyoum Kiros** for their encouragement and all rounded interactions during the time we had together. **Seyoum Kiros**, my dear colleague and friend, deserves a special appreciation for his constructive criticisms and comments throughout the times we were together. My former colleagues, **Fetku Akmel** and **Mesfin Belete,** deserve a mention here for their accommodations and hospitality at some stages of my study.

Chala Adugna is also well acknowledged for his consistent encouragement, and his support in data analysis. Furthermore, some of my close friends and all the good people that have encouraged and motivated me during my study periods, but not mentioned here are also well appreciated.

Finally, my genuine thanks go to my family for their constant presence, and unwavering moral and financial support when it matters most. I always remain grateful to my father, **Legese Kerorsa** and my mother, **Ayantu Jebessa** in particular because they played a crucial role in my academic career. My father has no academic qualifications and hardly writes his name, but he remains as one of my best teachers with huge academic influence.

Dear Dad! This is not only the result of my hard work, but it is your affection and persistent belief in education that is paid off. I genuinely believe that this is a catalytic and energetic drive that you have imparted into me has strengthened me during the tough times, awakened me from my deep sleep, and pushed me forward when I tailed off. Dear Mom, the sacrifices that you have paid for my successes throughout my life and education in particular are things that will remain with me for eternity. Dear Dad and Mom, this degree is not mine alone. It is also yours since it is you who have started it before me; battled and finally won it with me. I am always thankful to you! Thank you, my other family members, too!

DEDICATION

This thesis is dedicated to my field assistant, the late **Malela Shiferaw**, who was shot dead unjustly in his own compound. It hurts to lose such a hardworking, pure soul, an innocent father, and humble personality without any wrongdoing. My brother, my heart bleeds any time I notice that you are no more around, and you will also be well remembered throughout my life. May your soul rest in the highest place, in heaven. This thesis is also dedicated to other similar innocent lives that were cut short unjustly and unexpectedly throughout Ethiopia.

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LISTS OF ABBREVIATIONS

AAU: Addis Ababa University

FGD: Focus Group Discussion

m asl: meter above sea level

OTC: Oromia Tourism Commission

PAs: Protected Areas

KAP: Knowledge, Attitudes and Perceptions

UNWTO: United Nations World Tourism Organization

ABSTRACT

Studies on the Ecology and Conservation Status of Non-volant Small Mammals in Wenchi Montane Forests, Oromia Regional State, Ethiopia by: Kabeta Legese, PhD, AAU, 2024

The study of small mammals has paramount implications. Studies were carried out in Wenchi district of Southwest Shewa zone, Oromia regional state from August 2019 to January 2021 to explore the ecology and conservation of non-volant small mammals. Non-volant small mammals were trapped using Sherman and snap traps in standard trapping grids. Major conservation challenges and opportunities, and the knowledge and attitudes of local community on rodent damage and their management practices were collected through semi−structured questionnaires and focus group discussion. Diversity indices, descriptive statistics and Chi−square tests were used for data analysis. A total of 935 rodents belonging to 12 species, and 24 insectivores belonging to 3 species were trapped. These included Arvicanthis abyssinicus, Dendromus lovati, Desmomys yaldeni, Graphirius murinus, Lophiomys imhausi, Lophuromys brevicaudus, L. chrysopus, L. flavopunctatus, Mastomys natalensis, M. awashensis, Stenocephalemys albipes, Crocidura bailey, C. fumosa, C. olivieri and one unidentified murid rodent. Hystrix cristata and Tachyoryctes splendens were recorded through indirect evidence. About 52.9% of the identified small mammals were endemic to Ethiopia. Mastomys natalensis (30.86%) and S. albipes (27.53%) were the two most abundant species, whereas L. imhausi (0.1%) was the least. Small mammals showed spatiotemporal variations in abundance, density and trap success. The topmost species diversity (H'=1.74) was registered from Albesa Forest, while Qibate Forest had the least (H'=1.43). More individuals were recorded during the dry season (58.29%) than wet season (41.71%). The highest number of individuals were trapped from Lakeshore (27.73%), whereas the least was in Erica Forest (4.27%) in both seasons. Higher number of small mammals was trapped in the morning (84.98%) than evening traps. Seasonal differences in sexes and age groups were non−significant. Small mammals had higher density during the dry (83.33 ha^{-1}) than wet (59.35 ha^{-1}) seasons. Except, Lophuromys assemblages, rodents had omnivorous feeding habits with seasonally varying food items. Farmers identified rodents as major pests, and perceived them negatively. Crop damage (38.7%) and damage to human properties (27.9%) were the two predominant rodent related problems. Barley was the most susceptible crop type to rodent attacks (57.5%), and farmers mainly used cats as natural enemies (53.73%) and trapping (22.64%) to control rodents in storage. Overgrazing, firewood collection, land–use changes, exotic plantations, soil erosion, land grabbing and burning of the ericaceous belts were the major conservation challenges in the area. Of these, overgrazing, firewood collection and land–use changes were the most serious biodiversity threats. A unique topographic beauty, rich flora and fauna, recent global and regional recognitions, positive attitudes of the local people and an ongoing ecotourism development project in the area are the main potential opportunities for biodiversity conservation. Wenchi highlands are one of the small mammal diversity hotspots that face severe conservation challenges and need urgent conservation priorities.

Keywords/Phrases: Abundance, conservation challenges, conservation opportunities, crop damage, diversity, montane forest, spatiotemporal variations, small mammals, Wenchi highlands

1. GENERAL INTRODUCTION

1.1. Background of the study

Small mammals are the most diverse group of mammals that receive less attention than larger ones (Kumaran *et al*., 2016). The studies of these animal groups are the least favoured subjects among zoologists (Louis *et al*., 1988), and relatively little information is known about them (Denys *et al*., 2014). Thus, there are big knowledge gaps on their distribution, abundance and conservation status (Kumaran *et al*., 2016). The study of small mammals, however, has paramount implications due to their high abundance, relatively easy to study, well known principles of their ecology, good ecological indicators, display of habitat or dietary specificity and ease of specimen preparation and transportation (Barnett & Dutton, 1995; Torre, 2004; Tadesse Habtamu & Afework Bekele, 2012; Marques *et al*., 2015).

Small mammals display prominent seasonal and inter-annual fluctuations in their diversity and population (Makundi *et al*., 2006; Sintayehu Workeneh *et al*., 2011; Agerie Addisu & Afework Bekele, 2015; Seyoum Kiros & Afework Bekele, 2022). Such fluctuations determine their distribution and abundance (Mohammed Kasso & Afework Bekele, 2011), and are quantified through population density estimation (Krebs *et al*., 2011). Estimating the populations of small mammals are essential to understand their community structure, for wildlife conservation, and in many ecological investigations (Hopkins & Kennedy, 2004). The diversity and population dynamics of small mammals in a particular area is determined by several biological (Sintayehu Workeneh *et al*., 2011; Getachew Bantihun & Afework Bekele, 2015), climatic (Makundi *et al*., 2006) and anthropogenic (Addishiwot Fekdu *et al*., 2015) factors. A sound understanding of the population dynamics allows us to predict the changes in the population numbers, which is very important to devise management strategies (Afework Bekele & Leirs, 1997).

Rodents are a diverse group of small mammals that are well known to impact the global environment by providing many ecological, social, economic and cultural values (Kingdon, 1997; Mesele Yihune & Afework Bekele, 2012; Tadesse Habtamu & Afework Bekele, 2012; Agerie Addisu & Afework Bekele, 2013). They are important components of the natural system that aerate the soil by burrowing activities and assist plant propagation by consuming and disseminating seeds (Tobin and Fall, 2004). Some rodents in specific habitats are viewed as model organisms for the study of ecological processes and serve as good indicators of environmental quality due to their rapid responses to environmental changes (Tadesse Habtamu and Afework Bekele, 2012).

Rodents are among the most important food bases in the food chain and dietary components for many predators particularly mammals and birds (Tobin & Fall, 2004; Mulungu *et al*., 2008; Mesele Yihune & Afework Bekele, 2012). They are also reported to be a protein source for humans (Tadesse Habtamu & Afework Bekele, 2008; Palis *et al*., 2011; Meyer-Rochow *et al*., 2015; Gruber, 2016). In contrast, rodents are a threat to food production and human property, and a public health risk (Mesele Yihune & Afework Bekele, 2012; Garba *et al*., 2013; Panti-May *et al*., 2017). Consequently, they are considered as the most serious vertebrate pests worldwide (Staples *et al*., 2003; Brown *et al*., 2007).

Rodent pests cause a considerable yield loss throughout the world (Tsegaye Gadisa & Kitessa Hundera, 2015). They unreasonably affect the livelihood of smallholder farmers of developing countries through pre− and post−harvest crop damages, losses, contaminations and high costs to their management (Brown *et al*., 2013; Lund, 2015; Htwe *et al*., 2016; Swanepoel *et al*., 2017). The presence of rodents in the crops, houses and/or around human dwellings is devastating rather than regulating nature (Tobin & Fall, 2004; Tsegaye Gadisa & Kitessa Hundera, 2015). The economic and ecological benefits of rodents, however, outweigh these destructive effects (Tadesse Habtamu & Afework Bekele, 2012; Agerie Addisu & Afework Bekele, 2013). It is only about 10% of the rodent species are agricultural pests and carriers of infections (Meerburg *et al*., 2009; Tadesse Habtamu & Afework Bekele, 2012; Han *et al*., 2015, 2016), and even fewer cause problems in broader areas (Stenseth *et al*., 2003; Capizzi *et al*., 2014).

Ethiopia harbours a much higher endemic mammalian species than any other African countries (Lavrenchenko & Afework Bekele, 2017). The country has registered about 55 country endemics from nearly 311 mammals. The order Rodentia alone contributes most endemic species to the endemic mammals of Ethiopia (Dawit Kassa & Afework Bekele, 2008). It is still presumed that the diversity and endemism of mammals could be far higher than this (Lavrenchenko & Afework Bekele, 2017). This immense ecological diversity and huge wealth of biological resources are associated with the geographical position, altitudinal ranges, rainfall patterns, and soil variability of the country (Dawit Kassa & Afework Bekele, 2008; Mengesha Assefa *et al*., 2000).

Mammologists and ecologists are highly interested to study the spatial distribution of small mammals across the mountain ranges to document the turnover of species across the altitudinal gradients. Thus, efforts to document the mammals of several massifs in the world have been intensified over the past few decades (Mulungu *et al*., 2008; Stanley & Kihaule, 2016). Ethiopian highlands are the centres of small mammal species richness and endemism (Yalden & Largen, 1992; Lavrenchenko & Afework Bekele, 2017). Fourteen of the 15 endemic species of the country reside only in the highland ecosystems (Yalden & Largen, 1992). Still there are limited studies on small mammals along the elevational gradients in Ethiopia (Tadesse Habtamu & Afework Bekele, 2012; Mesele Yihune & Afework Bekele, 2012; Yonas Terefe & Fikresilasie Samuel, 2015). However, recording the altitudinal arrangement of these animals helps to monitor that species during the time of disturbances (Stanley & Kihaule, 2016).

More importantly, most of Ethiopian highlands have been modified into agricultural and pastoral lands to the point that potentially threatened many of the highland species (Addishiwot Fekdu *et al*., 2015; Lavrenchenko & Afework Bekele, 2017). This may also hold true for Wenchi highlands, and open the door for faunal diversity, distribution and other ecological studies. In these highlands, natural forests are fragmented into numerous patches, and most of the medium to large−bodied mammals are pushed out from the remaining forest fragments. Even primates that have probably a high level of tolerance to human disturbances (Bobo *et al*., 2014) are restricted except *Colobus guereza*. However, small mammals and birds relatively persist in these modified habitats (Gemechu Shale *et al*., 2014), and the ecology of these animal groups in the area is still poorly known.

Understanding how populations are adapting to these highly changing environments and coping with these disturbances is fundamental to manage and conserve the remaining natural communities (Martin *et al*., 2012). It is also very crucial to understand the effects of habitat availability and quality on species persistence (Honorato *et al*., 2015). Assessing this area for its faunal diversity may, therefore, contribute to their conservation, and enrichment of the faunal list of the country. Such studies could also help in predicting the trends of faunal potential of the area and document them before their local extinction (Lavrenchenko & Afework Bekele, 2017). Thus, the purpose of this study was to explore the faunal diversity, abundance and distribution, and conservation of small mammals (excluding chiropterans) in Wenchi montane forests.

1.2. Statement of the problem

Many of the pristine environments across the world are long gone (Martin *et al*., 2012). The degradation of natural environments and habitat fragmentation affect a species biological diversity (Torre *et al*., 2014). Habitat fragmentation in particular attracted worldwide public concern because it modified most of the natural habitats through isolation and area reduction, and led to the rapid loss of biodiversity (Mesquita & Passamani, 2012). Several anthropogenic factors have also diminished most of the natural habitats in Ethiopian highlands including Wenchi (Addishiwot Fekdu *et al*., 2015; Lavrenchenko & Afework Bekele, 2017). These have threatened many of the endemic mammals of the country (Lavrenchenko & Afework Bekele, 2017).

The hilly mountains around Lake Wenchi are covered by forests, small highland trees, and residential houses that could be a habitat for several mammals and birds. These highland environments faced severe environmental degradation that further threatened the health and livelihoods of the nearby communities (Gemechu Shale *et al*., 2014). The survival of species in such modified habitats depends on the species ability to use available fragmented landscape units (Martin *et al*., 2012). This opens a door to assess the faunal diversity, distribution and other related ecological studies for this area.

Faunal surveys are a critical first step in the documentation of forest faunas (Stanley *et al*., 1998), and may contribute to the enrichment of the faunal list of the country. Such studies also help in predicting the trends of faunal potential of the area and the potential economic and social risks particularly associated with rodents. Lavrenchenko & Afework Bekele (2017) have also urged the need of taxonomic and evolutionary studies of rodents for documenting them before their local extinction due to the rapid habitat destruction and fragmentation in the Ethiopian highlands.

Most studies on small mammals in Ethiopia are largely restricted to the protected areas (PAs), like that of larger mammals (Tilahun Dinaw *et al*., 2017; Seyoum Kiros & Afework Bekele, 2021b), and farmlands (Sintayehu Workineh & Reddy, 2016). Only few studies are conducted outside such areas (Adugnaw Admas & Mesele Yihune, 2016). However, comparative studies conducted in Tanzania suggested a higher diversity and abundance of small mammals outside than in PAs (Caro, 2001, 2002). Thus, conducting a scientific study in unprotected area like that of Wenchi natural forests is so appealing. Recognizing conservation initiatives outside PAs is also recently suggested as a prospective conservation policy (CBD, 2018; Alves−Pinto *et al*., 2021).

The scientific information on the geographical distribution, population ecology and spatiotemporal dynamics of most small mammals in many Africans including Ethiopia is still far from complete (Kingdon, 1997; Agerie Addisu & Afework Bekele, 2013). Documenting the species composition, distribution patterns, factors that affect the species, and conservation need of a particular area is also very essential for monitoring and evaluation of that ecosystem (Agerie Addisu & Afework Bekele, 2015; Lavrenchenko & Afework Bekele, 2017). This is one of the reasons that led to carry out these studies in Wenchi montane forests.

The relationship between species richness and elevation is inherent in mountain ecosystems (Grytnes & Vetaas, 2002). Assessing the patterns of species richness and composition of animal communities through elevational gradients has been one of the most recurrent issues in geographical ecology (Torre *et al*., 2004). At present, only limited studies were also carried out on small mammals in the central parts of Ethiopia (Afework Bekele, 1996; Afework Bekele & Leirs, 1997; Yonas Terefe & Fikresilasie Samuel, 2015). Moreover, the scientific information on the effects of altitudinal gradients on small mammals in Wenchi montane ecosystems is still lacking.

Rodents living in close association with man play a significant role in human health, welfare and economy (Han *et al*., 2015, 2016). Local perception and beliefs about rodents and their damage is a key element to design and implement rodent control or educational programmes (Garba *et al*., 2013; Panti-May *et al*., 2017). Studies have been carried out on this subject in northern and southern Ethiopia (Meheretu Yonas *et al*., 2010; Zewdneh Tomass *et al*., 2020; Bewketu Takele *et al*., 2021), but still there is no documented information from Wenchi highlands.

These knowledge gaps indicate the need of scientific studies on various ecological and biological aspects of small mammals in Wenchi montane forests. More importantly, assessing the conservation challenges and opportunities of wildlife and their habitats has a far fetching impact on the future of these biotas. Therefore, the current study aimed for detailed studies on the ecology, conservation and forms of rodent damage and management practices in this area.

1.3. Objectives of the study

1.3.1. General objective

The main objective of this study was to explore the ecology, rodent related damage and the conservation of non-volant small mammals in human–troubled Wenchi montane forests, Oromia Regional State, central Ethiopia.

1.3.2. Specific objectives

The specific objectives of this study were to:

- Assess the species richness and abundance of non-volant small mammals in Wenchi natural forests
- Examine the density and biomass of rodents and shrews in Wenchi montane ecosystem
- Assess the age and sex structure of rodents and shrews in Wenchi natural forests
- Document the reproduction and feeding habits of rodents in Wenchi forest remnants
- Determine the spatiotemporal dynamics of non-volant small mammals in the study area
- Document the impacts of altitude on the community structures of rodents and shrews in Wenchi highlands
- Identify major conservation challenges and opportunities in Wenchi natural forests
- Examine farmers' perceptions and management options of rodent pests in the area

1.4. Research questions

The following research questions were formulated to acquire scientific information with possible answers on the small mammals in Wenchi montane forests.

1. What type and in what number non-volant small mammals are there in Wenchi mountain forests?
2. Are there spatial and temporal variations in species composition and abundance of non-volant small mammals in Wenchi forest remnants?
3. Is the density and biomass of rodents and shrews in Wenchi montane ecosystem high or low?
4. Does the diet composition and age structure of non-volant small mammals change with seasons?
5. Do altitudinal gradients have effects on the community structures of rodents and shrews in Wenchi highlands
6. What are farmers' perceptions on rodent damage and management practices in Wenchi highlands?
7. What are the conservation challenges and opportunities for Wenchi montane forests?

2. REVIEW LITERATURE

2.1. An overview of small mammals

Small mammals (bats, rodents and shrews) are the most diverse and successful group of mammals (Kumaran *et al*., 2016; Sintayehu Workeneh *et al*., 2011; Tilahun Chekol *et al*., 2012; Demeke Datiko & Afework Bekele, 2014; Adugnaw Admas & Mesele Yihune, 2016). They are abundant in nearly every environment and constitute the highest percentage of mammals (Wilson & Reeder, 2005). This success is related to their diverse ecology, morpho–physiology, behavior and life history strategies, and capability to colonize every available habitat (Kingdon, 1997; Mesele Yihune & Afework Bekele, 2012; Stanley & Kihaule, 2016).

Small mammals are generally classified as volant (bats) and non-volant (rodents and insectivores) mammals (Munian *et al*., 2020). Non-volant small mammals are recognized by their small home range sizes (<0.2 ha) and short distances of dispersal (<200 m) (Presley *et al*., 2019; Seyoum Kiros & Afework Bekele, 2022). Order Rodentia contains around 2,552 species within 513 genera, which is the greatest number of species in the mammalian order (Burgin *et al*., 2018). This is followed by Order Chiroptera with 1,386 species within 227 genera. Order Soricomorpha is ranked third with 440 shrew species under 26 genera (Kingdon, 1997; Happold, 2013).

Family Muridae (834 species) and Cricetidae (792 species) are the two most dominant rodent families with a high number of species (Burgin *et al*., 2018). In Africa alone, there are 264 documented murid rodents (Happold, 2013). Genus *Mastomys* is a well-known genus with wide distributional ranges across Africa (Makundi & Massawe, 2011; Massawe *et al*., 2011; Sintayehu Workeneh *et al*., 2011; Seyoum Kiros & Afework Bekele, 2022).

Ethiopia has nine rodent families from which Muridae contains a large number of species and endemism (Dawit Kassa & Afework Bekele, 2008). *Crocidura* is the most dominant and widespread insectivore genus with over hundred shrew species (Happold & Happold, 2013). Most of the African shrews belong to Crocidurinae and Myosoricinae families (Kingdon, 1997; Happold & Happold, 2013).

Ethiopia harbours a much higher mammalian endemism than any other African countries (Lavrenchenko & Afework Bekele, 2017). The country is home to over 311 species of mammals in 144 genera, 43 families and 14 orders (Lavrenchenko & Afework Bekele, 2017) from which small mammals hold more species (Lavrenchenko *et al*., 2016). Rodents alone make up 39.4% of the Ethiopian mammal fauna and contribute half of the total endemic mammalian fauna of the country (Afework Bekele, 1996a; Dawit Kassa & Afework Bekele, 2008).

Based on their 30 years of study, Lavrenchenko & Afework Bekele (2017) have predicted that the diversity and endemicity of Ethiopian small mammals could be higher than what is expected. More recent research found that there are 104 rodent species belonging to 40 genera and 10 families in different parts of Ethiopia (Bryja *et al*., 2019). There are about 28 species of shrews belonging to a single family, Soricidae in Ethiopia. Over one third of these insectivores are country endemics (Lavrenchenko *et al*., 2016).

2.2. Ecology of small mammals

Understanding the distribution and abundance of organisms is a fundamental goal of ecology (Yalden & Largen, 1992). Small mammals have nearly a worldwide distribution, from the coldest to the driest regions except Antarctica (Kingdon, 1997; Sintayehu Workeneh *et al*., 2011; Mesele Yihune & Afework Bekele, 2012; Happold, 2013; Stanley & Kihaule, 2016). As a result, they are a key component of various ecosystems (Agerie Addisu & Afework Bekele, 2013, 2015). Such cosmopolitan distribution is associated with their small body size, short generation period and diverse feeding habits (Gezahegn Getachew *et al*., 2016).

A shorter generation time enables small mammals to quickly respond to environmental changes (Martin *et al*., 2012). This is particularly true for murid rodents (Paramasvaran *et al*., 2013). Small mammals display habitat specificity and different adaptations to their environment (Torre, 2004; Barragan *et al*., 2010; Marques *et al*., 2015). The distribution of small mammals in a particular habitat is the product of the interaction among the landscape context and species land use/cover of that habitat (Fischer *et al*., 2017).

In natural ecosystems, the diversity and distribution of a particular animal species are primarily affected by the seasonal availability of food and water, the species distributional area, habitat complexity, and area disturbances (Demeke Datiko *et al*., 2007; Tadesse Habtamu & Afework Bekele, 2008; Caceres *et al*., 2011; Demeke Datiko & Afework Bekele, 2014).

2.2.1. Species composition and distribution

Small mammal species select habitats as a function of the resources that habitat offers (Torre, 2004). Habitat selection in small mammals is related to the habitat structure (Pardini *et al*., 2005), high vegetative diversity and herbage production, and a relatively low level of disturbance (Getachew Bantihun & Afework Bekele, 2015; Zerihun Girma *et al*., 2012; Horncastle *et al*., 2019; Richard *et al*., 2020). The presence of diverse vegetation with adequate cover provides plenty of habitat choices and feeding items as well as hiding options from predators (Zerihun Girma *et al*., 2012).

The distribution of small mammals in a particular locality is principally affected by the biological, climatic and topographical factors of that area (Sintayehu Workeneh *et al*., 2011; Addishiwot Fekdu *et al*., 2015; Adugnaw Admas & Mesele Yihune, 2016). Some species use a wider range of resources and tend to persist over a long period of geological time, while others have restricted distribution either for a relatively shorter or longer time (Hadly *et al*., 2001). Thus, small mammals are classified either as generalist or specialist species based on their habitat use (Caceres *et al*., 2011). Great number of small mammals show environmental preferences (Yalden & Largen, 1992; Torre, 2004; Lavrenchenko & Afework Bekele, 2017), and are habitat specifics though there are few generalist species (Happold, 2013; Gezahegn Getachew *et al.,* 2016).

The distribution of small mammals in a particular area is also determined by the altitudinal gradients in that area (Stanley & Kihaule, 2016). This is directly associated with the role of altitudinal difference in structuring and determining the habitat types and climatic conditions of that environment (Caceres *et al*., 2011; Getachew Bantihun & Afework Bekele, 2015). Several rodents and insectivores are distributed in the forest and montane ecosystems of Ethiopia across diverse altitudinal ranges (Lavrenchenko *et al*., 2016).

In general, rodents inhabit almost all available terrestrial ecosystems (Happold, 2013; Akpan *et al*., 2015). Some rodent species also live in transformed habitats particularly in and around human inhabitations (Aplin *et al*., 2003). Rodent species belonging to the genus *Mastomys*, *Arvicanthis* and *Hystrix* are capable of using diverse habitats and tolerate several anthropogenic disturbances (Happold, 2013; Gezahegn Getachew *et al*., 2016).

2.2.2. Diets of small mammals

A study of the feeding habits and diets of rodents in a particular area is very important to know the kind of food items they consume for their survival and reproduction, and to understand their feeding behaviour, trophic level and ecological roles within their natural habitats (Demeke Datiko *et al*., 2007; Shiels *et al*., 2013; Sassi *et al*., 2017; Seyoum Kiros & Afework Bekele, 2022). It is also helpful information in understanding the actual impact of feeding competition with other animals, and supports the conservation of the species from extinction (Kronfeld & Dayan, 1998).

Besides, the information on the feeding habits of rodent pests is very crucial to develop species specific and effective control methods and to minimise their potential damages (Lavrenchenko & Afework Bekele, 2017). The diets of rodents are usually evaluated by analysing the stomach contents, and less frequently the faecal materials (Workneh Gebresilassie *et al*., 2004).

Rodents exploit a broad spectrum of food items (Bewketu Takele *et al*., 2022b; Seyoum Kiros & Afework Bekele, 2022). Most rodents are opportunistic feeders *i.e*., they consume any available food items. They consume plant parts such as fruits, stems, seeds, leaves, berries, flowers, tubers and roots, and animal matters specifically small invertebrates such as insects, spiders and worms (Mohammed Kasso & Afework Bekele, 2011; Happold, 2013; Kingdon, 2015). Small mammals may also display dietary specificity (Torre, 2004; Marques *et al*., 2015). Diet selection in small mammals is largely determined by the availability, diversity, quality and quantity of the existing food item within a particular time and place (Sassi *et al*., 2017).

Most rodents are either herbivorous or omnivorous though a few species are strictly carnivorous (Happold, 2013). Shrews are insectivorous because they primarily feed on small invertebrates (Happold, 2013; Kingdon, 2015). Mole rats are another specialised rodent species that feed on roots and tubers of different plants (Happold & Happold, 2013). Some small mammals also shift between herbivore and omnivore feeding habits depending upon the seasonal availability of a specific food item (Bergstrom, 2013). The feeding habits of particular small mammals is determined by the structures of the skull and teeth (Happold, 2013; Kingdon, 2015). That is why insectivores have sharp cusped molars and a slender muzzle, herbivores have broad incisors and a stout skull, while omnivores have intermediate characters (Kingdon, 2015).

2.2.3. Reproduction and population dynamics

Small mammals are interesting groups to study the population dynamics due to their demographic flexibility, high turnover rate and adaptability (Torre, 2004). They exhibit different adaptations to the environment and play a great role in determining the patterns of biodiversity and ecosystem functioning (Barragan *et al*., 2010). Understanding the population dynamics allows us to predict the changes in the population numbers, and to devise management strategies (Afework Bekele & Leirs, 1997).

The populations of small mammals experience dramatic seasonal and inter-annual variations in species composition and abundance due to the combined effects of ecological interactions, limiting factors, climatic factors and stochastic forces (Torre, 2004; Sintayehu Workeneh *et al*., 2011; Agerie Addisu & Afework Bekele, 2015; Yonas Terefe & Fikresilasie Samuel, 2015). Seasonality strongly influences the population dynamics of small mammals (Makundi *et al*., 2006; Wen *et al*., 2014; Agerie Addisu & Afework Bekele, 2015; Rocha *et al*., 2017). Such variations in diversity patterns of small mammals may be attributed to the response of small mammals to the temporal changes in vegetation structure (Misher *et al*., 2022), seasonal appearance and/or disappearance of some species (Asher & Thomas, 1985) and microhabitats (Mohammed Kasso & Afework Bekele, 2011).

Rodent community structure and species composition have been related to habitat structure and complexity, area productivity, predation, trampling and grazing, surrounding landscape and the distance between similar habitats, succession of vegetation, and presence of exotics (Sintayehu Workeneh *et al*., 2011; Mesele Yihune & Afework Bekele, 2012; Yonas Terefe & Fikresilasie Samuel, 2015). Anthropogenic activities also significantly impact the population dynamics of small mammals and their basic demographic processes (Gentili *et al*., 2014; Agerie Addisu & Afework Bekele, 2015; Gezahegn Getachew *et al*., 2016).

Heterogeneous habitats support different small mammal species and populations because they provide adequate food for survival and reproduction, and adequate shelters from natural predators (Agerie Addisu & Afework Bekele, 2015; Ofori *et al*., 2015). More importantly, the amount and patterns of rainfall also affects the population dynamics of small mammals since it shapes food availability that in turn determine their breeding capacities (Ejigu Alemayehu & Afework Bekele, 2013; Happold, 2013; Getachew Bantihun & Afework Bekele, 2015; Ofori *et al*., 2015). Overgrazing by livestock may also affect the abundance and species richness of herbivore small mammals of a given area, resulting in food competition and limitation, habitat disturbance and increasing risk of predation (Addishiwot Fekdu *et al*., 2015; Gezahegn Getachew *et al*., 2016).

The community organization and temporal changes of small mammals echo the fluctuations of the local species populations (Brown & Heske, 1990). Understanding the spatiotemporal variations of small mammals in a particular area is very important for ecological, economic and conservation reasons (Lavrenchenko & Afework Bekele, 2017; Rocha *et al*., 2017; Seyoum Kiros & Afework Bekele, 2021b). According to Wen *et al*. (2014), field surveys should consider temporal sampling, and ignoring the temporal variations in population studies may result in considerable errors (Asher & Thomas, 1985).

Most small mammals have high reproductive potential and rapid turn-over rate to invade new and a wide range of habitats (Agerie Addisu & Afework Bekele, 2015; Akpan *et al*., 2015; Li *et al*., 2015; Ofori *et al*., 2015). The rapid turn-over rate in small mammals may be associated with their small body size, short breeding cycles, and the ability to consume a variety of food items (Akpan *et al*., 2015: Adugnaw Admas & Mesele Yihune, 2016; Seyoum Kiros & Afework Bekele, 2022). Rodent population studies describe changes in their demographic parameters (Aplin *et al*., 2003) and the relationship between their abundance and damage (Swanepoel *et al*., 2017). Most rodents are characterized by having a large litter size, short generation time and rapid turnovers though this could be affected by their locality, habitat characteristics, season and size of the females. However, most rodents produce 3–6 young per litter (Happold, 2013).

2.3. Highlands as small mammal refugia

Montane ecosystems embody extraordinary biodiversity hotspots (Denys *et al*., 2014). These areas often also have high levels of biodiversity endemism because they provide important habitats or refugia for many species (Simelane *et al*., 2018) and opportunities for additional diversification (Brown, 2001). Mountains offer replicated units with large biotic and abiotic gradients in a reduced spatial scale (Camacho-Sanchez *et al*., 2017). Hence, they are key areas for conservation in a changing world, but a complete biological inventory of the world's mountains still does not yet exist (Brown, 2001). Moreover, most of these ecosystems are subject to strong anthropogenic pressure and climate change (Denys *et al*., 2014).

Small mammals show a greater tendency to high mountains and wetter environments (Yalden & Largen, 1992; Wood & Singleton, 1996; Torre, 2004; Lavrenchenko & Afework Bekele, 2017). They are more adapted to highland habitats than large mammals because they are capable of avoiding temperature adversity of these habitats (Mesele Yihune & Afework Bekele, 2012). Montane ecosystems are ideal for investigating processes that determine species assemblage along environmental gradients (Bateman *et al*., 2010).

Documenting and understanding the elevational arrangement of organisms in a given slope is very important to appreciate the progress and interactions of mountainous ecosystems, and design protection and monitoring approaches (Stanley *et al*., 2014; Stanley & Kihaule, 2016; Chen *et al*., 2020). So far, this was poorly known (Stanley *et al*., 2014), and only recently attracted the interests of ecologists and mammalogists (Mulungu *et al*., 2008; Stanley & Kihaule, 2016).

The composition of small mammal communities evidently and significantly varies with rising elevation due to changes in environmental conditions and the biological limits of the particular species in the altitudinal gradient along with the combination of neighboring habitats and the resources they provide (Kamenišťák *et al*., 2019). Many mammalian species follow a mid-altitudinal peak pattern, but this is not known for non-volant small mammals (Bateman *et al*., 2010). Changes of community characteristics (diversity, composition) in the altitudinal gradient are generally associated with common influences of climate (local abiotic conditions), topography (terrain relief), historical factors (occurrence of species across evolutionary timescales), heterogeneity and habitat complexity (vertical strata within habitat) and the influence of other biotic factors (Kamenišťák *et al*., 2019).

Ethiopian plateau comprises a mosaic of widely differing habitat types with extremely diverse relief and pronounced elevational zonation (Mengesha Assefa *et al*., 2000). Half of the land above 2000 m, and more than 3/4th of the African lands above 3000 m asl occur in Ethiopia. These unique environmental conditions have encouraged intensive speciation processes, making the Ethiopian plateau a "mammal diversity hotspot" (Kostin *et al*., 2016). The majority of these highlands are associated with many unique endemic wild plants and animals (Leykun Abune, 2000). Most rodents of Ethiopia are especially geographically restricted to these highlands. These highlands harbour 14 of the 15 endemic species of rodents (Yalden & Largen, 1992). Highland uplift forms new novel habitats with different topography and climatic conditions leading to species diversification and endemism (Mengesha Assefa *et al*., 2000).

Most of Ethiopian highlands have been modified into farming and grazing lands to the point that potentially threatened many of the highland rodents due to their extremely limited distributional ranges and habitat destruction (Addishiwot Fekdu *et al*., 2015; Lavrenchenko & Afework Bekele, 2017). Only limited studies are carried out on altitudinal patterns of small mammals in Ethiopian montane ecosystems (Tadesse Habtamu & Afework Bekele, 2012; Kostin *et al*., 2016).

2.4. Ecological roles and conservation of small mammals

Small mammals have an important role in the ecosystem balance and function. They are agents of nutrient cycling, gas exchange within the soil, plant gene flow through pollination and seed dispersal, and are key components of trophic levels (Tobin & Fall, 2004; Seyoum Kiros & Afework Bekele, 2022). Some rodents in specific habitats are viewed as ideal taxonomic groups to be used as model organisms for the study of ecological processes and to address questions at different spatial scales. This is because they have relatively small home ranges, are short-lived and disperse from their natal areas when they reach adulthood (Torre, 2004). Mice and rats are used as model animals in different basic researches, behavioral and basic pharmacology studies, and applied and military researches (Sabolik *et al*., 2011). They also serve as good indicators of environmental quality due to their rapid responses to environmental changes (Barragan *et al*., 2010; Tadesse Habtamu & Afework Bekele, 2012).

Small mammals regulate the population of arthropods that in turn help to reduce the transmission of disease (Jones & Safi, 2011). Some rodents also have a significant role in weed removal and regulation by consuming parts of active growing stages or seeds of a particular weed (Fischer *et al*., 2018). Rodents are among the most important food bases in the food chain, and dietary components for many predators particularly mammals and birds (Aplin *et al*., 2003; Tobin & Fall, 2004; Mulungu *et al*., 2008; Mesele Yihune & Afework Bekele, 2012; Demeke Datiko & Afework Bekele, 2014). They also contribute to animal biomass and vegetation regeneration of a particular habitat (Denys *et al*., 2014).

In some regions of the world including Africa, some small mammal species are used as sources of ethnomedicine and bushmeat for humans (Tadesse Habtamu & Afework Bekele, 2008; Akpan *et al*., 2015). Rodents are also reported to be a protein source for humans (Meyer–Rochow *et al*., 2015; Gruber, 2016). Tadesse Habtamu & Afework Bekele (2008) also reported the local use of small mammals as an important food source from western Ethiopia. According to this report, about 70% of rodent species are important components of the Gumuz people diet. Porcupines, squirrels, *Arvicanthis* and *Desmomys* rodent species are the most preferred rodents by these people.

African mammalian biodiversity is largely concentrated in human–dominated landscapes (Tyrrell *et al*., 2020). Ethiopian mountain ecosystems in particular have a high level of mammal endemism, and are threatened by intense and irreversible anthropogenic impacts (Leykun Abune, 2000; Kostin *et al*., 2018). However, conservation activities are still primarily focused on PAs (Mir & Dick, 2012). Thus, several studies suggested the need of dramatic conservation management measures and an equal conservation weight for natural habitats located outside PAs to allow the immediate conservation of biodiversity (Caro, 2001, 2002; Mir & Dick, 2012). That is why most conservation advocates are lately calling for the recognition of conservation initiatives outside PAs (CBD, 2018; Alves-Pinto *et al*., 2021).

Small mammal species are often neglected in conservation biology, and only a few of them are protected (Bertolinoa *et al*., 2015). As a result, the conservation status of most species of rodents is poorly known and very few protection programmes focus on them (Denys *et al*., 2014). Knowledge of small mammal population densities and species richness values, however, are crucial to wildlife conservation and many ecological investigations (Hopkins & Kennedy, 2004). A species sensitivity, habitat preferences and dispersal abilities affect the responses of small mammals to habitat destructions (Honorato *et al*., 2015).

Most natural habitats of Ethiopia absorb several anthropogenic pressures from the surrounding environment. Some of these pressures include illegal human settlement, agricultural expansion, fuelwood collection, forest clearings, infrastructure development, overgrazing, human–wildlife conflict, human induced fire, and introduction of invasive alien species (Seyoum Kiros & Afework Bekele, 2021a). These threats affect biodiversity through habitat loss and modifications, and are associated with the rapid human population growth and subsequent increase in the demands of existing natural resources (Israel Petros *et al*., 2016; Frick *et al*., 2019; Selemawi Abrehe *et al*., 2020). Such activities fragment or destroy numerous natural wildlife habitats and their wildlife (Musyoki *et al*., 2012; Mohammed Kasso & Afework Bekele, 2014; Kabeta Legese *et al*., 2019). Undoubtedly, these pressures are high in areas outside protected areas. Thus, the challenges that wildlife conservation of Ethiopia is facing are complex and require a readiness to address (Leykun Abune, 2000).

Deforestation and human–wildlife conflict is the two wildlife threatening factors posing a serious problem in Ethiopia (Aberham Megaze *et al*., 2017; Seyoum Kiros & Afework Bekele, 2021a). Deforestation leads to forest fragmentation that in turn decreases the amount of habitat available for wildlife, and increases the isolation of the remaining fragments and edge area that surrounds the fragments (Mohammed Kasso & Afework Bekele, 2014; Hernández-Palma & Stouffer, 2018). In human–dominated areas, habitat fragmentation severely threatens biodiversity and ecosystem functioning. The decline in biodiversity of fragmented landscapes is chiefly explained by habitat availability and habitat quality (Honorato *et al*., 2015). Habitat availability has a tendency to increase with increasing patch area, and dwindles with increasing fragmentation (Honorato *et al*., 2015).

Human–wildlife conflict usually happens when the needs of the wild fauna are hindered by the local community or when human properties are lost or damaged due to the surrounding wildlife species (Mesele Yihune *et al*., 2009; Seyoum Kiros & Afework Bekele, 2021a). This conflict can occur between humans with birds, reptiles or small to large mammals. Crop raiding, livestock predation, transmission of communicable diseases, and human injury or deaths are the main causes of human–wildlife conflict (Mesele Yihune *et al.,* 2009; Aberham Megaze *et al.,* 2017; Seyoum Kiros & Afework Bekele, 2021a). The level of conflict depends upon the diversity, population size and status of the hazardous wild animals, and the proximity to the wildlife habitats (Mesele Yihune *et al*., 2009; Seyoum Kiros & Afework Bekele, 2021a).

2.5. The harmful effects of small mammals

Small mammals are important components of the natural system with several ecological benefits. But they are also a threat to food production and human property, and are a public health risk (Panti−May *et al*., 2017). Rodents are among the most serious vertebrate pests in the world (Staples *et al*., 2003; Brown *et al*., 2007), and involved in the zoonotic transmissions of many pathogens (Mesele Yihune & Afework Bekele, 2012; Garba *et al*., 2013). The economic and ecological benefits of rodents outweigh these harmful effects (Tadesse Habtamu & Afework Bekele, 2012) because only <10% of rodents are major pest species, and even fewer cause problems over larger geographic areas (Stenseth *et al*., 2003; Capizzi *et al*., 2014).

Rodents cause huge economic losses in agricultural crops, chiefly tuber crops and cereals (Mulungu *et al*., 2005; Massawe *et al*., 2011; Jones *et al*., 2017). They are responsible to cause substantial crop damage and losses both in the field and storages, and incur significant cost of management across the world (Makundi & Massawe, 2011). These pests may notably affect global crop production and livelihoods of farmers because their cost to agriculture is enormous (Singleton *et al*., 2005, 2010). The damage can be severe, diverse, and show temporal and spatial variations (Gebhardt *et al*., 2011) because it is directly associated with rodent abundance, diversity, feeding habits and reproductive patterns (Swanepoel *et al*., 2017). Crop losses also vary between crops, cropping stages, and storage types (Swanepoel *et al*., 2017).

Rodents are to blame for consuming or spoiling food that could feed about 280 million people for a year (Meerburg *et al*., 2009). Rodent damages significantly affect food security and income of small-holder farmers of developing countries (Brown *et al*., 2013; Lund, 2015; Htwe *et al*., 2016). This is more hostile to rural communities because rodents damage agricultural crops in the field, and consume and contaminate stored grains (Meheretu Yonas *et al*., 2010; Mulungu *et al*., 2015).

Rodents consume foodstuffs, cause physical damage to packaging and storage materials, and contaminate products with hair, urine and faeces (Brown *et al*., 2013; Buckle, 2015; Lund, 2015). Rodent hair or droppings in food may create great problems for exporting countries up to the rejection of the entire load (Lund, 2015). Annual losses due to rodents in several countries are economically unacceptable (Meheretu Yonas *et al*., 2010). Such country level damages can have a major effect on the state's economy and all available consumers (Gebhardt *et al*., 2011).

Rodents are one of the major problems in Africa, and have been the number one crop pest in the eastern part (Makundi *et al*., 1999; Hill, 2008). Ethiopia also experiences constant rodent pest problems on different agricultural crops though enset, potatoes and maize are the most impacted crops (Ejigu Alemayehu & Afework Bekele, 2013; Meheretu Yonas *et al*., 2014; Zewdneh Tomas *et al*., 2020; Bewketu Takele *et al*., 2022). About 11 rodent species belonging to the genera *Arvicanthis*, *Lemniscomys*, *Mastomys*, *Mus* and *Tatera* are considered as major agricultural crop pests (Afework Bekele & Leirs, 1997; Afework Bekele *et al*., 2003; Lavrenchenko & Afework Bekele, 2017).

Ethiopia is ranked third in stored grain losses after Egypt and Tanzania (Mulungu, 2017). Studies also documented the highest yield loss in central (26%) and northern (9–44%) Ethiopia due to rodent crop damage (Afework Bekele *et al*., 2003; Meheretu Yonas *et al*., 2014). This suggests the need for ecological study on small mammals of a given area to identify economically important rodent species of that area and to develop effective pest management strategies that could minimise their impacts (Mohammed Kasso, 2013; Ofori *et al*., 2015).

Farmers across the globe apply different prevention methods primarily to reduce the impact of rodent pests (Capizzi *et al*., 2014). These preventive measures include trapping, hunting, rodenticide, habitat modification and management, fertility control, physical barriers, repellents, biological control and flooding of burrows (Hill, 2008; Capizzi *et al*., 2014; Meheretu Yonas *et al*., 2014). In Ethiopia, farmers also own cats as an additional biological rodent control method (Hill, 2008; Meheretu Yonas *et al*., 2010; 2014; Zewdneh Thomas *et al*., 2020). In developing countries, the ecosystem services of rodents are not often appreciated by the communities, and the control actions are, therefore, indiscriminately directed against both pest and non-pest species (Aplin *et al*., 2003; Lavrenchenko & Afework, 2017).

2.6. Farmers' perspectives to rodent damage and management

Rodent pest damage significantly affects the global crop production and livelihoods of farmers because their cost to agriculture is enormous (Singleton *et al*., 2005, 2010). They remarkably affect the incomes of small–holder farmers of developing countries (Brown *et al*., 2013; Lund, 2015; Htwe *et al*., 2016). This is more challenging for the rural community because rodents damage agricultural crops in the field, and consume and contaminate stored grains (Meheretu Yonas *et al*., 2010; Mulungu *et al*., 2015).

Controlling the population of rodents is economically helpful to reduce rodent linked losses (Skonhoft *et al*., 2006; Brown *et al*., 2013). This is influenced by the farmer's knowledge on variables affecting crop damage, the level of crop susceptibility, the rodent pest population during the most susceptible crop stage and how much they are prepared to control the pests (Makundi *et al*., 2005).

Human attitudes towards wildlife are the interrelationships among societal norms, values and value orientations. These are key drivers of attitudes and dictate human behaviour towards wildlife (Beale *et al*., 2013). Thus, it is more than just a collection of beliefs, emotions and behaviours. Local perceptions about rodents and their damage are the first step for designing and implementing rodent control or educational programmes (Panti-May *et al*., 2017). Studies have been carried out on this subject in northern and southern Ethiopia (Meheretu Yonas *et al*., 2010; Zewdneh Tomass *et al*., 2020; Bewketu Takele *et al*., 2021). In developing countries, public health problems of rodents are largely ignored by the general public (Belmain, 2002; Garba *et al*., 2013). There is also a limited knowledge and neglect of rodent borne diseases because of other pressing public health problems (Mackey *et al*., 2014).

3. MATERIALS AND METHODS

3.1. Study area description

The study was conducted in Wenchi district of southwest Shewa Zone, Oromia regional state. The area is located in the central highlands of Ethiopia between Ambo and Waliso towns, 155 km away from the capital, Addis Ababa (Fig. 1). It is geographically located between 37° 50' 0"E to 37° 55' 0"E latitudes and 8° 45' 0"N to 8° 55' 0"N longitudes. The elevation of the area ranges between 2,810 and 3,386 m asl (Bezeayehu Tefera *et al*., 2002). Its highest elevation is at Mount Wenchi (3,386 m asl).

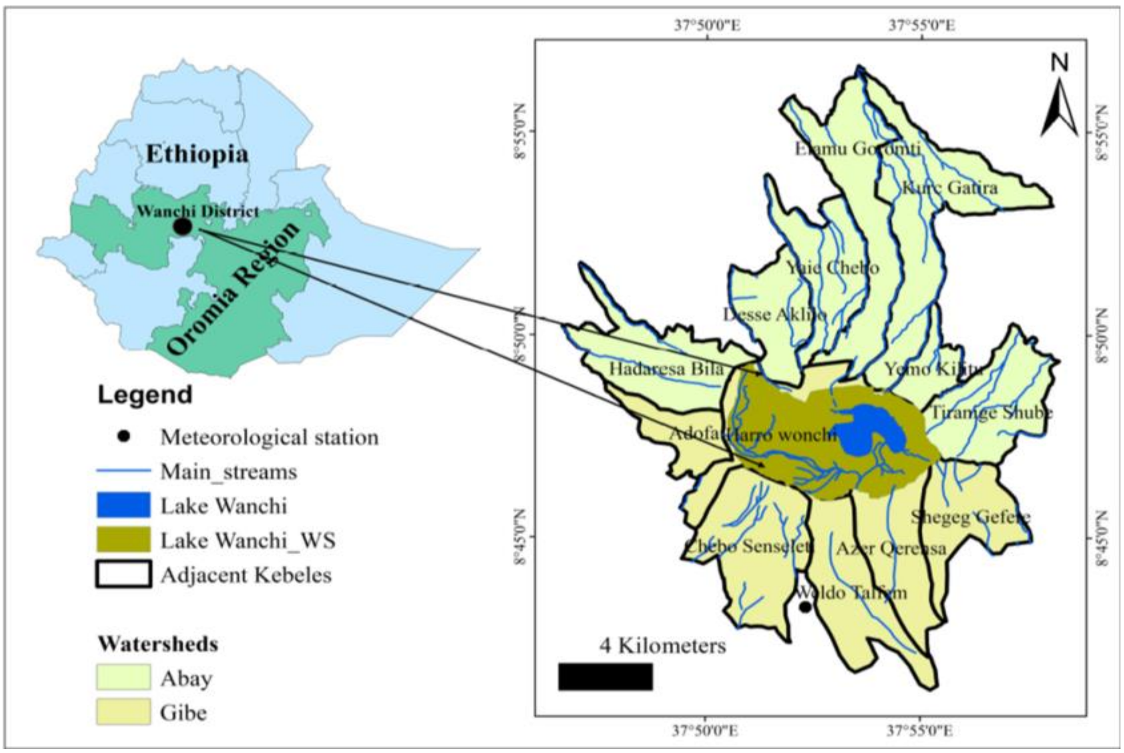

Figure 1. Map of the study area (Adopted − Abebe Tufa *et al*., 2022).

Wenchi highlands are characterised by highland sub–humid climate with the average annual rainfall of 1400 to 1420 mm (Gemechu Shale *et al*., 2014; Abebe Tufa *et al*., 2020). The rainfall is unimodal with a longer rainy period from May to September (Fig. 2). The peak rainfall occurs in July and August, while the cold–dry season occurs between October and January (Abebe Tufa *et al*., 2020). The temperature of the area varies between 14 to 26°C during the day and falls below 10°C at night (Fasil Degefu & Schargel, 2015).

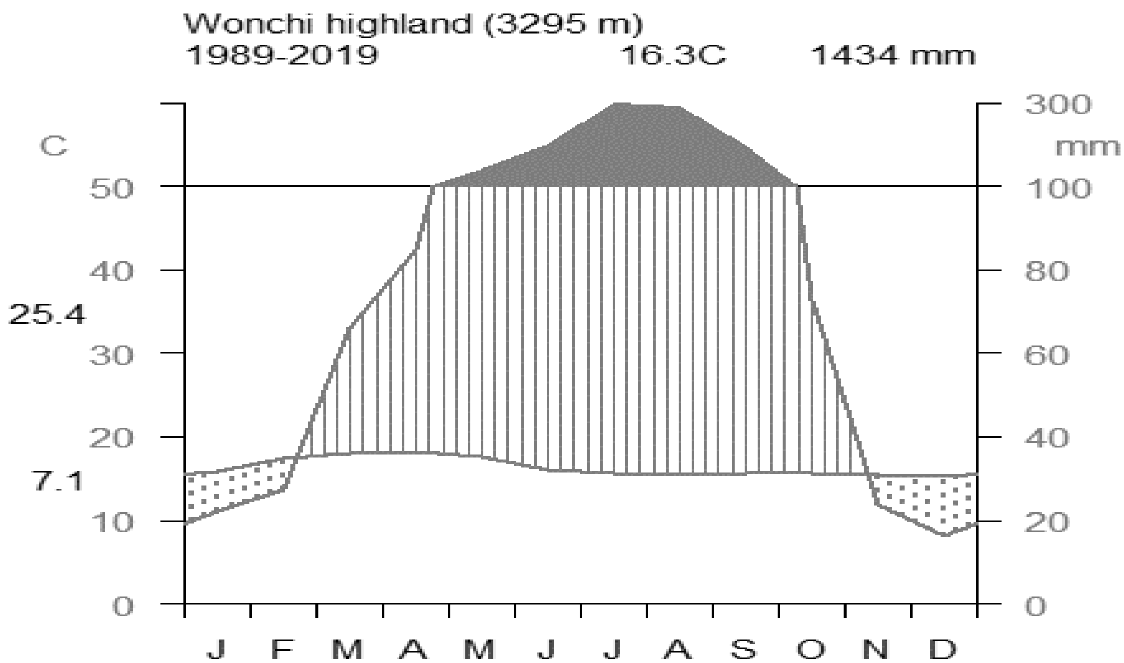

Figure 2. Walter and Leith climate diagram of Wenchi highlands (1989–2019).

Lake Wenchi is among the rare and relatively untouched volcanic highland lakes in central Ethiopia (Fasil Degefu & Schagerl, 2015; Abebe Tufa *et al*., 2020). It is one of the current tourist's attractions and exciting ecotourism destination in the area. The area also owns the 15th century Monastery and the hilly highland area covered with natural forests, mineral waters and hot springs (Fasil Degefu *et al*., 2014; Gemechu Shale *et al*., 2014). Accordingly, the government of Ethiopia has launched ecotourism development initiative at Lake Wenchi watershed in 2021 as part of Gebete Lehager projects, and Oromia Tourism Commission (OTC) recently recognized it as the best national tourism destination area in the region. It is also selected as the best tourist village of 2021 at the 24th assembly of the UN world tourism organization (UNWTO, 2021).

Wenchi highlands are characterised by sub–afro alpine vegetation type. The uplands which make up the Lake Wenchi watershed are dominated by *Erica* scrub. The lower altitude, Qibate and Lakeshore forests, are occupied by several ever–green highland trees, shrubs and herbs. Abebe Tufa *et al*. (2020) identified several species of woody plants in the lake escarpment.

Bracken fern, *Pteridium aquilinum* is a widespread invasive fern, whereas *Hagenia abyssinica*, *Juniperus procera*, *Olea europaea* subsp., *cuspidata*, *Ilex mitis* and *Myrsine melanophloeos* are some of the indigenous tree species in the area. The area also harbours different species of mammals, reptiles and birds. Among large mammals, colobus monkey, antelopes, and some nocturnal species such as aardvark and hyena occur. Other medium to large bodied mammals have been exterminated by explosive exploitation of their habitats in the last two decades.

Forest land, shrubland and lakeshore forests include the natural vegetation of the area. Forest land is the most common land type in the district after farmlands (District Land Administration Office, 2020 unpl.). It is located in the southwestern block of the lake, and is locally known as Qibate Forest. Lakeshore forests are natural forests that surround the lake, and are separated from the main Qibate Forest by the road leading down to the monastery and hot springs. Abebe Tufa *et al*. (2021) considered this habitat as a wetland habitat category. The area is mostly possessed by local community, and is fairly less reachable by the community (*i.e.*, mostly enclosed and managed by a nearby community). Albesa Forest is another natural forest patch located outside Lake Wenchi escarpment. It is geographically positioned in the southwestern direction of Qibate Forest and Haro town.

The main livelihood in Wenchi highlands is mixed agriculture (crop cultivation and livestock rearing), small and micro–enterprises, and income generating activities from ecotourism (Gemechu Shale *et al*., 2014; Abebe Tufa *et al*., 2022). The average land holding size for a single household is 0.5 ha, and the major crops grown in the area are enset (*Ensete ventricosum*), barley (*Hordeum vulgare*), potato (*Solanum tuberosum*) and wheat (*Triticum* species) (Gemechu Shale *et al*., 2014). Like other highlands in the country, Wenchi highlands are a highly overpopulated area in the district (District Land Administration Office, 2020 unpl.), and farming and harvesting is performed by traditional technologies (Meheretu Yonas *et al*., 2010).

3.2. Sampling design and sampled habitats

A reconnaissance survey was conducted along Wenchi highlands before the actual study was commenced to locate suitable sampling sites and then select sampling units. Then, four forest remnants were identified based on the topography, altitude, human disturbances and vegetation types, and further classified into dominant and representative habitats (Yonas Terefe & Fikrasilasie Samuel, 2015). For that reason, a single sampling site was allocated for the three forest fragments (Qibate, Lakeshore and Albesa forests) as they were characterised by a physically similar vegetation structure, while the remaining habitats were represented by two sampling areas due to their vegetational heterogeneity (*Hagenia* woodland and *Erica* Forests). The *Erica* scrub is a natural vegetation isolated from the main forests, and in the uplands of the lake watershed made the last habitat category.

We have also tried to increase the sampling efforts by incorporating an independent sampling site from either human settlement and/or farmland to have information on synanthropic rodents, and a full package of small mammal diversity from the mosaic landscapes of Wenchi highlands. However, this remained unattainable because of the unwillingness of the local communities. The sampling design was based on a spatial grid design approach (Dawit Kassa & Afework Bekele, 2008; Tadesse Habtamu & Afework Bekele, 2012). The sampling protocol was implemented in 49 sampling units encompassing all the native vegetation patches of the study area (Fig. 3).

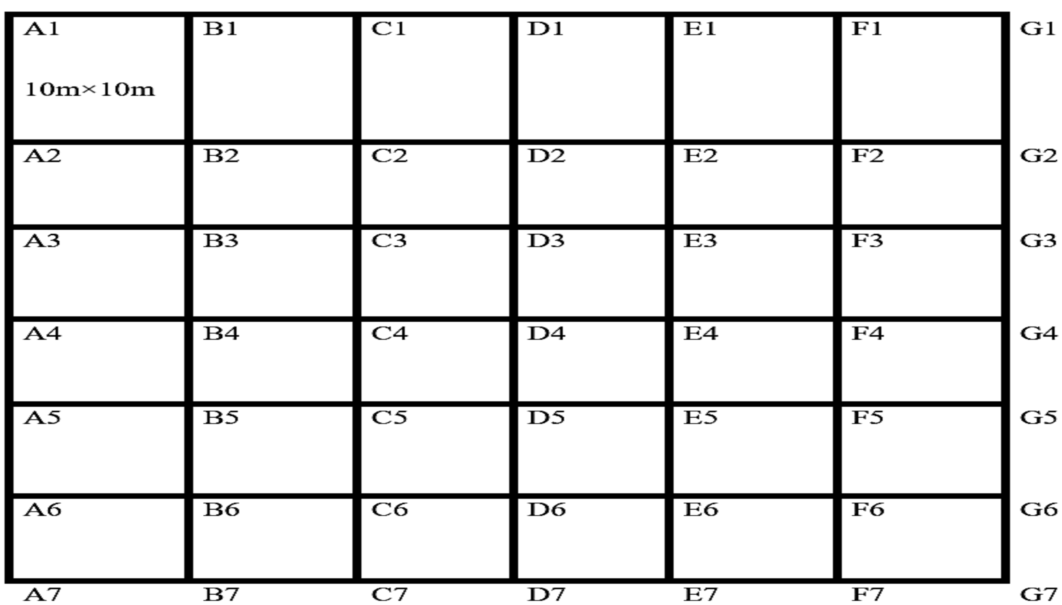

Figure 3. A diagrammatic illustration of live trap grids and tapping stations.

3.2.1. Description of the habitats

***Hagenia* Woodland** is located within 2900 to 3000 m altitude ranges at the gate and outskirts of Qibate Forest. It is adjacent to the main road that takes from Haro town to the Lake Wenchi, hot springs and monastery. The matrix of this habitat is greatly altered by human activities as it is at proximate distance to the residential areas, road networks, and absorbs maximum anthropogenic pressures. The canopy of this habitat is notably composed of the endemic *Hagenia* trees (Plate 1). The understory ranges from open to closed areas by bracken ferns. Only a few parts of this habitat have closed understory and minimal human interactions.

Plate 1. *Hagenia* woodland habitat (Photo by: Kabeta Legese).

Qibate Forest is the largest forest cover of Wenchi highlands. It is a mixed forest that is primarily dominated by *Olive* spp. and other indigenous trees (Plate 2). In some cases, it is interspersed with *Erica* wood and other tree species. This habitat has a wide spatial distribution and absorbs diverse pressures based on its proximity and accessibility to local communities. The areas that are remote from the local communities have medium to low exploitation probability than the proximate ones. Except the hilly and valley areas, this habitat is in open access to the local communities for firewood collection and cattle grazing. Since, surveying hilly and untouched areas is challenging, we opted to survey a relatively remote and medially exploited area of this habitat.

Plate 2. Qibate Forest habitat (Photo by: Kabeta Legese).

Lakeshore Forest is a forest area that is positioned along the borders of Lake Wenchi. It has a varying history of disturbances. Most areas are extensively exploited for firewood collection and cattle grazing by the local people. There are also a few areas, particularly the north−eastern section of Qibate Forest, which is privately owned by the farmers and investors, and has light human exploitation and cattle grazing pressures.

Since a heavily exploited habitat is already surveyed, a small mammal survey was conducted in this lightly exploited area. Furthermore, the area is also characterised by diverse vegetation cover with lightly planted *Eucalyptus* trees, shrubs with bracken ferns and large native trees such as *Olive* species (Plate 3). This vegetational diversity is supposed to host more diverse and abundant small mammals than other areas of such kind. This habitat is followed by *Erica* Forest habitat on its higher and north−western tips.

Plate 3. Lakeshore Forest habitat (Photo by: Kabeta Legese).

***Erica* Forest** is the portion of Lakeshore and Qibate forests that is dominated by *Erica* woods. Like the two forest habitats, it also has a varying history of disturbances. Some of this habitat is heavily exploited for firewood and grazed by cattle. However, the northern and western parts of this habitat were inaccessible for cattle grazing because of its sloppy landscape structures. The northern part of this area is an extension of lakeshore forest and privately owned by local farmers as well as investors. Comparatively, this area absorbs fewer human pressures than the same habitat in other parts of the forest.

Plate 4. *Erica* Forest habitat (Photo by: Kabeta Legese).

***Erica* Shrubland** habitat is an area that is located in a higher altitude (>3200 m). It is principally dominated by scrubby plants, *Erica* spp. (Plate 5). This habitat was formerly a continuation of the main forest habitat. A rapid human population growth in the area later on has resulted in the increase of land demands for both settlement and farming areas leading to its isolation from the main forest. At present, the area is sandwiched between human settlement and farmlands. It is also impacted by the expansion of exotic commercial plants, *Eucalyptus* trees, replacing the native plants.

This habitat is treated as an independent sampling site primarily to increase the heterogeneity of the sampling efforts, and to assess the mammalian diversity of Wenchi highlands at all possible altitudes. It also covers a wide geographic area of the uplands of Lake Wenchi, and shows unique elevational range, vegetation structure as well as disturbance histories.

Plate 5. *Erica* shrubland habitat (Photo by: Kabeta Legese).

Albesa Forest is a forest remnant located to the south western of Haro town in Cabo Sansalati village. It has more thick forest structure than Qibate Forest fragment. It is also occupied by fewer large trees and shrub components in its understory. This forest fragment is characterised by two habitat structures; ericaceous scrub at its tips and largely a mixed forest of different shrubs and trees (Plate 6). This habitat is included in the study to represent the diversity of forest remnants and showed the unique vegetational structure of Wenchi highland natural habitats. Like the *Erica* scrub habitat, Albesa Forest is also embedded in human settlement matrixes and largely exploited for firewood harvest by these local communities including the urban dwellers. A shrubland in this forest was not considered to avoid sampling repetition.

Plate 6. Albesa Forest habitat (Photo by: Kabeta Legese).

3.3. Species composition and distribution survey

Small mammals survey was conducted in two dry and wet seasons between August 2019 and January 2021. Sherman live−traps (to capture live rodents) and snap traps (to analyse embryo count and the stomach content) were used to capture small mammals (Dawit Kassa & Afework Bekele, 2008). The captured rodents were identified using standard keys, and field guides (Kingdon, 1997, 2015; Afework Bekele & Yalden, 2013; Happold, 2013). Personal observations and some indirect evidence such as quills, burrows and soil mounds were also employed to record some non−trapped rodents (Tadesse Habtamu & Afework Bekele, 2012).

3.3.1. Sherman live−traps

The study was conducted for two consecutive years in two different seasons. The representative live−trap grids were established randomly among the elevation and vegetation type based upon possible representation of different habitats (Tadesse Habtamu & Afework Bekele, 2012; Yonas Terefe & Fikrassilasie Samuel, 2015). Live−trapping grids representing the available habitat types were established for capture-mark-recapture study.

A single grid was set up in each of the representative sites of the habitat during the study periods. Each of the grids comprised of 7x7 lines at 10 m intervals. Then, a total of 49 Sherman live−traps (5.5 x 6.5 x 16 cm size) at 10 m intervals were placed for three successive days. Traps were set in the afternoon and baited with barley flour and peanut butter. Traps were inspected in the following dawn and dusk (Dawit Kassa & Afework Bekele, 2008). Old baits were substituted by new ones during trap checking (Dawit Kassa & Afework Bekele, 2008; Venance, 2009).

Traps were also covered with grass to reduce mortality from cold and to avoid damage by other animals (Caceres *et al*., 2011; Sintayehu Workineh & Reddy, 2016**)**. Each newly captured animal was marked by toe clipping and released at the point of capture to ensure it could be recognized if subsequently recaptured (Tuyisingize *et al*., 2013; Getachew Bantihun & Afework Bekele, 2015; Sintayehu Workineh & Reddy, 2016).

The reproductive status of trapped specimens was differentiated into adults, sub−adults and juveniles based on the fur colour and weight. Male and female reproductive conditions were recorded through the examination of scrotal and abdominal testes, and perforate or imperforate vagina, respectively (Tadesse Habtamu & Afework Bekele, 2012). Reproductive conditions were also determined by dissecting the animal following Tsegaye Gadisa & Kitessa Hundera (2015).

3.3.2. Snap traps

Snap traps (n=20) were placed at 10 m intervals in each habitat, 200 m away from the live trapping grids (Demeke Datiko & Afework Bekele, 2013). Trapped animals were weighed using Pesola spring balances and species were identified, sex was determined, and external body measurements were taken using a ruler graded in mm from snap trapped animals (Getachew Bantihun & Afework Bekele, 2015). Voucher specimens were prepared for species that were difficult to identify in the field, and then compared to the specimens at Zoological Natural History Museum, Addis Ababa University (Tadesse Habtamu & Afework Bekele, 2012; Demeke Datiko & Afework Bekele, 2013; Getachew Bantihun & Afework Bekele, 2015).

3.4. Diet analysis and embryo count

Dissection was performed on the snap trapped rodents to analyse the stomach contents and to count embryo of pregnant females. The stomach content was removed and individually preserved in formalin (10%) for further microscopic inspection, which is carried out in Zoology Laboratory, Addis Ababa University.

In laboratory, the contents were thoroughly mixed and sieved through 0.25 mm sieve followed by the removal of finely digested food particles by distilled water for a proper identification of the remaining parts. The contents were then spread onto a Petri dish and dried in open air for a day. Four slides were prepared for each sample, and the contents were smeared on a glass slide for microscopic observation of the type and proportion of food items. Then, the observed food items were clustered into animal matter (arthropods and earthworms), plant matter (seed, roots, and leaves) and unidentified food items. The mean percentage for each sample was computed from the particles that are counted and summed up from the entire slide (Getachew Bantihun & Afework Bekele, 2015; Bewketu Takele *et al*., 2022; Seyoum Kiros & Afework Bekele, 2022).

3.5. Questionnaire survey and focus group discussion

Main conservation threats and opportunities for Wenchi highlands biodiversity, natural resource utilizations, and knowledge, attitudes and perceptions (KAP) of farmers about rodent damage and management practices were collected from both primary and secondary sources. Primary data were obtained using semi–structured questionnaires, focus group discussion, and direct observations. Such data were gathered from the village administrators, agricultural extension workers and local communities. Other supportive information such as agricultural practices and farmers socio–demographic characteristics were also collected. Secondary sources of data included journal articles, websites, and reports.

Wenchi district contains a total of eight highland villages – Haro Wenchi, Shagag Gafare, Waldo Telfami, Damu Dagale, Azar Qeransa, Cabo Sansalati, Merega Abayi and Odo Fura. Of these, four highland villages: Haro Wenchi (856 households), Waldo Telfami (783), Azar Qeransa (860) and Cabo Sansalati (681) were considered for this study because they are relatively accessible, contain natural forest remnants, and neighbouring to an iconic Lake Wenchi. Haro Wenchi is a classic highland ecosystem with the highest elevation at Mount Wenchi (3,386 m asl), and Wenchi crater lake.

Household samples were computed using the formula, $n = Z^2P(1-P)/d^2$; where n is calculated sample size, Z is a critical value (1.96) at 95% confidence interval, P is a projected proportion (50%) and d is margin of error which is fixed at 5% (Daniel, 1995). Moreover, the sample size was proportionally assigned to each of the four villages using the formula, $nh = \frac{N(n)}{\sum N}$ (Pandey & Verma, 2008; Bewketu Takele *et al*., 2021); where, nh is the number of sample households to be selected from each village, N is the total number of households in each village, n is the calculated total sample size to be selected from all the study villages, and $\sum N$ is the sum total of households in the selected villages. Thus, questionnaires were administered to a total of 383 randomly selected households from lists obtained from the administration of the respective villages (Table 1). Individual household heads were selected randomly from the study villages by lottery method for data collection.

A semi−structured questionnaire was extracted from published studies with similar objectives (Brown *et al*., 2008; Meheretu Yonas *et al*., 2010; Stuart *et al*., 2011; Zewdneh Tomass *et al*., 2020; Seyoum Kiros & Afework Bekele, 2021a) and modified to the situation of the area (Appendix 1). It was formed not to be long and troublesome for the farmers, while allowing the gathering of relevant information (Foster *et al*., 2019). Both open and close ended questions were prepared in English and administered using local language (Afan Oromo) to one person to provide accurate information (Garba *et al*., 2013).

Table 1. The proportion of sampled households for the study villages.

Villages	No. of households			No. of sampled households		
	Female headed	Male headed	Total	Female headed	Male headed	Total
Haro Wenchi	106	746	852	12	91	103
Waldo Telfami	184	595	779	16	78	94
Cabo Sansalati	108	573	681	13	69	82
Azar Qeransa	114	746	860	13	91	104
Total	512	2660	3172	54	329	383

Permission to carry out the study was obtained from the Department of Zoological Sciences, Addis Ababa University. The objectives of the study were first informed for the study participants, and their consent of participation was obtained to comply to the ethical standard. They were also guaranteed that their responses are only used for this study. Each interview was conducted by the researcher and his field assistant for approximately 30 minutes in December, 2020 and January, 2021.

Focus group discussions were also conducted with key informant groups (village administrators, agricultural extension workers and selected farmers representatives) in the study villages to strengthen the information that was gathered through questionnaires. From 5 to 10 individuals in the study villages were participated in FGD (Table 2). In addition to the above key informants, ecotourism guides were also participated in Haro Wenchi FGD. The discussions were led by the researcher, and key informants were encouraged to express their ideas. Participatory discussions were made based on the summary of the semi−structured questionnaires.

Discussions on the attitude of farmers towards rodent pest species, level of crop damage, yield loss, management strategies and economic cost and related concepts were raised in the focus group discussion. Discussions were also made on the importance of the forest fragments and why the local people rely on its natural resources, the knowledge and attitudes of the local community towards wildlife conservation, the prevailing conservation challenges, and possible conservation measures and opportunities to lessen the major conservation challenges in Wenchi highlands.

Moreover, the prevailing conservation threats and opportunities were also documented through direct observation during small mammal trapping sessions. Then, observable threats were photographed and documented as supportive evidence.

Table 2. Profiles of key informants for conservation challenges.

Key informants	Informant profiles			
	Age (in years)	Sex		
		Male	Female	Total
Agricultural extension workers	26-32	1	1	2
Selected community members	28–75	8		8
Ecotourism guides	24–40	2	-	2
Wenchi District agricultural and natural resources administration head	42	1	-	1
Village administrators	32–65	12	-	12
Total		24	1	25

3.6. Data analysis

Data analyses were based on captures per unit effort to account for variation in effort among the study sites. Shannon−Wiener Diversity Index (H') was used to estimate species diversity (Shannon & Weiner, 1949). Shannon diversity index was computed using a formula: $H' = -\sum_{i=1}^{S} pi\ ln\ pi$; where H' is species diversity index, S is the total number of species and pi is the proportion of individuals of each species belonging to the ith species of the total number of individuals. Species distribution patterns in the community were assessed using Evenness index (E) (Tuyisingize *et al*., 2013).

Simpson's Similarity Index (SI) was used to compare the small mammals among the habitats (Demeke Datiko and Afework Bekele, 2014). Simpson's Similarity Index was calculated using a formula: SI = 2C/A+B+…+G; where, C is common species for the six habitat types and A+B+C+…+G are the sum number of species from each surveyed habitat. Sørensen's coefficient was used to estimate the similarity of small mammals among the habitats (Venance, 2009). The dissimilarity of small mammal communities among the habitats was also estimated using the dissimilarity index.

Spatiotemporal variations of small mammals were assessed by comparing the number of captured individuals and their relative abundance for a specific habitat, time, year and season. Relative abundance in each habitat was computed as the ratio of the number of species in each habitat and the total number of species in the study area (Venance, 2009). $Ra = \frac{n}{Ns} \times 100$; where, Ra is relative abundance, n is the total number of captured individuals of a single species and Ns is the total numbers of individuals of the whole species.

Trap success was also computed and compared with the relative abundance from the total trap nights and the trapped individuals (Gómez−Villafañe *et al*., 2012; Tuyisingize *et al*., 2013; Yonas Terefe & Fikrasilasie Samuel, 2015; Li *et al*., 2015; Kumaran *et al*., 2016). The total trapped individuals and the trap night was used to calculate trap success of each trap line (Kumaran *et al*., 2016). Trap success was computed using a formula: $TS = \frac{Nm}{Ntn} \times 100$; where, TS is trap success, Nm is the number of individuals trapped and Ntn is the number of trap nights.

Data sets from capture recapture sampling techniques were used for density estimations (Wiewel *et al*., 2009; Krebs *et al*., 2011). Small mammal density was computed as a ratio of abundance to trapping area (Wiewel *et al*., 2009; Seyoum Kiros & Afework Bekele, 2021b). Mathematically, $D = \frac{N}{A}$; where, D is density, N is the total number of individuals per grid, A is the area of the trapping grid (0.49ha) for each trapping session. Small mammal biomass was also computed by multiplying the density and average weight of each species (Agerie Addisu & Afework Bekele, 2015; Bewketu Takele *et al*., 2022; Seyoum Kiros & Afework Bekele, 2022).

Qualitative and quantitative data were analysed by appropriate statistical methods such as mean, percentage and Chi−square (χ^2) tests. Chi−square test was applied to compare spatiotemporal variations in small mammal species abundance and structure with respect to sex, age group, habitat and year. Chi−square test was also used to confirm the possible associations between socioeconomic profiles of the respondents and their response to KAP questionnaires.

Diet analysis and quantitative information obtained from semi−structured questionnaires were analysed using descriptive statistical methods such as percentages and count frequency. Qualitative data gathered through focus group discussions, interviews and observations were systematically condensed and summarised, and finally analysed by narration and descriptions through content analysis method (Kassegn Berhanu & Endalkachew Teshome, 2018; Seyoum Kiros & Afework Bekele, 2022). All statistical data were analysed using SPSS version 21 (SPSS, Inc. USA), and probability values were considered statistically significant when P−value is ≤ 0.05.

4. RESULTS

Information on species composition, abundance, spatiotemporal changes, and sex and age structures of non-volant small mammals in Wenchi montane forests are presented in this section. Furthermore, the assessment results obtained from external body measurements, reproductive and diet ecology of snap trapped species, and the density and biomass of live−trapped rodents are also presented. Lastly, findings on the perceptions and management options of rodent pests by local communities as well as the challenges and opportunities for biodiversity conservation in Wenchi highlands are presented in this section.

4.1. Species composition and abundance

A total of 935 individual rodents and 24 insectivores were captured in 4,968 trapping nights from six different habitats during the two trapping seasons. The captured rodents belonged to 12 species and four families. Of these, nine species were from the family Muridae (*Arvicanthis abyssinicus*, *Desmomys yaldeni*, *Mastomys natalensis, M. awanshensis*, *Stenocephalemys albipes*, *Lophuromys flavopunctatus*, *L. brevicaudus*, *L. chryopus*, and an unidentified murid rodent (*Murid* spp. *A*)). The others were only represented by a single species, and were from the family Gliridae (*Graphirius murinus*), Nesomyidae (*Dendromus lovati*) and Cricetidae (*Lophiomys imhausi*).

Crested porcupines (*Hystrix cristata*) and African mole rats (*Tachyoryctes splendens*) were neither live−trapped nor snap trapped rodents. Instead, they were confirmed through indirect evidence. Specifically, porcupines were confirmed through quills, while burrows and soil mounds were used for mole rat identifications. These rodents belong to the family Hystricidae and Spalacidae, respectively.

Bailey's shrew (*Crocidura bailey*), Smoky white-toothed shrew (*C. fumosa*) and African giant shrew (*C. olivieri*) were the three shrew species trapped in the present study area. More than half of the identified small mammals (52.9%) were endemic to Ethiopia. These included Yellow spotted brush−furred rat (*Lophuromys flavopunctatus*), Short tailed brush−furred rat (*L. brevicaudus*), Ethiopian forest brush−furred rat (*L. chryopus*), Yalden’s rat (*D. yaldeni*), Lovat’s climbing mouse (*D. lovati*), Abyssinian grass rat (*A. abyssinicus*), Awash multimammate mouse

(*M. awashensis*) and White footed mouse (*S. albipes*). Bailey shrew was the only endemic insectivore in the area.

Of the total non-volant small mammals captured, 841 were live−trapped, and the remaining 118 were snap trapped. The capture rate was higher in live traps (23.85%) than snap traps (8.26%). A total of 555 non-volant small mammals were new captures (including the snap trapped) and 404 were recaptures. There was a significant variation in the captures of small mammals (χ^2=511.698, df=1, P<0.05).

Multimammate mouse (*Mastomys natalensis*) was the dominant rodent species with 294 (30.86%) individuals followed by White footed mouse with 266 (27.82%) individuals, while Maned rat (*L. imhausi*) was the least, represented only by a single (0.10%) individual (Table 3). The total capture rate of individual small mammals showed a significant difference between the species (χ^2=2304.27, df=16, P<0.05).

Table 3. Species diversity, total captures and recaptures of small mammals (− = absent, * = observed).

Species	Live–trapped (Recaptures)	Snap trapped	Total	Relative Abundance
Multimammate mouse	146 (112)	38	296	30.86
Awash multimammate mouse	24 (26)	4	54	5.63
Yellow spotted brush−furred rat	46(24)	15	85	8.86
Ethiopian forest brush−furred rat	46(33)	11	90	9.4
Short tailed brush−furred rat	22 (12)	9	43	4.5
White footed mouse	114 (116)	36	266	27.5
Abyssinian grass rat	4	1	5	0.52
Yalden's rat	7 (2)	-	9	0.94
Murid spp. *A*	32(42)	6	80	8.34
Lovat's climbing mouse	6	-	6	0.62
African dormice	2	-	2	0.21
Crested or maned rat	1	-	1	0.10
African giant shrew	8	-	8	0.83
Bailey shrew	6	-	6	0.62
Smoky white-toothed shrew	8	-	8	0.83
African root rat	*	*	*	*
Crested porcupine	*		*	*
Total	841	118	959	100

The highest species richness (9) was registered from *Erica* scrub habitat followed by Albesa Forest and *Hagenia* woodland (8). The least species richness was recorded from Lakeshore Forest (6). Albesa Forest has shown the maximum species diversity (H'=1.74) followed by *Hagenia* woodland (H'=1.57). The lowest species diversity index (H'=1.43) was recorded from Qibate Forest habitat.

Simpson's diversity index was high in Albesa Forest (D=0.77) followed by *Erica* Forest (D=0.76). The lowest Simpson's diversity index was recorded from Lakeshore Forest (D=0.63). The highest evenness was recorded in *Erica* Forest (E=0.94) habitat followed by *Hagenia* woodland (E=0.75). Non-volant small mammals were unevenly distributed in *Erica* scrub habitat type (Table 4).

Table 4. Diversity indices of small mammals.

Habitats	Species richness	Total trapped individuals	H'	D	E
HW	8	144	1.57	0.73	0.75
QF	7	194	1.43	0.69	0.68
LSF	6	265	1.56	0.74	0.71
EF	7	41	1.52	0.76	0.94
ES	9	146	1.54	0.65	0.60
AF	8	169	1.74	0.77	0.72

(HW= *Hagenia* Woodland, QF= Qibate Forest, LSF= Lakeshore Forest, EF= *Erica* Forest, ES= *Erica* scrub, AF= Albesa Forest)

Sørensen similarity coefficient (Ss) showed a varying degree of similarities among the small mammals' community between the paired habitats. The highest similarity index (0.85) was recorded between Qibate and Lakeshore Forests, while the lowest score (0.35) was between *Erica* Forest and scrub. The second highest similarity index (0.71) was observed between *Erica* Forest and both Lakeshore and Qibate Forests. In contrast, the highest dissimilarity index (Ds) was scored between *Erica* Forest and scrub (0.65), while the lowest score was between Qibate and Lakeshore Forests (0.15).

Multimammate mouse and Yellow spotted brush−furred rat were recorded in all habitats. White footed mouse, and Ethiopian forest brush−furred rat was recorded in all four forest habitats, but absent from the scrubland. Yalden's rat and Abyssinian grass rat were the two rodent species captured from two different habitat types. Yalden's rat was first trapped from a cleared forest in Qibate Forest and an open–spaced upland ericaceous scrub, whereas Abyssinian grass rat was trapped from the outskirt of *Hagenia* woodland, and in ericaceous scrub, the same area where Yalden's rat was captured. Lovat's climbing mouse, African dormice (*Graphirius murinus*), Maned rat and *Murid* spp. *A*. were limited to a single habitat type. They were captured from *Hagenia* woodland, Lakeshore Forest, Albessa and ericaceous scrub habitat, respectively (Table 5).

Table 5. Small mammals' distribution and abundance in the study habitats.

	Habitat type						
Species	HW	QF	LSF	EF	ES	AF	Total
Multimammate mouse	58	85	92	15	27	22	296
Awash multimammate mouse	5	12	31	6	–	–	54
Yellow spotted brush–furred rat	7	11	25	3	10	36	105
Ethiopian forest brush–furred rat	12	15	32	3	-	24	88
Short tailed brush–furred rat	12	-	-	-	14	14	43
White footed mouse	46	63	83	6	-	63	266
Abyssinian grass rat	1	–	–	–	4	-	5
Yalden's rat	–	7	–	–	2	-	9
Murid spp. *A*	–	–	-	–	80	–	80
Lovat's climbing mouse	6	-	–	–	-	-	6
African dormice	-	-	-	-	-	2	2
Crested or maned rat	-	-	1	-	-	-	1
African giant shrew	-	-	-	-	2	4	8
Bailey shrew	-	1	1	-	4	-	6
Smoky white-toothed shrew	-	-		5	1	2	8
African root rat	-	*	-	-	*	*	
Crested porcupine	*	-	-	-	*	*	
Trap success (%)	17.4	23.4	32.2	4.95	17.5	20.4	19.24
Total	144	194	265	41	146	169	959

Crested porcupine was evident in Albesa Forest and shrubland habitat types. The indirect evidence was also encountered at the entry point to the *Hagenia* woodland and on the main road during the dry season. This rodent was a pest to the common crops (potatoes and enset) in the area. African mole rats were recorded only from Qibate Forest and Albesa Forest habitats. Local people also claimed its distribution and pest nature in farming areas primarily after the rainy season. No squirrel species was observed in the study area during the study periods. Insectivores were recorded from all the habitats, except in the *Hagenia* woodland.

From the total small mammal populations, the highest number of individuals, 266 (27.73%) were recorded in Lakeshore Forest followed by Qibate Forest, which was represented by 194 (20.23%) individuals. The least small mammal individuals, 41 (4.27%) were recorded in *Erica* Forest. The highest number of insectivores, 7 (27.16%) were recorded in the scrubland, while the least was in Qibate and Lakeshore Forests, each represented by a single encounter. There was a significant difference in the total abundance of small mammals among the habitat types (χ^2=169.644, df=5, $P<0.05$).

The abundance of species also varied within the habitat types. From the total population of Multimammate mouse, 92 (31.1%) individuals were recorded in Lakeshore Forest, while the lowest population, 15 (36.58%) was from *Erica* Forest. Out of the total population, the highest population of White footed mouse, 83 (31.20%), Awash multimammate mouse, 31 (57.41%) and Ethiopian forest brush−furred rat, 32 (35.55%) were recorded in Lakeshore Forest. The lowest population record for these species was also from the same habitat, in *Erica* Forest.

The highest population of Yellow spotted brush−furred rat, 36 (42.35%) was registered in Albesa Forest, while the lowest, 3 (17.07%) was in *Erica* Forest. The highest population of Short tailed brush−furred rat, 14 (9.65%) was recorded in *Erica* scrub. The population of this species was also fairly represented in *Hagenia* woodland and Albesa Forest. Smoky white-toothed shrew and African giant shrew were the two most abundant shrew species with joint number of occurrences 8 (33.33%), while Bailey shrew was the least (Table 6).

Relative abundance of species varied within the habitat types. Multimammate mouse was the most abundant rodent species in Qibate Forest (43.81%), *Hagenia* woodland (38.82%) and Lakeshore Forest (34.58%). In scrubland, *Murid* spp. *A*. (55.17%) was the most abundant species. White footed mouse (37.27%) was the dominant rodent species in Albesa Forest. Maned rat was the least abundant species, only represented by 0.37% of Lakeshore Forest captures.

Table 6. Relative abundance of small mammals in the study habitats.

Species	Relative abundance (%)/habitats					
	HW	QF	LSF	EF	ES	AF
Multimammate mouse	40.27	43.81	34.58	15	36.58	13.01
Awash multimammate mouse	3.47	6.18	11.65	14.63	–	–
Yellow spotted brush−furred rat	4.86	5.67	9.39	7.3	6.89	21.3
Ethiopian forest brush−furred rat	8.33	7.73	12.03	7.31	-	14.2
Short tailed brush−furred rat	8.33	-	-	-	9.65	8.28
White footed mouse	31.94	32.47	31.2	14.63	-	37.27
Abyssinian grass rat	0.69	–	–	–	2.0	-
Yalden’s rat	–	3.6	–	–	1.37	-
Murid spp. *A*	–	–	-	–	55.17	–
Lovat’s climbing mouse	4.16	-	–	–	-	-
African dormice	-	-	-	-	-	1.18
Crested or maned rat	-	-	0.37	-	-	-
African giant shrew	-	-	-	-	1.37	2.36
Bailey shrew	-	0.51	0.37	-	2.75	-
Smoky white-toothed shrew	-	-		12.2	0.69	1.18
Total	100	100	100	100	100	100

4.2. Altitudinal distribution

The species richness and abundance of non-volant small mammals varied with altitudes. A higher altitude has registered the highest species richness (13 species) than the lower one (10 species). Small mammals also showed variations in abundance along the altitudinal ranges. The highest number of small mammal individuals (40.35 %) were recorded between 2850−2950 m asl, while the lowest number of small mammals (21.27%) were recorded between 3200−3300 m asl (Table 7). There was a significant difference in the abundance of small mammals along the altitudinal ranges (χ^2=63.343, df=2, P<0.05). Total trap success also showed a significant difference across the altitudes; higher between 3200−3300 m asl, and lower between 2850−2950 m asl.

Table 7. Small mammals’ richness and diversity along elevational ranges.

	Altitudinal ranges (m asl)			
Species	2850−2950	2951−3050	3200−3300	Total
Yalden’s rat	7	-	2	9
Lovat’s rat	-	6	-	6
White footed mouse	109	128	29	266
Multimammate mouse	159	98	39	296
Yellow spotted brush−furred rat	19	48	18	85
Ethiopian forest brush−furred rat	41	40	9	90
Short tailed brush−furred rat	7	26	10	43
Maned rat	1	-	-	1
Murid spp. *A*	-	1	79	80
Abyssinian grass rat	-	1	4	5
Awash multimammate mouse	37	10	7	54
African giant shrew	-	6	2	8
Bailey shrew	2	-	4	6
Smoky white-toothed shrew	5	2	1	8
African dormice	-	2	-	2
Total	387	368	204	959
Number of species	10	12	13	15
Trapp success (%)	15.57	22.22	24.63	

The abundance of small mammal species also showed significant variations within altitudinal zonation (χ^2= 438.93, df=2, P<0.05). The highest number of individuals of Multimammate mouse (52.7%), Ethiopian forest brush−furred rat (45.55%) and Awash multimammate mouse (68.52%) were documented at the middle altitude. White footed mouse (48.12%) and Yellow spotted brush−furred rat (56.47%) had also a higher number of individuals at the middle altitude. However, four rodent species showed a restricted altitudinal distribution. Maned rat was restricted to a lower altitude, whereas Lovat's climbing mouse and African dormice were limited to a middle altitude. *Murid* spp. *A*. was, however, restricted to the uplands.

Non-volant small mammals showed a significant variation in altitudinal distribution between the seasons (χ^2=56.71, df=2, P<0.05). A higher number of small mammals were trapped during the dry seasons in both lower (57.88%) and higher (79.41%) altitudes (Fig. 4). However, more small mammal individuals (52.98%) were recorded during the wet seasons at the middle altitude. White footed mouse (χ^2=22.66, df=2, P<0.05), Awash multimammate mouse (χ^2=16.16, df=2, P<0.05), Multimammate mouse (χ^2=13.0, df=2, P<0.05), Ethiopian forest brush−furred rat (χ^2=8.66, df=2, P<0.05) and Yellow spotted brush−furred rat (χ^2=6.19, df=2, P<0.05) were the only species that showed significant difference in altitudinal zonation between the two seasons.

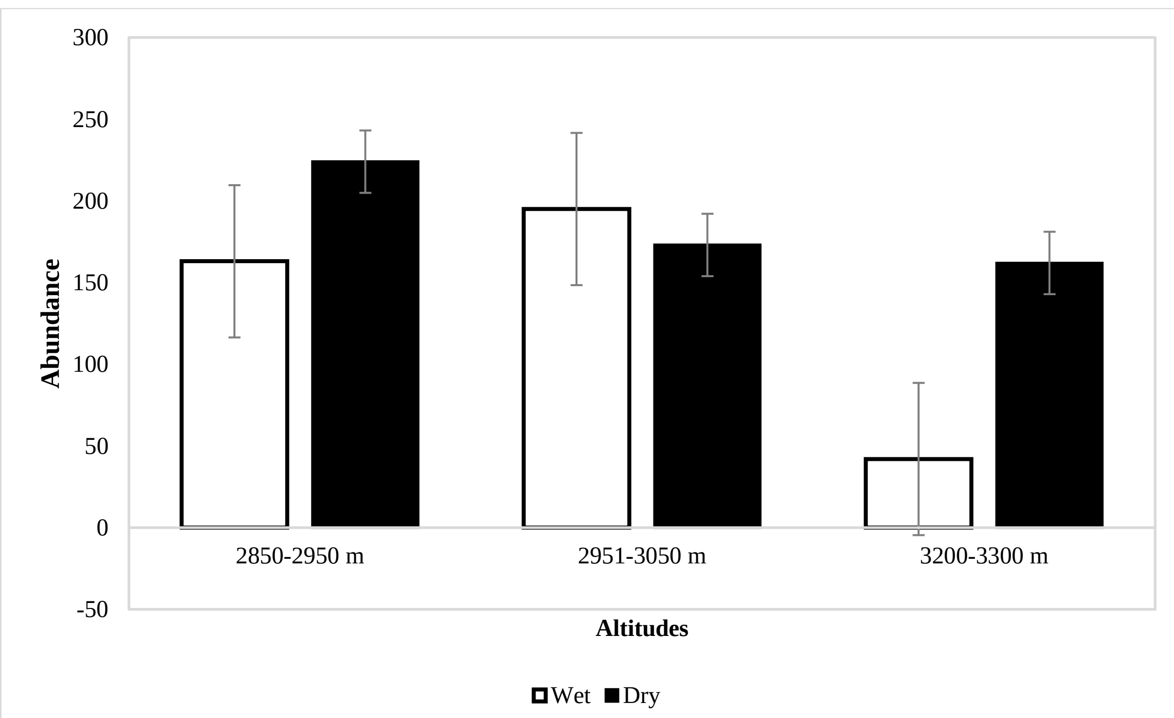

Figure 4. Seasonal abundance of small mammals across the altitudes.

4.3. Sex and age structures

A total of 494 (51.51%) female and 465 (48.49%) male small mammals were recorded (Fig. 5). There was statistically insignificant variation in the abundance of small mammals between sexes (χ^2=28.789, df=1, P>0.05). An overall ratio between male and female small mammals was 1.0:1.06. Age structure of small mammals was dominated by adults (71.53%), while juveniles (8.55%) made the least contribution. There was statistically a significant variation in the age structure of small mammals (χ^2=2304.27, df=1, P<0.05).

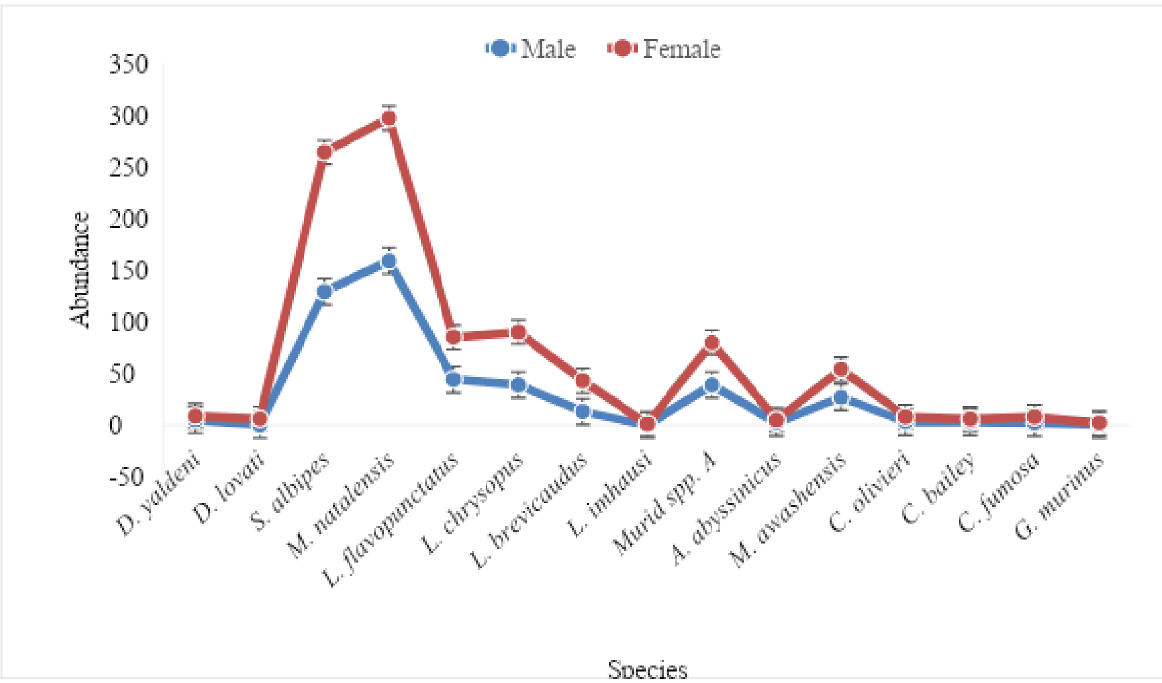

Figure 5. Sex structure of small mammals in Wenchi montane forests.

4.4. Density and biomass

Most of the small mammals in Wenchi montane forests had very low population density. The total small mammal density in this area was 121.61/ha. It was only three rodent species that registered a double-digit figure in their population density (Table 8). From the identified small mammals, White footed mouse had the highest population density (23.45/ha), while Maned rat had the lowest (0.5/ha). Multimammate mouse had the second highest population density (21.76/ha).

The density of each small mammal species also differed among habitats. For example, Multimammate mouse had the highest population density in Qibate Forest, but the least in Albesa Forest. Similarly, White footed mouse had the highest population density in Lakeshore Forest habitat, while the least in *Erica* Forest. An unidentified murid rodent was recorded only in *Erica* scrub habitat, and had an exceptionally high population density (37.75/ha).

From *Lophuromys* assemblages, Ethiopian forest brush−furred rat had the highest population density (8.26/ha), while the remaining two species had relatively low and very close population density. The three species of insectivore registered the least population density across all the study habitats, which ranges from 1.02 to 2.04/ha.

Table 8. Small mammal density (ha^{-1}) in the study habitats.

	Habitat type						
Species	HW	QF	LSF	EF	ES	AF	Total
Multimammate mouse	29.59	43.36	46.93	7.65	13.7	11.2	21.76
Awash multimammate mouse	2.55	6.12	15.8	3.06	−	−	6.37
Yellow spotted brush−furred rat	3.57	5.61	12.75	1.53	5.10	18.36	5.95
Ethiopian forest brush−furred rat	6.12	7.65	16.32	1.53	-	12.24	8.26
Short tailed brush−furred rat	6.12	-	-	-	7.14	7.14	5.78
White footed mouse	23.46	32.14	42.34	3.06	-	32.1	23.46
Abyssinian grass rat	0.51	−	−	−	2.04	-	1.02
Yalden's rat	−	3.57	−	−	1.02	-	2.29
Murid spp. *A*	−	−	-	−	40.8	−	37.75
Lovat's climbing mouse	3.06	-	−	−	-	-	3.06
African dormice	-	-	-	-	-	1.02	1.02
Crested or maned rat	-	-	0.5	-	-	-	0.5
African giant shrew	-	-	-	-	1.02	2.04	2.04
Bailey shrew	-	0.51	0.51	-	2.04	-	1.02
Smoky white-toothed shrew	-	-		2.25	0.51	1.02	1.36
Total	73.46	98.97	135.2	20.9	74.5	86.22	121.6

The biomass of most small mammals in Wenchi montane forests was very low like that of population density. The total biomass of small mammals in the study area was 5206.2 g/ha. Small mammal biomass varied among the species and habitat types (Table 9). From the identified small mammals, White footed mouse had the highest biomass (1290.3g/ha) followed by Multimammate mouse (1218.5g/ha), while Maned rat had the lowest biomass (9 g/ha).

Table 9. Biomass (g/ha) of small mammals.

Species	Habitat type						Total (g/ha)
	HW	QF	LSF	EF	ES	AF	
Multimammate mouse	1745.8	2558.2	2768.8	451.3	812.4	660.8	1218.5
Awash multimammate mouse	153	367.2	948	660.8	−	−	381
Yellow spotted brush−furred rat	178.5	280.5	637.5	76.5	255	918	297
Ethiopian forest brush−furred rat	275.4	344.25	734.4	68.85	-	550.8	371
Short tailed brush−furred rat	299.88	-	-	-	349.8	349.8	283.2
White footed mouse	1290.3	1767.7	2323.2	168.3	-	1767.7	1290.3
Abyssinian grass rat	40.8	−	−	−	163.2	-	81.1
Yalden’s rat	−	232	−	−	66.3	-	160.3
Murid spp. *A*	−	−	-	−	3468.8	−	2827
Lovat’s climbing mouse	48.96	-	−	−	-	-	64.8
African dormice	-	-	-	-	-	19.38	20.4
Crested or maned rat	-	-	9.18	-	-	-	9
African giant shrew	-	-	-	-	7.65	30.6	30.6
Bailey shrew	-	7.65	7.65	-	30.6	-	16.32
Smoky white-toothed shrew	-	-		33.75	7.65	30.6	21.76
Total	3085.3	4156.7	5678.4	878.2	3128.1	3621.2	5206.2

From *Lophuromys* assemblages, Ethiopian forest brush−furred rat had the highest biomass (8.26g/ha), while the remaining two species had very close biomass to one another. The three *Crocidura* spp. had the least biomass in the studied habitats. The biomass of small mammals also differed among habitat types for each species. For example, in *Erica* shrubland, the highest biomass was 2827g/ha for an unidentified murid rodent.

4.5. Spatiotemporal variations

From the total small mammals, 559 (58.29%) individuals were trapped during the dry seasons, while the remaining 400 (41.71%) were from the wet seasons. There was a significant difference in the total abundance of small mammals between seasons (χ^2=26.36, df=1; P<0.05). From the total 2484 trap nights, the overall trap success was higher during the dry (22.59%) than the wet (16.10%) seasons. The highest numbers of small mammal species (86.66%) were trapped during the wet seasons compared to the dry seasons (73.33%). There was a significant variation in the species richness and abundance of small mammal between the seasons (χ^2=104.12, df=1, P<0.05).

During the dry seasons, Multimammate mouse (37.03%) was the most abundant small mammal species followed by White footed mouse (28.44%), while two shrew species (*C. olivieri* and *C. bailey*) and African dormice were the joint least small mammals. White footed mouse (26.75%) was the most abundant small mammal species followed by Multimammate mouse (22.25%) during the wet seasons, while Maned rat and Yalden's rat were the joint least small mammal species each represented with one individual (Table 10).

The highest number of non-volant small mammals (84.98%) was trapped during the morning trapping sessions, while the remaining 15.01% were obtained from the evening traps. There was a significant difference in the trapping of small mammals between the trapping times (χ^2=469.490, df=1, P<0.05). From the total identified small mammal species, all of the species (15) were trapped in the morning, while only ten species were trapped in the evening. There was a significant dissimilarity in small mammal species richness between the trapping times (χ^2=197.206, df=1, P<0.05).

Maned rat, Lovat's climbing mouse and African dormice were rodent species that were only trapped during the morning trapping times. However, none of the shrew species were trapped during the evening sessions. Most small mammals in the present study favoured nocturnal habits. It was only *Lophuromys* assemblages that relatively showed a cathemeral distribution with 57.34% traps in the morning and 42.66% in the evening. Species wise, it was only Ethiopian forest brush−furred rat that showed significant variations between the trapping times and seasons (χ^2=197.206, df=1, P<0.05).

Table 10. Temporal variations of small mammal's abundance.

Species	Seasons		Trapping time		Year		
	Wet	Dry	Morning	Noon	1st	2nd	Total
Multimammate mouse	89	207	288	8	168	128	296
Awash multimammate mouse	35	19	52	2	19	35	54
Yellow spotted brush−furred rat	50	35	52	33	38	47	85
Ethiopian forest brush−furred rat	58	32	48	42	39	51	90
Short tailed brush−furred rat	22	21	25	18	21	22	43
White footed mouse	107	159	240	26	114	150	266
Abyssinian grass rat	-	5	4	1	1	4	5
Yalden's rat	1	8	4	5	3	6	9
Murid spp. *A*	16	64	71	9	33	47	80
Lovat's climbing mouse	6	-	6	-	3	3	6
African dormice	-	2	2	-	1	1	2
Crested or maned rat	1	-	1	-	1	-	1
African giant shrew	6	2	8	-	5	2	8
Bailey shrew	4	2	6	-	6	0	6
Smoky white-toothed shrew	5	3	8	-	4	4	8
Total	400	559	815	144	456	503	959

More individuals of small mammals (52.24%) were trapped during the second trapping year than the first year (47.75%). However, no significant variation was observed in the total abundance of small mammals between the trapping years (χ^2=1.928, df=1, P>0.05). Out of the total small mammals, all of the species (15) were represented in the first trapping year, while two less species were trapped in the second year. There was a significant dissimilarity in small mammal species richness between the trapping years (χ^2=30.548, df=1, P<0.05).

Bailey's shrew and Maned rat were the two species that were not trapped during the second trapping year. Statistically, Multimammate mouse (χ^2=8.678, df=1, P<0.05) and *Murid* spp. *A* (χ^2=14.045, df=1, P<0.05) were the only rodent species that showed significant disparity between the trapping years. There was significant variation in the abundance of small mammal species between the two trapping years (χ^2=10.749, df=1, P<0.05).

From the total of 465 male and 494 female small mammals, 191 (47.75%) males and 209 (52.25%) females were recorded during the two wet seasons. The remaining 274 (49.01%) males and 285 (50.9%) females were trapped during the two dry seasons. There was a slight difference in the overall capture rate of females (9.9%) and males (9.36%) between the two seasons. More female individuals were also trapped both in the morning and evening trapping sessions than males. There was an insignificant difference in the sex structure of small mammals between the seasons (χ^2=0.15, df=1, P>0.05) and trapping times (χ^2=0.109, df=1, P>0.05).

Similarly, more female individuals were trapped than male counterparts in both trapping years with insignificant variations (χ^2=8.811, df =1, P>0.05). Female small mammals capture rate (8.41%) was higher than that of males (7.7%) between the two wet seasons. The capture rate of female small mammals (11.47%) was insignificant compared to the males (11.07%) between the two dry seasons (Table 11).

Most small mammals in the present study area showed high male to female ratios. In most species, female individuals showed numerical increase during the wet season. In contrast, the number of females of Multimammate mouse, White footed mouse and *Murid* spp. *A*. increased during the dry seasons. Smoky white-toothed shrew recorded a 1:1 male to female ratio during the wet seasons. Exceptionally, male individuals were not trapped for three rodent species − Lovat’s climbing mouse, African dormice and Maned rat.

Table 11. Seasonal sex structure of small mammals.

Species	Wet season		Dry season		
	Male	Female	Male	Female	Male: Female
Multimammate mouse	51	38	108	99	1.16:1
Awash multimammate mouse	18	17	9	10	1:1
Yellow spotted brush−furred rat	23	27	21	14	1.07:1
Ethiopian forest brush−furred rat	26	32	13	19	1:1.24
Short tailed brush−furred rat	9	13	4	17	1:2.3
White footed mouse	52	55	77	82	1:1.06
Abyssinian grass rat	-	-	2	3	1:1.5
Yalden's rat	1	-	4	4	1.25:1
Murid spp. *A*	5	11	34	30	1:1.05
Lovat's climbing mouse	-	6	-	-	0:6
African dormice	-	-	-	2	0:2
Crested or maned rat	-	1	-	-	0:1
African giant shrew	1	5	2	-	1:1.67
Bailey shrew	3	1	-	-	3:1
Smoky white-toothed shrew	2	3	-	3	1:3
Total	191	209	274	285	1:1.06
Relative abundance (%)	19.91	21.8	28.57	29.72	48.48:51.51
Trap success (%)	7.69	8.41	11.03	11.47	9.36: 9.9

The present study recorded a high number of adult small mammals, and fewer juveniles in between the trapping seasons, times and years (Fig. 6). However, there was no significant difference in the age groups between seasons (χ^2=2.791, df=1, P>0.05), trapping times (χ^2=2.791, df=2, P>0.05), and trapping years (χ^2=1.92, df=1, P>0.05). Short tailed brush−furred rat (χ^2=9.92, df=2, P<0.05), Awash multimammate mouse (χ^2=2.79, df=2, P<0.05) and *Murid* spp. *A* (χ^2=3.88, df=2, P<0.05) were the only rodent species that showed a significant difference in their age structure between the seasons.

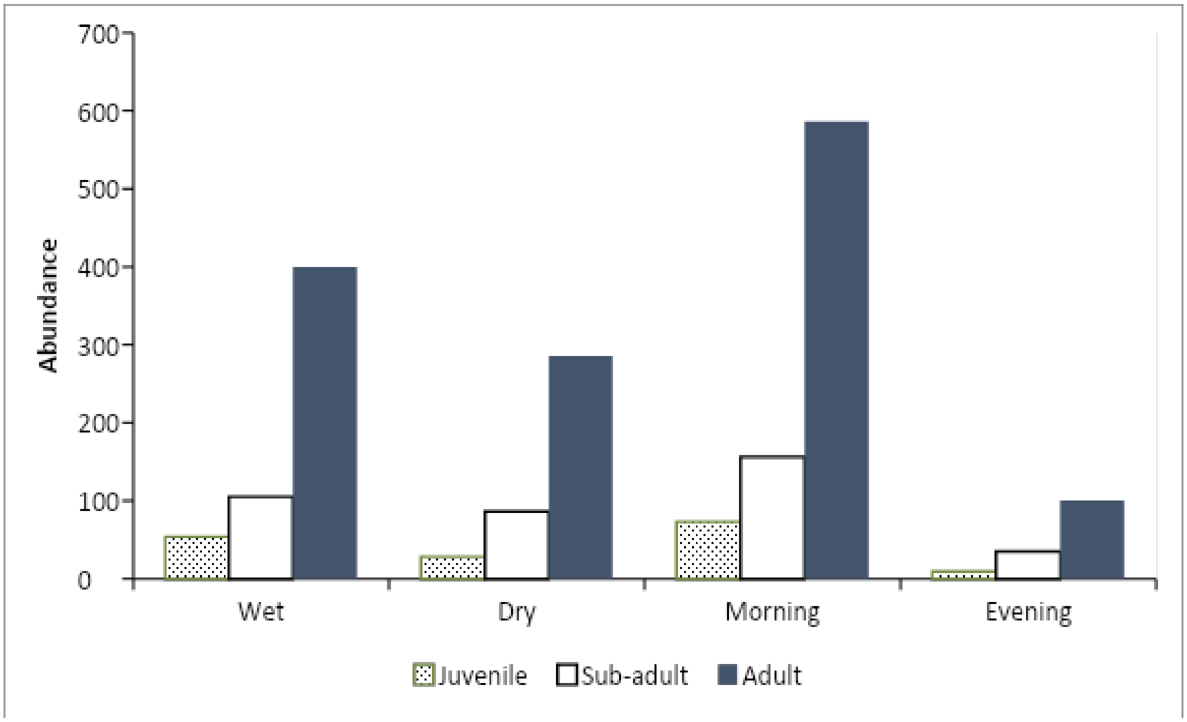

Figure 6. Temporal variations in age structure of small mammals in Wenchi montane forests.

The total abundance of small mammals was higher in all habitat types during the dry seasons than wet seasons, except in Albesa Forest. Statistically, a significant variation was observed in the spatial distribution of small mammals between seasons (χ^2=30.11, df=5, P<0.05). Lakeshore Forest habitat yielded the highest proportions of small mammals during the dry (27.01%) and the wet (28.75%) seasons. The lowest figure of small mammals was trapped from *Erica* Forest habitat in both seasons (Table 12). There was also a significant difference in the capture of small mammals between times of the day across the habitat types (χ^2=12.917, df=5, P<0.05).

Multimammate mouse (χ^2=34.40, df=4, P<0.05), Awash multimammate mouse (χ^2=14.30, df=3, P<0.05), Yellow spotted brush−furred rat (χ^2=10.357, df=4, P<0.05) and Short tailed brush−furred rat (χ^2=11.15, df=2, P<0.05) were the only rodent species that showed a significant difference in distribution between the seasons across the habitat types. More small mammals were captured during the morning trapping sessions than the evening across the habitat types.

Table 12. Seasonal abundance of small mammals in the study habitats.

Habitats	Seasons		Total	Trapping nights	Trap success	Relative abundance
	Wet	Dry				
HW	66	78	144	828	17.39	15.01
QF	78	127	194	828	23.43	20.23
LSF	115	151	266	828	32.12	27.73
EF	15	26	41	828	4.9	4.27
ES	42	103	145	828	17.51	15.12
AF	95	74	169	828	20.41	19.62
Total	400	559	959	4968	19.30	100

Small mammal density and trap success also varied between the seasons and habitat types. Small mammals had higher density during the dry seasons (83.33 ha^{-1}) than wet seasons (59.35 ha^{-1}). The highest density was registered in Lakeshore Forest (135.71 ha^{-1}) followed by Qibate Forest (118.36 ha^{-1}) during the dry seasons. The lowest density (15.30 ha^{-1}) was recorded from *Erica* Forest during the wet seasons. The overall trap success of small mammals was 19.30. The highest trap success (90.47) was recorded from Lakeshore Forest, while *Erica* Forest (10.20) was the least (Table 13**)**.

Table 13. Seasonality of small mammal density and trap success across the habitats.

Habitat	Season	Total captured	Density (ha^{-1})	Trapping nights	Trap success
HW	Wet	58	59.18	147	39.45
	Dry	57	58.16	147	38.77
QF	Wet	62	63.26	147	42.17
	Dry	116	118.36	147	78.91
LSF	Wet	102	104.08	147	69.38
	Dry	133	135.71	147	90.47
EF	Wet	15	15.30	147	10.20
	Dry	20	20.40	147	13.60
ES	Wet	35	35.71	147	23.8
	Dry	93	94.89	147	63.26
AF	Wet	75	76.53	147	51.0
	Dry	70	71.42	147	47.61

4.6. Snap trapped rodents

The present study trapped 118 rodent individuals belonging to eight species in 1,440 trapping nights. No insectivores were trapped using snap traps. Among the snap trapped species, Multimammate mouse and White footed mouse were the two dominant species represented by 38 and 36 individuals, respectively. Abyssinian grass rat was the least abundant species with only a single snap trapped individual (Table 14). Statistically, a significant difference was observed in the abundance of snap trapped small mammal species (χ^2=42.09, df=6, P<0.05).

Table 14. Spatial distribution and total capture of snap trapped small mammals.

Species	Habitat type						
	HW	QF	LSF	EF	ES	AF	Total
Abyssinian grass rat	−	−	−	−	1	−	1
Yellow spotted brush−furred rat	3	−	4	4	−	4	15
Ethiopian forest brush−furred rat	2	1	6	−	−	−	9
Awash multimammate mouse	−	−	2	2	−	−	4
Multimammate mouse	11	7	8	2	4	6	38
Short tailed brush−furred rat	3	−	−	−	2	4	9
Murid spp. *A*	−	−	−	−	6	−	6
Whited footed mouse	10	4	11	2	−	9	36
Total trapped	29	12	31	6	17	23	118

Measurements of external body parts and body weight were taken from 112 snap trapped rodents belonging to 7 species (Table 15). Adult rodents are the only small mammals that were considered for morphometric measurements. These measurements were also used for taxonomic identification purposes. The highest body weight was registered for Yellow spotted brush−furred rat and *Murid* spp. *A.*, while White footed mouse scored the highest head and body length and Short tailed brush−furred rat was the least.

Table 15. Body measurements of snap trapped small mammals (HBL= Head-Body Length, BW= Body Weight, HFL= Hind Foot Length, EL= Ear Length, TL= Tail Length).

Species	N	Body measurement				
		BW	HBL	TL	EL	HFL
Abyssinian grass rat	1	80g	14.2cm	12.1cm	1.7cm	2.5cm
Yellow spotted brush−furred rat	15	50g	12.5cm	6.5cm	2.2cm	2.2cm
Ethiopian forest brush−furred rat	9	45g	12cm	7.5cm	2.1cm	2.2cm
Awash multimammate mouse	4	60g	13.2cm	11.6cm	1.8cm	2.4cm
Multimammate mouse	38	56g	13.6cm	11.7cm	1.8cm	2.2cm
Short tailed brush−furred rat	9	49g	12.3cm	6.6cm	1.7cm	2.2cm
Whited footed mouse	36	55g	14.7cm	14.9cm	2.5cm	2.3cm

4.7. Reproductive conditions and embryo count

The reproductive conditions of 890 rodents (469 males and 421 females) were examined. Most females (56 %) had perforated vagina, while 18.76 % had imperforated. The majority of the males (82.30 %) had also enlarged scrotum, and only in 6.1 % the scrotum was not enlarged. There was a significant variation in the reproductive conditions of rodents (χ^2=224.448, df=5, P<0.05).

Embryo count was carried out for 38 pregnant rodents belonging to six species in both wet and dry seasons (Table 16). Compared to the dry season (13), higher pregnant females were trapped during the wet season (25). The total number of counted embryos varied among the species and between seasons. A relatively greater number of embryos was counted during the wet season than the dry seasons. Multimammate mouse accounted for the highest number of embryos (12), while the lowest embryo count was recorded in *Lophuromys* assemblages.

Table 16. Seasonal variations of embryo count in pregnant rodents.

Species	Season	No of pregnant individuals	No of embryo counted
Yellow spotted brush−furred rat	Dry	2	2
	Wet	3	2–4
Ethiopian forest brush−furred rat	Dry	1	2
	Wet	2	2–4
Awash multimammate mouse	Dry	–	–
	Wet	2	8
Multimammate mouse	Dry	4	7-10
	Wet	8	8–12
Short tailed brush−furred rat	Dry	2	2
	Wet	3	2–3
White footed mouse	Dry	4	5–8
	Wet	7	4–6

4.8. Stomach content analysis

Stomach content analysis was carried out on 111 individuals of six rodent species. The proportion of food items in the diet of rodents fluctuated between species and seasons (Table 17). Most rodent species displayed omnivorous feeding habits. However, omnivorous rodents also relied more on plants (71.1%) than animal matters (19.69%). From plant materials, seeds were the highest food components (39.18%) of rodents.

Table 17. Stomach content analysis of snap trapped rodents (DS= Dicot seed, MS= Monocot seed, LG= Leaves and grasses, AC=Animal components, UC=Unidentified components).

Species	Season	Stomach sample	Food item (%)				
			MS	DS	LG	AC	UC
Yellow spotted	Dry	8	13.36	10.73	16. 47	45.13	14.31
brush−furred rat	Wet	7	15. 45	11. 49	17. 55	46.69	8. 82
Ethiopian forest	Dry	4	16.95	12.58	23.32	31.89	15.26
brush−furred rat	Wet	5	15.28	13.39	24.20	34.28	12.85
Awash multimammate	Dry	5	14.24	11.36	56.47	8.38	9.55
mouse	Wet	4	13.85	12.15	59.20	4.62	10.21
Multimammate mouse	Dry	2	32. 85	28. 26	20.95	9.49	8.45
	Wet	2	18.20	19. 17	38.42	16. 84	7.37
Short tailed	Dry	20	29.83	31.37	29.73	5.49	4.58
brush−furred rat	Wet	18	22.73	23.36	35.82	15.82	3.27
White footed mouse	Dry	20	23.71	34.54	27.32	6.60	7.83
	Wet	16	21.56	25.86	33.61	10.72	8.14

Some rodents also showed a preferential feeding habit. For instance, Yellow spotted brush−furred rat and Short tailed brush−furred rat were more reliant on animal matters, while Ethiopian forest brush−furred rat preferred leaves and grasses than any other plant parts in its feedings. Multimammate mouse also preferred seeds (53.44%) more than any other available food item. A relatively higher percentage of plant materials were recovered from the stomach content of most rodents during the wet season than the dry season.

More specifically, leaves and grasses were relatively higher in the diet of rodents during the wet than the dry season. In contrast, most rodents consumed seeds at a higher rate in dry season than wet season. Rodents also consumed animal matter at a higher rate during the wet season than in the dry seasons.

4.9. Questionnaire survey

Out of the 383 studied participants, 329 (84.8%) were males and 54 (15.2%) were females. The majority of the respondents (82.2%) were between 20 and 50 age ranges. Nearly half (47.8%) of the study participants were not registered for any formal education, while 36.9% attended a primary education. Majority of the respondents (86.5%) had between 5 and 10 family sizes, while the remaining had also at least 3 and above family members.

The respondents spent from 5 years to more than 50 years in the area on farming. Most of the respondents (78.2%) had a farmland size below one to two hectares, while only 7.3% of them had more than three hectares. Most (84.8%) of the respondents supported their livelihoods through mixed farming practices. Only 15.2% of the respondents generated additional income through ecotourism (Table 18).

Crop and livestock productions are the chief income sources for the farmers in Wenchi highlands. The major crop types grown in the study area are enset, barley, potato and wheat. Barley and enset were the two chief crop types produced by all the farmers. In addition to these two crops, wheat and potato were produced in relatively lower and upland areas, respectively.

4.9.1. Crop pest rodents

Results from farmers' interviews and indirect observations showed that rodents were the major crop pests in the area. Abyssinian grass rat, Multimammate mouse, Awash multimammate mouse, Porcupine and African mole rat were the five rodent pest species recorded from their occurrences in the neighbouring natural habitats, indirect evidence and the surrounding community reports. The first three pests were live and snap trapped from the adjoining forest remnants, while the remaining two were documented through indirect evidence such as porcupine quills and mole hills, and reports from the surrounding community. There was no significant variation in crop damage and forms of rodent management among the villages, age groups, the family size, and education background of the study participants.

Table 18. Socio–demographic characteristics of farmers.

Variables		No. of respondents	Percentage (%)
Sex	Male	329	84.8
	Female	54	15.2
Age in years	20–30	99	26.07
	31–40	134	34.93
	41–50	82	21.26
	>50	68	17.72
Educational status	Illiterate	183	47.84
	Primary education	140	36.96
	Secondary education	21	15.18
Family size	<5	113	29.62
	5–10	219	56.96
	>10	51	13.41
Farming years	<10	45	12.4
	10–20	88	22.78
	>20	250	64.81
Farmland size	<1ha	211	54.43
	1–2ha	90	23.79
	2.1–3ha	55	14.43
	>3ha	27	7.34
Economic activity	Ecotourism	54	15.18
	Mixed farming	329	84.82

Farmers in the study area believed that rodents are useless and damaging creatures. There was no significant difference in the attitude of farmers towards rodents based on their sex, educational levels, age and duration in the study area. The respondents cited crop damage, disturbance, food contamination and damage to human properties as the most rodent inflicted problems in the area.

Crop damage (38.7%) and damage to human properties (27.9%) were the two predominant rodent related problems in the area (Table 19). There was a significant difference in the types of rodent damage in the study area (χ^2=112.698, df=3, P<0.05).

Table 19. Types of rodent damage in Wenchi highlands.

Villages	No. households	Rodent damage (%)			
		Crops	Properties	Contamination	Disturbing
Haro Wenchi	103	40.2	23.8	19.4	16.4
Waldo Telfami	94	41	28.5	17.8	12.5
Cabo Sansalati	82	33.3	31.2	24.4	11.1
Azar Qeransa	104	40.6	28.1	18.5	12.5
Total	383	38.7	27.9	20	13.1

Most of the respondents claimed the vulnerability of all the crops grown in the area to rodent damage. However, barley (57.5%) was reported as the most affected crop by rodents followed by root crops (Table 20). Mice and rats damage barley and wheat, while mole rats and porcupines damage enset and potato. There was a significant variation among the major crop types susceptibility to rodent pest attack (χ^2=143.26, df=3, P<0.05).

Table 20. Types of crops grown and their susceptibility to rodent attack.

Villages	No. of households	Damage due to rodent pests (%)			
		Barley	Enset	Potato	Wheat
Haro Wenchi	103	52.23	19.40	26.86	4.47
Waldo Telfami	94	48.21	16.07	23.21	12.5
Cabo Sansalati	82	51.11	33.33	26.66	11.11
Azar Qeransa	104	43.75	18.75	34.37	6.25
Total	383	57.5	13.5	23.0	6.0

The annual crop yield varied among the farmers in relation to their farmland size. Most of the farmers, 54.5% obtain a very low amount of crop yield, which is less than 5 quintals on average. Only a few farmers (21.7%) harvested more than 15 quintals yields on average (Fig. 7). There was statistically a significant difference in the annual crop yields among farmers (χ^2=214. 451, df=4, P<0.05).

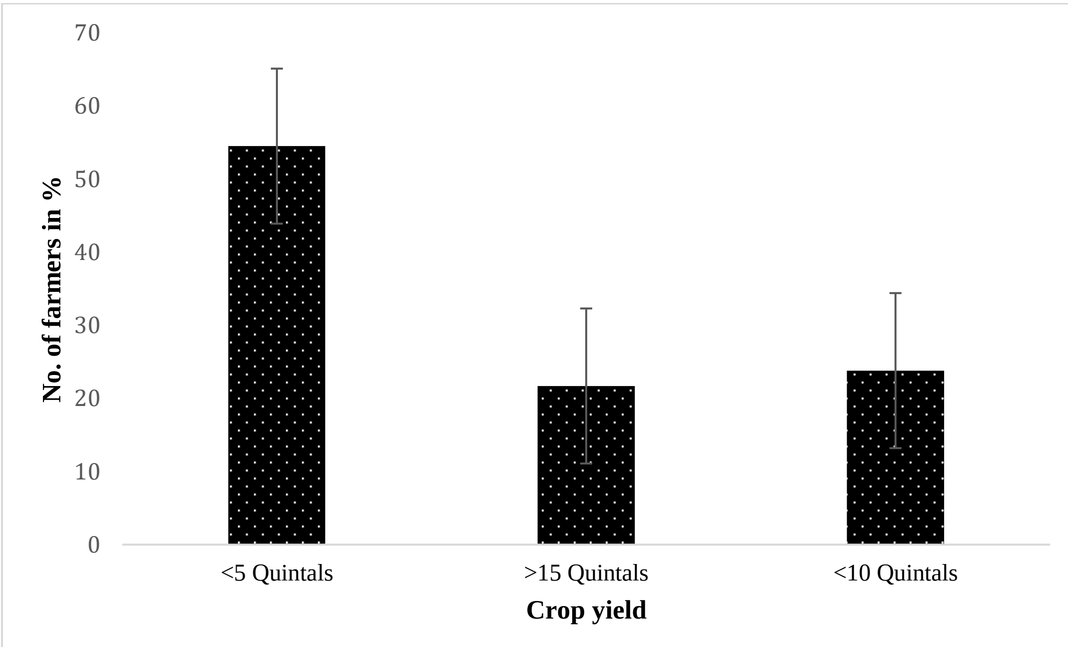

Figure 7. Average annual crop yield of the farmers in the study area.

Farmers also crudely estimated crop losses due to rodent pests. Most respondents (74.5%) estimated an average of 1.5 quintals of crops might be damaged by rodents in the storage. However, they were unable to figuratively estimate rodent damage in the crop fields. The level of rodent crop damage in the area is generally high. Most of the respondents (87.4%) associated a high crop damage to rodent pests in the area. Only less than 10% of the farmers reported low crop damage by rodent pests (Fig. 8). Statistically, a significant variation was observed in the responses of farmers on the level of crop damage by rodents (χ^2=196. 371, df=2, P<0.05).

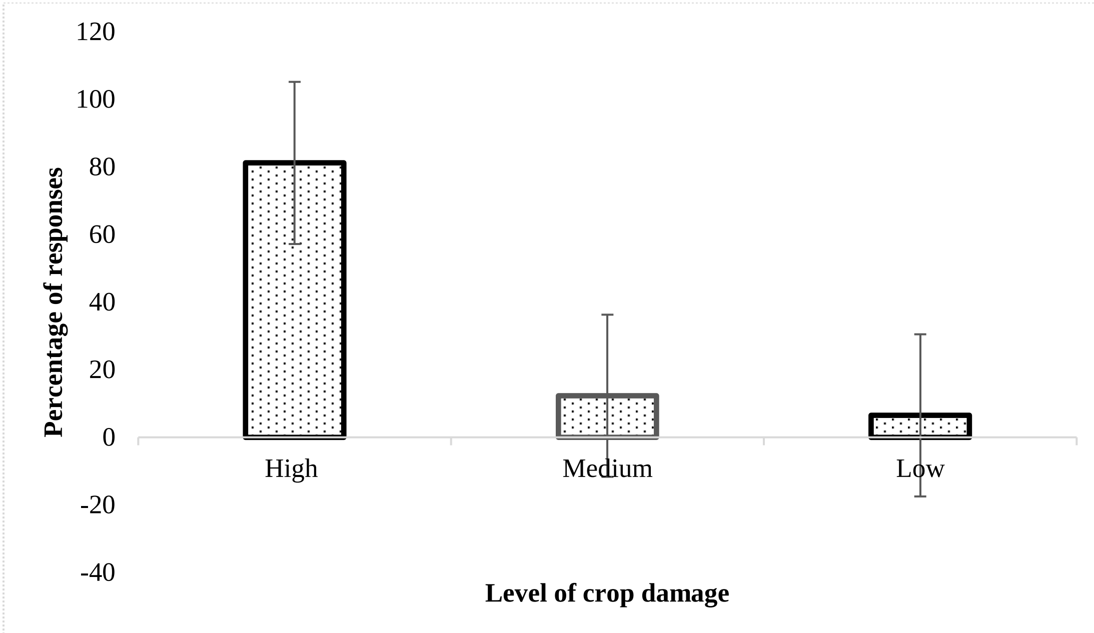

Figure 8. Level of crop loss due to rodents in the study area.

The majority of farmers (72.5%) reported a seasonal variation of rodent damaging behaviour in the houses and crop fields. House rodent infestation was higher during the wet seasons, but the damage was significant during the dry season in the crop fields. Most farmers reported regular presence of rodent damage (in every cropping season/year) in their locality (Table 21). The responses of farmers on the occurrence frequency of rodent pests varied significantly (χ^2=193.826, df=2, $P<0.05$).

Table 21. Frequency of rodent crop damage in Wenchi highlands.

Villages	No. of households	Frequency of crop damage (%)		
		Regular	Frequent	Occasional
Haro Wenchi	103	56.71	25.37	17.1
Waldo Telfami	94	41.07	26.78	32.14
Cabo Sansalati	82	44.44	24.44	33.33
Azar Qeransa	104	43.75	21.87	32.37
Total	383	47.5	25.0	28.0

Crop damage by rodent pests occurred both during post−harvest and pre−harvest stages. Farmers identified rodent damage at different cropping stages starting from sowing to harvesting for different crop types. They have noted serious damage on barley (42.5%) and enset (35%) crops during maturity. These crops were also vulnerable to rodent damage during vegetative and booting stages. Potatoes were highly damaged both during sowing and after their maturity (Fig. 9). There was a significant difference in crop damage between the cropping phases (χ^2=110.82, df=2, P<0.05).

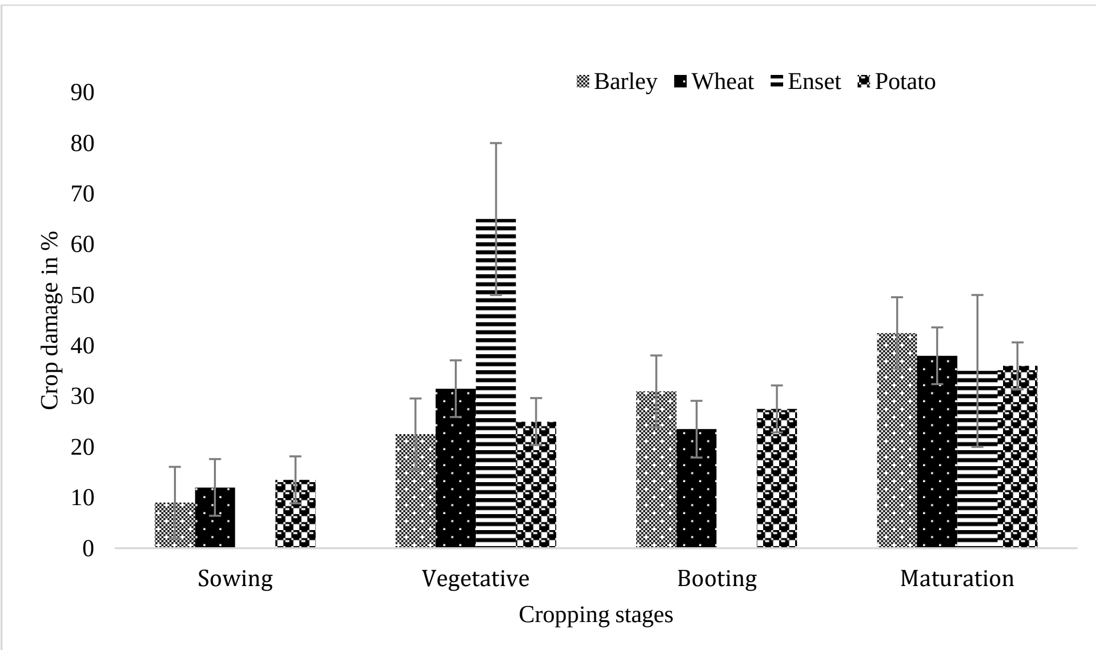

Figure 9. Rodent crop damage in different cropping stages in the study area.

Most farmers in the study area supervise their farms occasionally before harvesting and rarely after harvesting. There was no significant variation on farm supervision practices among farmers (χ^2=1.691, df =1, P>0.05). Farmers assess and detect the presence and damage of rodents in the storage and crop fields using different mechanisms. Observation of damaged seeds (32%), damaged stores (27%) and rodent droppings (23%) were the most employed methods to detect the damage or/and presence of rodents in the house. Stem cut of standing crops (73.5%) was the most used assessment method of rodent damage detection in the crop fields (Fig.10).

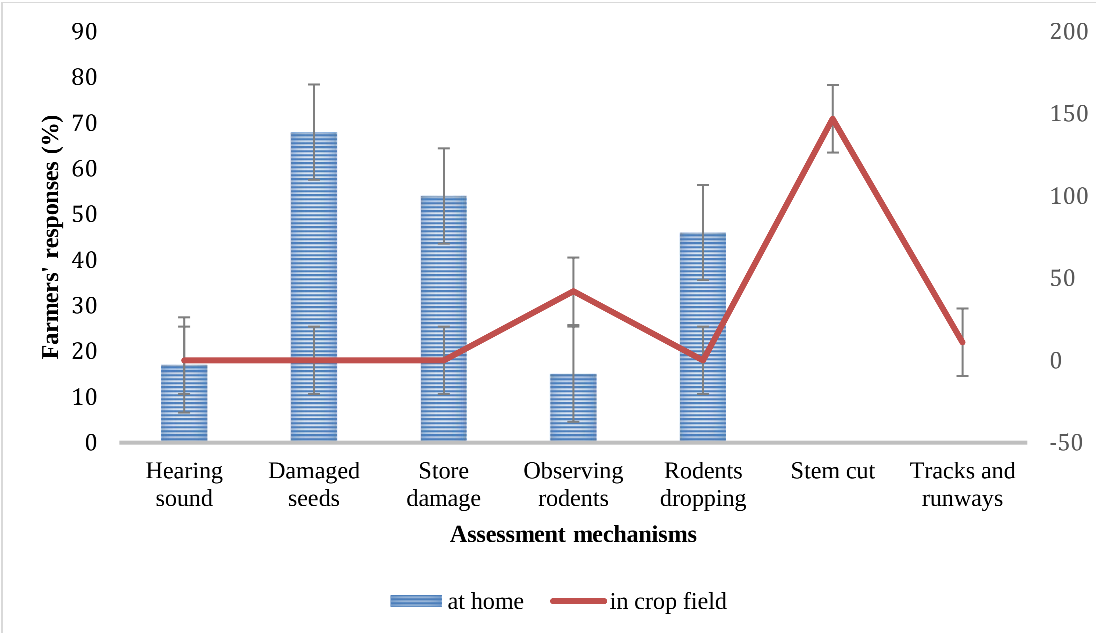

Figure 10. Assessment mechanisms of farmers on rodent damage

Farmers in the study area employed diverse management approaches to control rodent damage in storage (Table 22). They mostly used domestic cats (53.73%) followed by trappings (22.64%) to contain rodent damage in storage. A significant variation was shown among the rodent pest preventing mechanisms used by the respondents during storage (χ^2=89.63, df=3, P<0.05). Trapping and hunting were employed to control rodent damage on enset and potatoes. However, none of the interviewed farmers employed any management strategies in the barley crop fields. Farmers in the study area claimed that rodenticides were not safe, and rodents have developed an adaptation to avoid rodenticides and traps.

Table 22. Rodent pest management techniques used in the study area during storage.

Villages	No. of households	Management strategies (%)			
		Cats	Trapping	Rodenticide	Hunting
Haro Wenchi	103	53.73	28.35	7.46	10.44
Waldo Telfami	94	37.5	28.57	12.5	21.42
Cabo Sansalati	82	40.0	22.22	28.89	8.89
Azar Qeransa	104	34.37	25.0	21.87	18.75
Total	383	43.0	22.0	16.0	14.5

4.9.2. Resource utilizations and conservation challenges

4.9.2.1. Responses of local people on resource utilizations

Majority of the current study respondents used the natural forests as sources of firewood (70.19%) and for cattle grazing (63.51%). Almost all of the respondents obtained firewood from the montane forest remnants. However, there was no respondent that obtained charcoal from the forest remnants. The local community also used forest products and thatch grass as raw materials for house and fence constructions.

Local communities also obtained some food items (wild honey and wild edible fruits) and other benefits in the form of animal fodder, medicinal plants, hot spring for bathing and mineral water for drinking, traditional farm tools and as a source of income by selling thatching grass and firewood (Table 23). Statistically, a significant difference was observed among the forms of natural resource utilizations by the respondents (χ^2=87.94, df=4, P<0.05).

Table 23. Forms of resource utilizations by the local people.

Villages	No. of participants	Forms of natural resource exploitations (%)				
		Grazing area	Firewood	Construction materials	Food sources	Other benefits
Haro Wenchi	103	81.74	96.10	46.53	38.96	43.75
Waldo Telfami	94	74.17	71.88	24.38	23.51	21.62
Cabo Sansalati	82	65.72	52.26	41.45	35.55	12.14
Azar Qeransa	104	32.43	60.53	33.16	12.32	8.21
Total	383	65.71	70.19	36.38	27.58	21.43

The majority of the study respondents (53.84%) used the natural habitats for livestock grazing areas during the wetter than dryer seasons, and for two to four months. About 38.11% of the respondents, however, use the forest habitats for livestock grazing throughout the year. There were also a small number of households (12.25%) that did not use the forest habitats as grazing areas (Table 24). Statistically, a significant difference was observed in livestock grazing intensity of the natural habitats by the respondents (χ^2=137.70, df=2, P<0.05).

Cattle, small ruminants (sheep and goat), and horses and/or donkey are the major types of livestock reared by the Wenchi highlands community. Sheep (on average, 7 per household) are the most produced livestock in the area followed by cattle (averagely, 5 per household).

Table 24. Type and number of livestock and grazing intensity on natural habitats.

Villages	No. of households	Livestock/households			Grazing intensity		
		Cattle	Sheep	Horses/ Donkey	Year round	Wet season	Never used
Haro Wenchi	103	5	8	2	46.24	53.86	12.80
Waldo Telfami	383	4	6	2	25.81	40.73	10.62
Cabo Sansalati	82	6	6	1	38.65	48.42	13.37
Azar Qeransa	104	5	10	2	41.74	54. 65	12.24
Average	383	5	7.5	1.75	38.11	50.32	12.25

4.9.2.2. Local community attitudes towards conservation

Majority of the respondents had positive attitudes (56.47%) and the least number (12.14%) had no idea towards conservation of biodiversity in Wenchi highlands (Table 25). A significant difference was observed in the attitudes of the respondents (χ^2=110.92, df=2, P<0.05). Individuals that have a positive attitude considered the economical, ecological and aesthetic values of the natural environments, and most of them were from Haro Wenchi village.

Table 25. Local community attitudes towards biodiversity conservation.

Villages	No. of respondents	Local community attitudes (%)		
		Positive	Negative	Neutral
Haro Wenchi	103	71.55	26.47	15.72
Waldo Telfami	94	52.34	35.32	12.16
Cabo Sansalati	82	55.71	33.54	11.24
Azar Qeransa	104	46.28	30.41	9.43
Total	383	56.47	31.39	12.14

The local people also reflected on the existing conservation threats and their severity levels (Table 26). The majority of the respondents (40%) stated that Wenchi natural habitats and their biodiversity are highly threatened. About 27% of the respondents, however, rated the threats at a low level. There was a significant difference on the severity level of conservation threats (χ^2=243.519, df=6, $P < 0.05$).

Table 26. Biodiversity threats and severity levels in Wenchi highlands (HW: Haro Wenchi).

Threat type	No. of respondents	Severity impact level (%)			Areas of occurrences
		High	Medium	Low	
Overgrazing	383	40.62	42.25	17.13	In all villages
Human settlement	383	45.34	33.14	20.52	In all villages
Farmland expansions	383	56.53	27.83	15.64	In all villages
Fuelwood collection	383	63.37	24.15	12.48	In all villages
Exotic plantations	383	18.27	24.36	55.74	Predominantly in HW
Human induced fire	383	21.63	26.27	52.10	Predominantly in HW
Construction materials	383	34.58	48.75	16.67	In all villages
Total	383	32.39	27.57	45.04	

4.9.2.3. Conservation challenges from FGD

The key informants recognized the importance of the forest remnants to the local community as a source of firewood, construction materials, grasses for thatching and animal fodder, and livestock grazing areas. The discussants also believed that the forest coverage of the area is alarmingly shrinking, many wild animals are exterminated and the climatic conditions of the area is changing with time. They suggested that these problems are the consequence of irresponsible and unsustainable use of the natural forests by the local people.

Firewood collection, farmland expansions, human settlement and overgrazing were the predominant biodiversity threats identified by the discussants. Exotic plantations, construction materials and human induced fire were the remaining conservation challenges raised during FGD. The discussants consider land grabbing along the lake shores as a good opportunity for the local community than a threat to biodiversity.

4.9.2.4. Conservation challenges from field observations

Direct field observations confirmed the biodiversity threats mentioned by the respondents and key informants. Soil erosion, land grabbing around lakeshores, insufficient information and monitoring, and household poverty due to small land size of the farmers were additionally recorded conservation challenges to Wenchi biodiversity (Table 27). Fuelwood collection, farming land expansions and overgrazing were relatively the most commonly observed biodiversity threats with varying intensity among the forest remnants.

Table 27. Observed conservation challenges in Wenchi montane forests.

Challenges	Forms of the threats	Impacted habitat	Possible causes
Land use-changes	Farming expansions Human settlement	All habitats	Farmland shortage Population growth
Fuelwood collection	Firewood collection	All habitats	High demand of energy Economic sources
Soil erosion	Gully erosion affected many areas	*Hagenia* and shrubland habitats	Clearing of forests Road construction
Human–induced fire	*Erica* shrubs set on fire	*Erica* shrubland	Farmlands expansion
Land grabbing	Building houses	Lakeshore forests	Its natural beauty
Overgrazing	Year-round grazing	Almost all	Shortage of options
Exotic plants plantations	*Eucalyptus* spp. is replacing *Erica* spp.	*Erica* shrubland	High demands and prices of this plant
Insufficient data and monitoring	No scientific information	All areas	Ignorance and poor conservation policy
Poverty	Small size land holding	All areas	Household poverty

The area on the entry to Lake Wenchi and downstream forests is dominated by the matrix of *Hagenia* trees and absorbs maximum anthropogenic pressures as it is at proximate distance to the residential areas. It was constantly accessed by the local communities for fuelwood collection and cattle grazing. This area is also threatened by fragmentation and soil erosion (Suppl. b).

Qibate Forest was impacted by systemic firewood collection, overgrazing and extraction of forest products for other purposes. The claims by the local communities and some key informants that this forest is rarely exploited and local militias inspect the exploitations was false. In contrast, individuals were routinely observed carrying forest products intended for construction purposes and firewood during the study periods. Furthermore, grounded trees for firewood exploitation and construction uses were also encountered in the forest (Suppl. a). On average, more than ten firewood exploiters were seen in this forest during the wet season (Table 28).

Table 28. Trends of firewood exploitation in Wenchi montane forests.

Exploited forests	No. of exploiters		Forms of exploitation	Purposes
	Wet	Dry		
Qibate Forest	50	23	Individually Individuals assisted by children and donkeys In groups of 4 to 6 individuals	Commercial purpose House consumption
Albesa Forest	18	11	Women assisted by children and donkeys	Commercial purpose House consumption
Lakeshore Forest	12	6	Both men and women aided by boat In groups of 2 to 3 individuals	House consumption
Erica shrubland	4	-	Individually	House consumption

Albesa Forest was the second most exploited natural habitat, while *Erica* shrubland was the least. Firewood exploiters were either for home consumption or as a source of income by selling it to the urban residents who are in much need of it, particularly in the winter seasons. The former usually carry on their back to satisfy their household needs, while the latter were observed in numbers and assisted by children and donkeys. Lakeshore forest was also threatened by firewood extraction where firewood collections were aided by locally made boats. There was also an incident of charcoal production at the outskirts of Albesa Forest, which was the first observation in Wenchi highlands.

4.9.2.5. Conservation actions and opportunities

The respondents in Haro Wenchi village claimed that there is a relatively suitable conservation practices and an increase in the local community awareness after the establishment of ecotourism association in the area. There is also job creation in this village. According to these informants, cutting of live and indigenous trees, and exploitations of forest products for construction materials from Qibate Forest are prohibited as a means of forest conservation. They also suggested that local militias are responsible to inspect and control such malpractices.

The participants also recognized the needs of conservation priorities for the forest remnants through integrated conservation and development project options such as ecotourism. They also recommended the regional and federal governments to develop conservation laws and directions, introduce initiatives of replanting deforested areas, demarcate some of the areas either as forest priorities or reserve area, scale up environmentally friendly investments, create conservation awareness, and increase the local community involvements. The construction of terracing in the uplands through community participation was an encouraging effort in reducing the effects of erosion and fragmentation in the lower grounds. Such soil conservation activities should also be scaled up to the remaining areas.

The unique natural topographic beauty, rich flora and faunas, government led ecotourism development project, recent national and global recognitions of the area, and positive attitudes of the local people towards the habitats and its conservation were the potential biodiversity conservation opportunities in Wenchi highlands (Table 29). Some of these opportunities were shared among the forest remnants. However, most of them were limited to forest remnants located in Lake Wenchi watershed. For instance, Albesa Forest is not privileged to gain the recognition, and ecotourism project that other forest remnants cherished.

Table 29. Possible conservation opportunities for Wenchi highlands biodiversity.

Opportunities	Details of these opportunities	Supportive evidences
Rich faunas and floras	Indigenous and endemic plants Several endemic small mammals *Colobus guereza* and birds	Abebe Tufa *et al*. (2020) Gemechu Shale *et al*. (2014) Direct observation
Unique natural topographic features	Lake Wenchi Hot springs and mineral waters Monastery and a forested hilly highland area	Gemechu Shale *et al*. (2014), Fasil Degefu & Schagerl, (2015), Abebe Tufa *et al*., (2020), Direct observation
Recent national and global recognitions	Best national tourism destination area in Oromia and Best tourist village of 2021 of UNWTO	OTC UNWTO (2021)
National development project	One of the three nationally launched ecotourism projects	Abebe Tufa *et al*. (2022) National and regional medias
Local people positive attitudes	Most appreciated conservation efforts and willing to cooperate	Abebe Tufa *et al*. (2022) Interviews and questionnaires

5. DISCUSSION

5.1. Species composition and abundance

In the present study, we recorded diverse non-volant small mammals in the study area, which is one of high ground areas in central Ethiopia. This supports the general patterns of spatial and environmental preferences of small mammals (Yalden & Largen, 1992; Torre, 2004; Lavrenchenko & Afework Bekele, 2017), and the confinement of small mammals to Ethiopian highlands (Yalden & Largen, 1992; Mesele Yihune & Afework Bekele, 2012; Afework Bekele & Yalden, 2013; Lavrenchenko & Afework Bekele, 2017). The study also recorded a high number of non-volant small mammal species for a disturbed environment, and area outside protected areas. This result supports the idea that a high number of small mammal species are found outside protected areas (Caro, 2001, 2002). However, it is against the notion that protected areas are fairly helpful, and unprotected areas are rather detrimental to their inhabitants (Caro, 2002). This could be associated with an intricate interaction of several living and non−living factors in the study area.

The number of identified non-volant small mammals in the study area is high compared to several reports from other unprotected areas in Ethiopia (Zerihun Girma *et al*., 2012; Getachew Simeneh, 2016; Kostin *et al*., 2018, 2020; Bewketu Takele *et al*., 2022), and elsewhere in the world (Vazquez *et al*., 2000; Richard *et al*., 2020). It is more than double figure compared to reports from some protected areas (Mesele Yihune & Afework Bekele, 2012; Dawd Yimer & Solomon Yirga, 2013; Addishiwot Fekdu *et al*., 2015; Alembrhan Assefa & Srinivasulu, 2019), and comparable to a report of Demeke Datiko & Afework Bekele (2014) from Chebera Churchura National Park. The topographic, climatic nature and vegetation structure of this area are some of the most probable explanations to a relatively high species diversity. As noted by Caro (2001), a low predator density and adequate food availability may also contribute to the small mammal diversity in the study area.

The total number of identified non-volant small mammals in the current study is still a way behind the reports from some protected areas − Alatish National Park (Tadesse Habtamu & Afework Bekele, 2012) and Nechisar National Park (Sintayehu Workeneh *et al*., 2011). This discrepancy might be due to the difference in the habitat structure, resource distribution, climatic conditions, and species adaptability between these areas (Tadesse Habtamu & Afework Bekele, 2008; Mohammed Kasso & Afework Bekele, 2017; Alembrhan Assefa & Srinivasulu, 2019).

The present study registered a high number of endemic non-volant small mammal species (9 species) in Wenchi highlands. This is congruent to the fact that Ethiopian highlands are hot spots and centre of small mammal endemism (Yalden & Largen, 1992; Bryja *et al*., 2017; Lavrenchenko & Afework Bekele, 2017), and shows a good reason for the uniqueness of the area. This high endemism in the area is directly associated with the high elevation levels as indicated by Yalden & Largen (1992).

Small mammals endemicity in the present study is very high as compared to the reports from both protected and unprotected areas in the northern parts of Ethiopia (Eshetu Moges *et al*., 2016; Getachew Simeneh, 2016; Kostin *et al*., 2020; Bewketu Takele *et al*., 2021), but it is a way behind to the Chilalo–Galama Mountain ranges (Mohammed Kasso *et al*., 2010) and Arsi Mountains (Kostin *et al*., 2018). Such geographic discrepancy in species endemism might be associated with the difference in the habitat quality and productivity of the two parts of the country (Bryja *et al*., 2017). The southern parts have numerous isolated and heterogeneous high grounds that may allow geographic speciation to happen and hosts more endemic small mammals than its northern counterparts.

Studies have suggested that small mammals exhibit different adaptations to their environment (Torre, 2004; Barragan *et al*., 2010; Camacho−Sanchez *et al*., 2019), and the highest species diversity of small mammals is registered from Albesa Forest. This is attributed to the spatial factors (Camacho−Sanchez *et al*., 2019), the habitat structure and complexity (Mesele Yihune & Afework Bekele, 2012; Yonas Terefe & Fikrasilasie Samuel, 2015), quality of food and vegetation cover, diverse microhabitats, and the surrounding landscape (Torre, 2004; Horncastle *et al*., 2019) that this habitat provides.

The lowest small mammal species diversity is from Qibate Forest. The result disagrees with the reports of Afework Bekele (1996) and Zerihun Girma *et al*. (2012), where *Erica* scrub is more specious. This may be because of the diminishing in the size and structure of forest, less diverse micro-habitats, and intensive grazing by livestock of this habitat (Horncastle *et al*., 2019). This habitat is also an open access area for cattle grazing, fuelwood collection and other related human disturbances.

In the present study, the overall abundance of small mammals is high in Lakeshore habitat. This is possibly associated with the vegetation structure (Pardini *et al*., 2005), high vegetative diversity and herbage production (Getachew Bantihun & Afework Bekele, 2015; Horncastle *et al*., 2019), a relatively low level of disturbance, diverse microhabitats, proximity to water sources and presence of adequate vegetation cover of this habitat (Zerihun Girma *et al*., 2012; Richard *et al*., 2020). The presence of diverse vegetation with adequate cover provides plenty of habitat choices and feeding items as well as hiding options from predators (Zerihun Girma *et al*., 2012).

Several studies from various parts of Ethiopia, however, documented a high abundance of small mammals in scrubland habitat (Afework Bekele, 1996a; Mohammed Kasso *et al*., 2010; Zerihun Girma *et al*., 2012). This discrepancy might be because of the varying degree of human interferences (Afework Bekele, 1996b), the size of forest fragments (Pardini *et al*., 2005), vegetation diversity and herbage production, and underground cover (Horncastle *et al*., 2019) of the habitats. The proximity of this habitat to water sources might be an additional quality this habitat provides than the other habitat types.

In the current study, the *Erica* scrub has supported a higher species richness. This is in agreement to the several reports in Ethiopia (Afework Bekele, 1996a; Mohammed Kasso *et al*., 2010; Zerihun Girma *et al*., 2012). However, it also contradicts with other findings (Demeke Datiko &Afework Bekele, 2014; Gezahegn Getachew *et al*., 2016; Tilahun Dinaw *et al*., 2017; Bewketu Takele *et al*., 2022), where a high number of small mammals are trapped outside shrubland habitats. Such variation may be associated to spatial factors, environmental variables, species requirements and biological interactions (Gómez−Villafañe *et al*., 2012; Lavrenchenko & Afework Bekele, 2017).

A comparable and low small mammal species richness is recorded in *Erica*, Qibate and Lakeshore Forest habitats. This agrees to the intrinsic behaviour of small mammal habitat selection based on the resources it offers (Torre, 2004). Such a low small mammal species richness and abundance in *Erica* Forest habitat may be ascribed to the sloppy landscape, a single species dominated vegetation, *Erica* trees, and a bare ground cover of this habitat (Demeke Datiko & Afework Bekele, 2014). These in turn lead to the shortage of foods and shelters while increasing small mammal vulnerability to natural predators. A low species richness of Qibate Forest maybe explained by the modification of this habitat by continuous livestock grazing, firewood exploitation and other human disturbances that could reduce the ground cover and microhabitats (Afework Bekele, 1996a; Zerihun Girma *et al*., 2012; Horncastle *et al*., 2019).

Multimammate mouse is a most common and widespread small mammal species in Wenchi montane forests. This is in agreement with the widespread distribution of this species across the Ethiopian highlands (Demeke Datiko *et al*., 2007; Getachew Bantihun & Afework Bekele, 2015; Alembrhan Assefa and Srinivasulu, 2019; Martynov *et al*., 2020). However, the finding also disagrees with other reports from different parts of the country (Afework Bekele, 1996b; Mohammed Kasso *et al*., 2010; Zerihun Girma *et al*., 2012; Bewketu Takele *et al*., 2022). This discrepancy might be associated to the difference in the geography, habitats and environmental variables among these areas.

The highest population of Multimammate mouse, White footed mouse, Awash multimammate mouse, and Ethiopian forest brush−furred rat is documented in Lakeshore Forest. This is against several reports in Ethiopia (Demeke Datiko *et al*., 2007; Sintayehu Workeneh *et al*., 2011; Demeke Datiko & Afework Bekele, 2014; Alembrhan Assefa & Srinivasulu, 2019), where these species are abundant in the farmlands and crop fields. This variation may be ascribed to a dissimilarity in the habitat preferences of these rodents, shelters and food items availability, and accessibility of these areas to humans (Lavrenchenko & Afework Bekele, 2017). More importantly, small mammal trappings for this study were restricted to natural habitats.

The present study recorded three species of brush−furred rats (*L. chrysopus*, *L. brevicaudus* and *L. flavopunctatus*). This finding is in line with the wide distribution of the genus *Lophuromys* in moist and forest highlands of central Ethiopia (Afework Bekele, 1996b; Lavrenchenko *et al*., 2001; Lavrenchenko & Afework Bekele, 2017; Bryja *et al*., 2019). The Ethiopian Forest brush−furred rat inhabited forested areas, but Short tailed brush−furred rat is largely confined to the ericaceous belt. This agrees with the finding of Lavrenchenko *et al*. (2001) and Ivlev & Lavrenchenko **(**2016).

Yellow spotted brush−furred rat was well documented throughout the study habitats. This is in agreement with the finding of Afework Bekele (1996a), and perhaps due to this rodent ability to inhabit less conducive habitat, and insectivore feeding habit (Zerihun Girma *et al*., 2012). The population of Short tailed brush−furred rat was also fairly represented in *Hagenia* woodland and Albesa Forest. This is in disagreement with the findings of Lavrenchenko *et al*. (2001) and

Lavrenchenko & Afework Bekele (2017), where Yellow spotted brush−furred rat and Short tailed brush−furred rat are confined to the forested and shrubland habitats, respectively. This disparity implies that these species were widespread in the continuous forest of this highland, and probably separated from their sister populations over time due to the fragmentation of these habitats into separate forest and scrubland habitats.

African dormice, Lovat's climbing mouse, Abyssinian grass rat, *Murid* spp. A and Yalden's rat were recorded in few numbers and from limited habitats. African dormice, Maned rat and Lovat's climbing mouse were only trapped from a single habitat, Albesa Forest, Lakeshore Forest and *Hagenia* woodland, respectively. Surprisingly, African dormice was trapped only twice, while crested or maned rat was trapped only once throughout the study periods. This is perhaps due to the imbalance between the habitat preferences of these species and the available habitat in the area. African dormice, in general, prefer dense woodlands, thickets and forests (Happold, 2013). This suggests why this species is limited to the only a relatively densely forested habitat, Albesa Forest. The low abundance of this and the other rare species in the area might also be associated with the decline in their populations along with the ongoing habitat fragmentations, losses and destructions.

Maned rat was trapped from the dry rocky forested ground of the Lakeshore Forest. This finding is in agreement with the rarity, habitat preference and distributional range of this species, which is in the centre of the country (Afework Bekele & Yalden, 2013). Lovat's climbing mouse is an endemic rodent trapped from open spaced and grassy areas of *Hagenia* woodland. This is in agreement with the species distributional range, in the upland grassland and across the Ethiopian highlands (Afework Bekele & Yalden, 2013). The low abundance of this species is also reported by Zerihun Girma *et al*. (2012). However, no species encounter was made from the shrubland habitat (Afework Bekele & Yalden, 2013). This is primarily due to the habitat need of this species is limited to a relatively dense afro−montane vegetation with high understory cover.

The present study recorded Abyssinian grass rat in very low abundance with limited distribution. This report is the fourth to document this species from the western of the great Rift Valley, and against the species distributional range, which is largely limited to the eastern Rift Valley and northern Ethiopia (Mesele Yihune & Afework Bekele, 2012; Afework Bekele & Yalden, 2013; Kostin *et al*., 2020; Bewketu Takele *et al*., 2022). A limited distribution of this species is also documented (Afework Bekele & Yalden, 2013; Bewketu Takele *et al*., 2022). The trapping of this rodent species from *Erica* scrub, and areas close to farmlands supports the pest nature of this rodent (Happold, 2013). The species also avoids heavily grazed areas and long grass–short grass mosaics (Happold, 2013; Bryja *et al*., 2017).

Porcupine and African mole rat are the two rodent species that were observed based on indirect evidence such as quills and mole hills, respectively. Porcupine was a common rodent species in the uplands and scrubby habitats as it was encountered only on one occasion at the edges of forested areas. The distribution of this species is probably impacted by the availability of food sources and concealing places. Sampled forest habitats are at a distance from main farming areas and human settlements than scrubland, and Albesa Forest that are sandwiched between human settlement and cultivation. This hypothesis is well substantiated by the farmers' appeals about the crop damages of this rodent (Kechinu Fayera, 2019, *Pers. comm*.). Rodent species belonging to the genus *Hystrix* are also capable of using diverse habitats and tolerate several anthropogenic disturbances (Happold, 2013; Gezahegn Getachew *et al*., 2016).

African mole rat is widely distributed in farming areas mainly after rainy seasons. It is a major rodent pest in high ground and farming areas (Mengesha Jirata, 2020 *Pers. comm*.). Mole hills were observed only twice in forested areas. A rise in this rodent population shortly after the rainy season and its close association to farming areas suggests that it is largely reliant on plant products that mature shortly after the rainy season. Such behaviour may be an adaptation to food availability and the way to avoid flooding from the rainy condition of the area due to percolating rainy droplets to their nests and feeding tunnels.

The current study recorded a very low population of shrews. Such encounters are within their habitat requirements, which is humid and diverse microhabitats (Li *et al*., 2015; Bryja *et al*., 2017). These shrew species are also patchily distributed with one seemingly endemic to Ethiopia. This is in agreement with the general distribution and species richness pattern of shrews (Stanley *et al*., 1998; Bryja *et al*., 2017). Such a patchy distribution and low population abundance of shrews may be because of the limited availability of shelters, food items, and their own shortcomings (Stanley *et al*., 1998; Timbuka & Kabigumila, 2006**)**. More individual shrews were recorded from the *Erica* dominated areas, and this agrees with the finding of Zerihun Girma *et al*. (2012). The confinement of these mammals to the ericaceous habitats could be because the sparse herb and shrub vegetation provide ideal habitat as cover, breeding ground and food source.

The present study recorded numerically more individuals of female rodents than males. This is in agreement with the findings of Eshetu Moges *et al*. (2016) and Beketu Takele *et al*. (2022). Such lower abundance of male individuals can be well explained by their higher mobility in search of opposite sex, and more exposure to predators. Similarly, more adult rodents are trapped than other age groups. The age structure in a population of small mammals is in direct relationship with the reproduction seasonality of that species (Tadesse Habtamu & Afework Bekele, 2008). The result is against the finding of Adugnaw Admas & Mesele Yihune (2016), where a larger number of sub−adults are trapped. This might be related to adult rodents being more active than other age groups, and the difference in the habitat characteristics of these areas.

5.2. Altitudinal gradient

Small mammal showed significant variations in species composition and abundance along the rising elevation. Similar trends have also been observed in other studies (Stanley & Kihaule, 2016; Bewketu Takele *et al*., 2022a; Richard *et al*., 2022). This might be linked to the differences in the availability of resources and shelter, the biological limits of a particular small mammal species, and changes in the environmental conditions across the altitudes (Kamenišťák *et al*., 2019). The finding of the present study is in agreement with the findings of several studies in different localities of Ethiopia (Sillero−Zubiri *et al*., 1995; Seyoum Kiros & Afework Bekele, 2022). However, it disagrees with the finding of Bewketu Takele *et al*. (2022a) from south Gondar. This variation could be due to the differences in the adaptability and species requirements and adaptations, geographical and habitat structure of the study areas.

Small mammals in the current study area displayed varying distributional patterns in species richness, diversity and abundance across altitudinal ranges. Some small mammals are more in abundance at lower grounds, while others are at higher altitudes. This is in agreement to the general distribution of small mammals along the altitudinal gradients (McCain, 2005; Bateman *et al*., 2010; Kamenišťák *et al*., 2019; Lavrenchenko & Afework Bekele, 2017; Bewketu Takele *et al*., 2022a).

Several biological and physical factors are responsible for the spatial arrangements of small mammals in each elevation zone among mountain ranges (Kasangaki *et al*., 2003; Kameništ'ák *et al*., 2019; Seyoum Kiros & Afework Bekele, 2022). Altitudes determine the vegetation, precipitation and temperature of a particular habitat (Lavrenchenko & Afework Bekele, 2017). This also indicates that altitude alone may not be the sole and final element of mammalian diversity.

Few numbers of small mammals showed a limited altitudinal distribution. Such restricted occurrences of some species to a particular altitudinal range may be attributed to the habitat preference of that species which is determined by habitat productivity, vegetation composition, competition, degree of anthropogenic disturbance, and/or grazing patterns (Timbuka & Kabigumila, 2006; Demeke Datiko & Afework Bekele, 2014; Kameništ'ák *et al*., 2019; Seyoum Kiros & Afework Bekele, 2022). However, *Crocidura* spp. were observed across the three altitudinal ranges. This confirms that different small mammal groups have different needs and tolerance capacities (Kameništ'ák *et al*., 2019; Bryja *et al*., 2017), and it is against mid−elevation abundance of shrews in Tanzania (Richard *et al*., 2022). According to Bateman *et al*. (2010), whether rodents and insectivores display a mid−altitudinal peak pattern is not known.

5.3. Population density

The population density of rodents in Wenchi montane forests showed variations in habitats, seasons and species. The mean rodent population density was 121 ha^{-1}. Several studies reported a lower density than the present study from different parts of Ethiopia (Sintayehu Workeneh *et al.*, 2011; Getachew Simeneh, 2016; Bewketu Takele *et al*., 2022b), and elsewhere in the world (Ruscoe *et al*., 2001; Wilson & Lee, 2010; Krebs *et al.*, 2011).

For instance, Sintayehu Workeneh *et al.* (2011) reported the lowest small mammal density (21 ha^{-1}) from Nechisar National Park, while Bewketu Takele *et al*. (2022b) recorded a relatively higher density (47.4 ha^{-1}) from Alemsaga Forest Priority Area in south Gondar. Such deviations might be related to the difference in habitat characteristics and trapping efforts in these studies. The current result is still lower than the reports from Ethiopia (Gezahegn Getachew, 2019, 432.6 ha^{-1}), Tanzania (Massawe *et al*., 2011, 140 ha^{-1}), New Zealand (Goldwater *et al*., 2012, 160 ha^{-1}), and Australia (Singleton *et al*., 2007, 2000 individuals ha^{-1}). Such variations in small mammal densities could be associated with the variances in predator's density, species competitions, characteristics of the study habitats, availability and suitability of food and shelter, and climatic conditions in these study areas.

The intra−specific competition among small mammals for resources can restrict their population growth through depressing their reproduction, or leading them to emigration from their habitats (Massawe *et al*., 2011). The fluctuations in the small mammal densities among studies might also be linked to the trapping techniques, the number and size of study grids, the duration of trapping nights, and the types of traps used for small mammal trapping (Singleton *et al*., 2007; Massawe *et al*., 2011; Bewketu Takele *et al*., 2022b).

5.4. Spatiotemporal variations

Small mammals showed temporal variations in their species composition. This supports the seasonal and interannual changes in small mammals' diversity and abundance (Makundi *et al*., 2006; Sintayehu Workeneh *et al*., 2011; Wen *et al*., 2014; Agreie Addisu & Afework Bekele, 2015; Seyoum Kiros & Afework Bekele, 2021b). Such variations in diversity patterns of small mammals may be attributed to the response of small mammals to the temporal vegetation structure changes (Misher *et al*., 2022), seasonal dis−/appearance of some species (Asher & Thomas, 1985) and microhabitats (Mohammed Kasso & Afework Bekele, 2011).

In the present study, a high number of non-volant small mammal individuals was recorded during the dry than wet seasons. The seasonal fluctuations in the abundance and distribution of small mammals are also well documented (Whitsitt & Tappe, 2009; Marques *et al*., 2015; Richard *et al*., 2022). This result agrees with several reports from different parts of Ethiopia (Demeke Datiko *et al*., 2007; Tadesse Habtamu & Afework Bekele, 2008; Sintayehu Workeneh *et al.,* 2011; Demeke Datiko & Afework Bekele, 2014; Gezahegn Getachew *et al*., 2016), and elsewhere in the world (Delcros *et al.*, 2015). However, it also contests with the findings of several reports across the country (Tilahun Chekol *et al.*, 2012; Alembrhan Assefa & Srinivasulu, 2019; Seyoum Kiros & Afework Bekele, 2021b), and in Tanzania (Richard *et al*., 2022). This variation might be due to the differences in the climatic conditions, vegetation cover (Mohammed Kasso & Afework Bekele, 2011), life histories of the species (Rocha *et al*., 2017), food availability and feeding habits (Brown & Heske, 1990) and the suitability of habitats in these areas (Asher & Thomas, 1985).

The high abundance of small mammals during the dry seasons is widely associated to a superior bait attractiveness as a response to shortage of natural food items (Demeke Datiko *et al*., 2007; Mesele Yihune & Afework Bekele, 2012; Demeke Datiko & Afework Bekele, 2014; Delcros *et al*., 2015; Gezahegn Getachew *et al*., 2016; Rocha *et al*., 2017), a reproductive response to a previous rainy season (Tadesse Habtamu & Afework Bekele, 2008; Rocha *et al*., 2017), and the timing of study period (Tilahun Chekol *et al*., 2012; Alembrhan Assefa & Srinivasulu, 2019, Seyoum Kiros & Afework Bekele, 2021b). Some other scholars still contested that the increase is only limited to the early dry season following the rainfall patterns, and then decline as the season progresses and the resources run out (Happold & Happold, 1990; Mulatu Osie *et al*., 2010; Kiros Welegerima *et al*., 2020).

The high abundance of non-volant small mammals during the dry season in this area, however, is most possibly due to the seasonal abundance of a widespread herbaceous plant, bracken fern. The presence of herbaceous plants and diverse microhabitat features plays an important role in structuring the population of small mammals (Delcros *et al*., 2015; Li *et al*., 2015). Bracken ferns in the area flourishes in the dryer season and die out in the wetter season, and could contribute for the shift in the ground cover and the abundance of small mammals from the wet to dry seasons.

The ground cover of the area is well covered by dense bracken during the dry season, but an open space during the wet seasons. This provides an ideal habitat for the insects that are the food items of insectivores (Zerihun Girma *et al*., 2012), and protects small mammals from livestock trampling and natural predators. Misher *et al*. (2022) also reported small mammal community fluctuations with the seasonal abundance of invasive shrub *Prosopis juliflora* in western India. The low population abundance of small mammals during the wetter seasons may perhaps be attributed to the increase in the risk of predation and food starvation due to the absence and/or reduction in the ground cover (Seyoum Kiros & Afework Bekele, 2021b).

This study recorded insignificant sexual variation, but slightly female biased during both seasons. This is in agreement to reports from different parts of Ethiopia (Tadesse Habtamu & Afework Bekele, 2008; Mohammed Kasso & Afework Bekele, 2011; Eshetu Moges *et al*., 2016; Alembrhan Assefa & Srinivasulu 2019; Bewketu Takele *et al*., 2022a). However, it disagrees with other findings across the country (Afework Bekele, 1996a; Getachew Bantihun & Afework Bekele, 2015; Gezahegn Getachew *et al*., 2016; Seyoum Kiros & Afework Bekele, 2021b). Such variation may be associated with the difference in ecological distribution of resources between these areas.

The higher number of female individuals in the area is most probably due to the nutritional quality the area provides for small mammals. Females that inhabit nutritionally deficient areas tend to produce a high production of female progenies (Rosenfeld & Roberts, 2004; Shilereyo *et al*., 2020). This assumption may be the probable explanation to the current study because the herbaceous diversity of the area is primarily dominated by bracken ferns that may limit the feeding options of the small mammals, and leads to female skewed sex ratio. A relatively lower number of males in the area may also be well explained by their more mobile nature and reproductive costs (Eshetu Moges *et al*., 2016; Bewketu Takele *et al*., 2022a).

Adult small mammals were more abundant than other age groups during both seasons. Similar findings were reported across Ethiopia (Alembrhan Assefa & Srinivasulu, 2019; Seyoum Kiros & Afework Bekele, 2021b; Bewketu Takele *et al*., 2022a). The age structure of small mammal populations in different seasons is well explained by their reproductive seasonality (Tadesse Habtamu & Afework Bekele, 2008; Bewketu Takele *et al*., 2022a). The result contradicts with the findings of Mohammed Kasso & Afework Bekele (2011) and Adugnaw Admas & Mesele Yihune (2016), where a higher number of sub−adults are captured during wet seasons. This might be associated with the functional endurance of the adults than the other age groups. According to Seyoum Kiros & Afework Bekele (2021b), higher smelling capacity to trapping baits and the utilisation of relatively larger home ranges contributed to the higher abundance of adults.

The highest trap success was documented during the dryer than wet seasons in Lakeshore Forest. The overall trap success in this study (19.30%) is higher than some reports from protected areas (Demeke Datiko & Afework Bekele, 2014; Alembrhan Assefa & Srinivasulu, 2019), and outside protected areas (Tilahun Chekol *et al*., 2012). However, it is still lower than the findings from numerous protected areas (Tadesse Habtamu & Afework Bekele, 2008; Sintayehu Workeneh *et al*., 2011; Mohammed Kasso & Afework Bekele, 2011; Eshetu Moges *et al*., 2016; Seyoum Kiros & Afework Bekele, 2022).

Such spatiotemporal variations in trap success could be associated to changes in the climatic conditions, habitat structure, food and shelter availability, reproductive pattern, predators and other anthropogenic disturbances in these areas (Tilahun Chekol *et al*., 2012; Seyoum Kiros & Afework Bekele, 2021b). Habitat type, seasonality and microclimates strongly influenced the abundance and diversity of small mammals (Stephenson, 1994; Mohammed Kasso & Afework Bekele, 2011; Bösing *et al*., 2014). The differences in the trapping efforts between studies could also contributed to the variations in trap success.

The highest population density of non-volant small mammals was registered during the dry than wet seasons. Such seasonal based small mammal density oscillation supports the findings of previous reports (Wirminghaus & Perri, 1993; Massawe *et al*., 2011; Seyoum Kiros & Afework Bekele, 2021b; Bewketu Takele *et al*., 2022b). Seasonality strongly influences the population dynamics of small mammals (Makundi *et al*., 2006; Wen *et al*., 2014; Agerie Addisu & Afework Bekele, 2015; Rocha *et al*., 2017). This is against the general trends of population density of small mammals in Ethiopia and other African states (Massawe *et al*., 2011; Bewketu Takele *et al*., 2022b).

In most studies, African small mammals score a high population density during the wet season through high reproduction that is initiated and promoted by chemical ingredients in the new foliage following the rain seasons (Massawe *et al*., 2011; Bewketu Takele *et al*., 2022b). These fluctuations might be attributed to the differences in the densities of annual plants (Brown & Heske 1990), the fluctuations of some small mammal populations (Brown and Heske 1990; Rocha *et al*., 2017), and degree of disturbances and environmental variables of these areas (Tilahun Chekol *et al*., 2012; Sintayehu Workineh & Reddy, 2016; Seyoum Kiros & Afework Bekele, 2021b). The flourishing and widespread nature of bracken during the dry seasons might have contributed to the rise in the population of worms and arthropods (Mosisa Geleta *et al*., 2011) as food sources of insectivores (Zerihun Girma *et al*., 2012).

Lakeshore Forest recorded the highest density of non-volant small mammals. Wiewel *et al*. (2009) also reported a spatial difference in mammalian density. However, the current result is against reports from Ethiopia (Ashetu Debelo & Afework Bekele, 2020; Bewketu Takele *et al*., 2022b), and elsewhere (Massawe *et al*., 2011). These studies reported a high small mammal density in bushland habitats. The level of population density recorded in this study habitat is also higher than that of Bewketu Takele *et al*. (2022b). This might be attributed to the variation in the habitat structure, degree of disturbances, and the abundance of natural predators (Wiewel *et al*., 2009) in these areas. The population status of small mammal species is also linked with geographical and habitat quality differences (Bowman *et al*., 2000).

Small mammals showed marked fluctuations in abundance and distribution between the trapping times, and inter−annually. Inter−annual fluctuations of small mammals are widely documented (Butet *et al*., 2006; Makundi *et al*., 2006; Agerie Addisu & Afework Bekele, 2015). Most of the small mammals favoured a nocturnal habit. However, *Lophuromys* species showed a cathemeral distribution. The variations in the trapping times may be well explained by the adaptations of mammals to avoid high level of disturbances such as cattle trampling and to reduce the risks of predation (Afework Bekele & Yalden, 2013). Natural habitats are more disturbed during the day than night sessions.

The higher number of small mammals during the second trapping year could be well explained by the inter−annual differences in the climatic conditions, rainfall in particular because of its effect on vegetation (Makundi *et al*., 2006). The higher rainfall across the country in the second trapping year, therefore, could have contributed to the higher abundance of small mammals of the area in that year. Higher reproduction after long rainy seasons and increased small mammal populations thereafter is well documented (Happold & Happold, 1990; Mulatu Osie *et al.*, 2010; Kiros Welegerima *et al*., 2020), and supports this hypothesis.

5.5. Diet and embryo count

In the present study, most rodents showed omnivorous feeding behaviours with the exception of Yellow spotted brush−furred rat and Ethiopian forest brush−furred rat that showed an insectivorous feeding habit. Similarly, omnivores dominated feeding habit is also documented in Gibe Sheleko National Park (Seyoum Kiros & Afework Bekele, 2022) and Alemsega Priority Forest Area (Bewketu Takele *et al*., 2022b). The diet selection of small mammals is largely determined by the availability, diversity, quantity and quality of food (Sassi *et al*., 2017; Seyoum Kiros & Afework Bekele, 2022).

Stomach content analysis of rodent diets varied between species and across the seasons. This result is congruent to several reports in Ethiopia (Mosisa Geleta *et al*., 2010; Agerie Addisu & Afework Bekele, 2013; Getachew Simeneh, 2016; Gezahegn Getachew, 2019; Seyoum Kiros & Afework Bekele, 2022; Bewketu Takele *et al*., 2022b). This might be due to the opportunistic nature of rodents depending on food availability (Workneh Gebresilassie *et al*., 2004; Mohammed Kasso & Afework Bekele, 2011; Happold, 2013; Kingdon, 2015).

Omnivorous rodents in the study area relied more on plants than animal matters. This finding agrees with several findings from Ethiopia (Mosisa Geleta *et al*., 2010; Bewketu Takele *et al*., 2022b; Seyoum Kiros & Afework Bekele, 2022), and might be due to the fact that rodents mostly prefer plant matter to any other food category. Animal matter feeding is higher during the wetter season than the dryer season. Comparable findings are also documented across the world (Atanassova *et al*., 2012; Bewketu Takele *et al*., 2022b). This might be due to the high population of worms and arthropods following the rainy seasons (Bewketu Takele *et al*., 2022b).

The highest amount of food item was documented in Yellow spotted brush−furred rat, which was worms and arthropods. This agrees with the general feeding behaviour of this species (Clausnitzer, 2003; Afework Bekele & Yalden, 2013; Happold, 2013; Lavrenchenko & Afework Bekele 2017). Such mode of feeding by *Lophuromys* species contributed to the success of these rodents in areas that are usually unsuitable for other rodents (Clausnitzer, 2003; Bewketu Takele *et al*., 2022b).

A relatively higher amount of plant materials was also recorded in most rodents during the wet season. This is in agreement with a report of Bewketu Takele *et al*. (2022b), and might be due to the unimodal nature of the rainy season in these areas. Large proportion of seeds were also recovered from the stomach of rodents. Multimammate mouse in particular showed a more frugivore feeding habit than any other rodent. This is in agreement to the general feeding habit of this species (Happold, 2013; Kingdon, 2015). However, this is against the finding of Demeke Datiko *et al*. (2007), where Multimammate mouse preferred monocot plants. This is because these studies are conducted in natural habitats and maize crop field, respectively.

The present study has recorded varying embryo counts in pregnant rodents in the two seasons. Such seasonal variations of embryo count in pregnant rodents are in congruent to several reports (Makundi *et al*., 2006; Happold, 2013; Bewketu Takele *et al*., 2022b). This can be affected by the type of species, locality, habitat characteristics, season and size of the female (Happold, 2013). More diverse habitats support different small mammal species as they can provide adequate food for their survival and reproduction, and adequate shelters from their natural predators (Agerie Addisu & Afework Bekele, 2015; Ofori *et al*., 2015). Rainfall also strongly influences the reproduction and population dynamics of rodents, probably because of its effect on their food resources (Makundi *et al*., 2006).

The highest embryo count was recorded from Multimammate mouse, also the most widespread rodent species in the study area. The variations in the number of embryos among rodent species might be related to the differences in climatic factors, age, genetic structures, and the number of sampled pregnant rodents (Bewketu Takele *et al*., 2022b). This finding agrees with several reports from diverse geographic setups (Mosissa Geleta *et al*., 2010; Demeke Datiko & Afework Bekele, 2013; Dobigny, 2014; Getachew Simeneh, 2016; Bewketu Takele *et al*., 2022b). The variations in litter size of rodents may also be associated with their differences in maternal care, nipple−clinging behaviour, physiological weaning, evolutionary traits and phylogenetic constraints (Bewketu Takele *et al*., 2022b).

In the present study, pregnant rodents were numerically higher during the wet season than the dry season. This is also in line to the findings of Meheretu Yonas *et al*. (2015) and Bewketu Takele *et al*. (2022b). The general seasonal reproduction pattern of small mammals is mainly due to resource availability that is associated with rainfall (Makundi *et al*., 2006; Dobigny, 2014). The amount and patterns of rainfall affects the population dynamics of small mammals since it shapes food availability that in turn determines their breeding capacities (Makundi *et al*., 2006; Ejigu Alemayehu & Afework Bekele, 2013; Happold, 2013; Getachew Bantihun & Afework Bekele, 2015; Ofori *et al*., 2015).

In seasonally reproducing rodents, the supplemental food items that they gain during the wet seasons have the potential to initiate reproductive states from non−reproductive states (Bewketu Takele *et al*., 2022b). In contrast, commensal rodents follow year−round reproduction because resources are always available (Dobigny, 2014).

5.6. Farmers' perspectives on rodent pests

The farmers in Wenchi highlands totally rely on farming and rearing cattle for their livelihoods. Only a few of them have generated additional income from ecotourism as previously documented (Gemechu Shale *et al*., 2014; Abebe Tufa *et al*., 2020). Enset, barley, potato and wheat were the chief crops grown in the study area. Cattle, horses/donkeys, sheep, and goats are the livestock types reared in Wenchi highlands.

The present study has revealed that rodent pests damage these commonly grown crops in the area. It also identified five rodent species − Abyssinian grass rat, Multimammate mouse, Awash multimammate mouse, Porcupine and African root rat − as major crop pests in the area from their occurrence in the neighbouring natural habitats, indirect evidence and reports from the local community. Similarly, different rodent pest species were reported from numerous localities of Ethiopia (Afework Bekele *et al*., 2003; Makundi *et al*., 2005; Meheretu Yonas *et al*., 2010; Agerie Addisu & Afework Bekele, 2013; Mohammed Kasso, 2013; Redwan Mohammed *et al*., 2017; Zewdneh Tomass *et al*., 2020).

In the current study, rodent pest species assessment was not carried out in the farmlands because of the unwillingness of the community implying the need of on−farm survey to identify the presence or absence of further pest species and to demonstrate the potential damage and loss that is actually occurring in the area (Buckle, 2015).

The current study revealed that rodents were the most leading pests to farmers. This finding conforms with the worldwide problem associated with rodents (Staples *et al*., 2003; Brown *et al*., 2007). Farmers often listed rodents as one of the most important pests to their crops (Tsegaye Gadisa & Kitessa Hundera, 2015; Bewketu Takele *et al*., 2022). Farmers were also well aware of rodent problems and expressed their frustration and anger toward these mammals. This result is consistent with earlier findings from Ethiopia (Makundi *et al*., 2005; Meheretu Yonas *et al*., 2010;

Tsegaye Gadisa & Kitessa Hundera, 2015) and elsewhere in the world (Tobin & Fall, 2004; Makundi *et al*., 2005; Brown *et al*., 2010).

Furthermore, farmers believed that rodents were useless and damaging creatures. Such perception was common among different sexes and all age groups of the inhabitants. This finding is also in agreement with the findings from northern Ethiopia (Meheretu Yonas *et al*., 2014) and India (Singla *et al*., 2012). There were occasions when individuals of different ages were harassing us verbally and intimidating us physically only because we made contact with rodents. This implies that there is a big knowledge gap about the biological and ecological values of these natural biotas, and a need for community wide education and training programmes on the matter.

A significant difference in the types of rodent damage was recorded in the present study area. A closely related finding has been reported by Zewdneh Tomass *et al*. (2020) and Panti−May *et al*. (2017). Garba *et al.* (2013) reported an apparent absence of knowledge about the possible role of rodents in the public health issues of Niger. This variance might be due to the difference in the species of rodent pests involved and knowledge gap of the respondents. Crop damage and damage to properties were the two predominant rodent damages. This is also in agreement with the finding of Panti−May *et al*. (2017).

Most respondents have described that barley was the most affected crop by rodent pests. This finding is in agreement with that of Meheretu Yonas *et al*. (2010) from Tigray highlands, and Bewketu Takele *et al*. (2021) from south Gondar, northern Ethiopia. However, it goes against several reports from the lowlands, where maize is the most vulnerable crop to rodent attacks (Afework Bekele *et al*., 2003; Makundi *et al*., 2005; Zewdneh Tomass *et al*., 2020). This difference is associated with variation in climatic conditions, the types of crops grown, the wide distribution of these crops, and the inherent crop preferences of the rodent pest species present in these areas.

In the current study, farmers have observed rodent damage of barley from the sowing to harvesting times. Similar results were documented by Meheretu Yonas *et al*. (2010) and Bewketu Takele *et al.* (2021) from northern Ethiopia. However, the damage is higher in the maturation stage, when the barley is near to its harvesting. This is in agreement with the experimental finding of Bewketu Takele *et al*. (2021) from south Gondar and the general patterns of rodent damage in the field crops (Lund, 2015). The finding is, however, against a report from northern Ethiopia, where damage is severe at booting stages (Meheretu Yonas *et al*., 2010). This variation might be associated with the difference in the accessibility and vulnerability of the crop, species richness and abundance of the rodent pests in the study areas.

Farmers reported a seasonal variation in rodent infestation of residential houses and crop fields. This finding is in congruent to the finding of Gebhardt *et al*. (2011) since damage is directly linked with the abundance, feeding habits, reproductive rates and diversity of rodents (Swanepoel *et al*., 2017). However, it disagrees with a report of Staurt *et al.* (2011) that farmers considered significant rat damage during both the wet and dry seasons. This difference could be associated with the difference in geography, pest species, crop types and climatic variations between the areas.

Farmers have crudely estimated crop losses due to rodent pests. The estimation is in the same range of experimentally proved barley crop loss in south Gondar (Bewketu Takele *et al*., 2021), but lower than by the farmers from Tigray highlands (Meheretu Yonas *et al*., 2010). This result confirms that rodent damages significantly affect the income and food security of small−holder farmers of the developing states (Brown *et al*., 2013; Lund, 2015; Htwe *et al*., 2016; Swanepoel *et al.*, 2017). There is a need for on−field rodent damage assessment to figure out the actual crop damage inflicted by rodents in the field.

In the present study, most farmers carried out farm supervision on occasions. The result is against a report of Meheretu Yonas *et al*. (2010) from Tigray. This might be due to the belief that farmers were powerless to control rodent damages in the field. In consistent with an earlier report from Tigray, and Tanzania (Mulungu *et al*., 2015), rodent damage was assessed by observing damaged seeds, damaged stores and rodent droppings, and stem cut of standing crops in the storage and crop fields, respectively.

Farmers in the study area employed several indoor and outdoor rodent pest management strategies. Similar findings reported that farmers are responsible for the control of rodents (Meheretu Yonas *et al*., 2010; Mulungu *et al*., 2015; Zewdneh Tomass *et al*., 2020). The farmers used rodenticides, trappings, natural enemies, and hunting either separately or together. Trapping and hunting were employed to control rodent damage on enset and potatoes by the farmers in the current study area. These methods are well documented, and the most practised rodent control techniques in Ethiopia

(Makundi *et al*., 2005). But it is against the findings of Meheretu Yonas *et al*. (2010), where farmers were reliant on rodenticides for rodent pest management.

In the current study, none of the interviewed farmers used any management strategies in the barley crop fields. This finding is against the findings of Meheretu Yonas *et al*. (2010) from northern Ethiopian highlands, and Mulungu *et al*. (2015) from Central−eastern Tanzania, where most farmers used rodenticides in the crop fields. The current study area farmers believed that managing rodents in the barley crop fields is difficult. This is in disagreement with the findings of Brown *et al*. (2010), but in total agreement with other studies conducted elsewhere in the world (Singleton & Petch, 1994; Palis *et al*., 2011; Singla *et al*., 2012).

In these areas, many farmers accepted that they have no power to control rodents damage to their crops in the field. Asian farmers, for instance, plant two rows of grain for every 10 rows for rodents (Singleton & Petch, 1994). This might be due to the fact that farmers habitually ignored rodents because they are minor and periodic pests in the area. A similar scenario has been reported from India (Singla *et al*., 2012).

Another possible reason that could lead the farmers to a level of acceptance of rodent crop damage could be the chronic and prolonged nature of rodent depredation. This is the most likely rationalisation for the current study area since it is experimentally supported, and Ethiopia experiences chronic rodent pest problems on different agricultural crops (Mulungu, 2017). This situation is unbearable in the current state because it is experienced by small farm holders and the country is experiencing an ever−increasing population and stunning economic inflation.

The farmers in the study area claimed that rodents may developed an adaptation to avoid rodenticides and traps. We believed that these claims are unsubstantiated, and rodenticide avoidance of rodents could be associated with the quality of baiting foods. It is well documented that the use of poor baiting food has low rodent attraction potential to the rodenticide and leads to the point where rodents avoid its consumption (Hill, 2008). Using high quality and palatable baits can easily reduce such problems. The second and most likely problem in the area could be the dose level of rodenticide preparation. This problem can be easily solved by balancing the amount of rodenticide and baiting food in the way that it could be efficient and effective in attracting rodents.

But, if rodents really developed rodenticide avoidance behaviour, the only possible solution could be using other forms of rodenticides and rodent management strategies.

Farmers in the study area used domestic cats as a natural enemy to control rodent pests in storage. Owning local cats in the residential house is a widely employed biological rodent control method in different parts of Ethiopia (Hill, 2008; Meheretu Yonas *et al*., 2010; 2014; Zewdneh Thomas *et al*., 2020). This practice has a major suppressive effect on the local rat population (Hill, 2008). The effectiveness of this rodent management strategy in the area disagrees with other findings from other parts of Ethiopia (Mohammed Kasso, 2013; Meheretu Yonas *et al*., 2014) and elsewhere in the world (Brown *et al*., 2010).

A possible explanation to this state of affairs could be due to the cost effectiveness of this method. Mohammed Kasso (2013) has argued that the use of domestic cats to contain rodent pests is not effective in the same manner in all areas because cats may avoid catching and consuming rodents. Little is known about use of the field sanitation in rodent pest management among the farmers.

5.7. Conservation implications

The present study recorded a high number of non-volant small mammal species in Wenchi montane forests. This finding confirms that a significant proportion of biodiversity is also located outside of PAs, and as mammalian biodiversity is largely concentrated in human−dominated landscapes (Tyrrell *et al*., 2020). The study also supported the notion that PAs alone will not ensure the survival of species and ecological communities, and areas outside PAs can play the supplementary role for protected areas in harbouring and conserving small mammals. Thus, such habitats should be equally managed as PAs in the ways that allow the immediate conservation of biodiversity (Mir & Dick, 2012). However, like elsewhere in the world, conservation activities in Ethiopia are still focused only on PAs. The finding of the present study also suggests the need for the exploration of other similar areas, and further faunal investigations.

The current study recovered numerous rare and country endemic species in the forest remnants. This warrants the wide geographical distribution of these unique faunas in montane forest remnants of the country. It also shows the conservation needs of such areas to retain them in all possible areas. Further surveys at low altitudes and other forest remnants in Wenchi highlands are needed to document a full and complete package of fauna in the area. What is worrisome here is that small mammal species are frequently ignored in conservation sciences, and only a few of them are protected (Bertolinoa *et al*., 2015). Furthermore, most small mammals in this study are in least concern conservation status of IUCN threat category, except Short-tailed brush-furred rat and Yalden's rat, which are near threatened and vulnerable, respectively. The trapping of these two rodent species in few numbers particularly Yalden's rat strengthen the conservation significance of this area.

Small mammals are a good indicator of habitat quality (Tadesse Habtamu & Afework Bekele, 2012), and in aiding potential conservation actions (Root−Bernstein *et al*., 2014). The overall abundance and endemic assemblages of non-volant small mammals in Wenchi montane forests could aid potential conservation interventions of the area. The population abundance of most small mammal species, particularly those that are endemic is very low, and clearly suggests that the area is highly threatened by various anthropogenic factors.

Habitat disturbance of this area has great implications for the conservation of biodiversity therein (Fuentes−Montemayor *et al*., 2009). The disturbance of habitats is linked to the existence or absence of indicators, and a decline in rodent richness (Avenant & Cavallini, 2007). In addition to retaining these precious biological resources, the conservation of Wenchi natural forests, particularly the upland shrublands and Lakeshore forests, have holistic ecological and economic significance to the area. The upland shrublands have a potential to safeguard and protect Lake Wenchi from sediment filling and eutrophication that could jeopardize the existence of this unique highland lake. It also contributes to the soil conservation of this area since it is easily susceptible to erosion and fragmentation.

5.8. Conservation challenges and opportunities

Local people in Wenchi highlands acquire different natural resources from the forest remnants either as recreation and enjoyment, income source, grazing area, source of construction materials or firewood. Countless forms of natural resource utilizations by the local community even from PAs is widely documented in different parts of Ethiopia (Mesele Yihune *et al*., 2009; Israel Petros *et al*., 2016; Mengistu Wale *et al*., 2017; Azmeraw Alemkere, 2018; Ayenew Biset *et al*., 2019). Nevertheless, the unforgivable use of natural resources and other anthropogenic activities are responsible for a global crisis due to the loss of biodiversity (Frick *et al*., 2019; Seyoum Kiros & Afework Bekele, 2021a).

Information obtained from the selected households, focus group discussions, local administrations and direct observations showed that overgrazing, land use changes due to farming land expansions and human settlement, firewood collection, plantations of commercial exotic plants, human induced fire, soil erosion, household poverty, insufficient information and monitoring, and illegal land grabbing were the major biodiversity threats in Wenchi highlands.

Most of these threats are also reported from both protected areas (Atakilt Berihun *et al*., 2016; Israel Petros *et al*., 2016; Mengistu Wale *et al*., 2017; Sefi Mekonen *et al*., 2017; Seyoum Kiros & Afework Bekele, 2021a) and outside protected areas (Munns, 2006; Imre & Derbowka, 2011; Mohammed Kasso & Afework Bekele, 2014; Mosisa Geleta & Afework Bekele, 2016; Ndegwa *et al*., 2019; Kabeta Legese *et al*., 2019) with varying intensity. According to Kideghesho *et al*. (2001), animal populations are negatively impacted by a surge in arable land sizes, soil erosion and siltation of water bodies, reduction of woody plants, depletion of rangelands, and a decline in soil productivity.

Anthropogenic activities threaten biodiversity through habitat loss and modifications. Habitat loss and forest clearings threaten mammals either via decreasing fragment size and connectivity or/and increasing the number of fragments and edge effects (Musyoki *et al*., 2012; Mohammed Kasso & Afework Bekele, 2014; Kabeta Legese *et al*., 2019). This is exacerbated by the rapid population growth, and the rise in demands of natural resources in most African countries including Ethiopia (Mengistu Wale *et al*., 2017; Azmeraw Alemkere, 2018). The rapid increase in human population in the universe has been connected to widespread habitat disturbance and demands of more land for settlement and agriculture, food and alternative sources of income leading to extensive resource extraction, and widespread fragmentation of the remaining natural forests (Imre & Derbowka, 2011; Atakilt Berihun *et al*., 2016; Kabeta Legese *et al*., 2019).

Land–use changes for agricultural production and human settlement are the main biodiversity threats in Wenchi highlands. This is in agreement with the findings of Leykun Abune (2000), Selemawi Abrehe *et al*. (2020), and Seyoum Kiros & Afework Bekele (2021a). The conversion of lands for agricultural activity is one of the most important land-use changes in the world (Frick *et al*., 2019). Agricultural expansion into the natural habitats is primarily associated with the higher crop productivity in these areas than farmlands (Seyoum Kiros & Afework Bekele, 2021a). In the present study area, a very small land holding size of the farmers, which is 0.5 ha per household, forced the farmers for additional settlement and farming areas (Gemechu Shale *et al*., 2014).

Continuous livestock grazing is the predominant biodiversity threat in Wenchi montane forests. High levels of livestock grazing may affect the quality of the wildlife habitat (Afework Bekele & Yalden, 2013; Mohammed Kasso & Afework Bekele, 2014; Addishiwot Fekdu *et al*., 2015; Selemawi Abrehe *et al*., 2020). Overgrazing is known affect the demography, population structure, spatial range of individuals and species, and change in the community structure (Mohammed Kasso & Afework Bekele, 2014; Selemawi Abrehe *et al*., 2020).

Fuelwood provision is a chief ecosystem service of natural forests and woodland habitats (Kabeta Legese *et al*., 2019). But this may lead to their deterioration and degradation (Wuver & Attuquayefio, 2006, Ndegwa *et al*. 2019). Firewood collection is one of the major biodiversity threats in Wenchi highlands. Similar findings were also reported by Mosissa Geleta & Afework Bekele (2016), Kabeta Legese *et al*. (2019) and Selemawi Abrehe *et al*. (2020) from different parts of Ethiopia. This is because the majority of the rural communities in the country do not have access to electricity, and they rely on fuelwood as sources of energy. Poor people also have no alternative income sources and use firewood and charcoal production as the only means of generating incomes (Kabeta Legese *et al*., 2019; Seyoum Kiros & Afework Bekele, 2021a). Kabeta Legese *et al*. (2019) documented that the closeness of urban areas to the natural forest increases the rate of forest destructions for firewood and charcoal production.

Human induced fire also commonly occurs in ericaceous belts of Wenchi natural forests. Burning was actually associated with the local communities' farming land expansion. Plantation of exotic commercial plants was another reason behind human induced fire in the area. Local community set fire to the *Erica* shrubs in order to plant *Eucalyptus* trees. In Gibe Sheleko National Park, burning was associated with pasture management system, to discourage hazardous wild animals, to create human or livestock pathways, to reduce the infestation of tsetse flies and to collect wild honey (Seyoum Kiros & Afework Bekele, 2021a).

Soil erosion is associated with forest clearings and infrastructural developments in the area posed a serious existential threat to the forests and its biodiversity by fragmenting continuous forests into small and isolated fragments. This disconnects species and leads to the loss of species that have large area requirements (Mohammed Kasso & Afework Bekele, 2014). A continuous grazing of these habitats further exacerbates the problem of soil erosion the area is experiencing. Overgrazing by domestic livestock is the major cause of land degradation (Addishiwot Fekdu *et al*., 2015; Gezahegn Getachew *et al*., 2016; Horncastle *et al*., 2019).

Human−wildlife conflict was not as such a major problem in the present study area. This finding is against several reports from different areas of Ethiopia (Aberham Megaze *et al*., 2017; Seyoum Kiros & Afework Bekele, 2021a), where human−wildlife conflict is a serious problem. The most likely reason for this might be the presence of a limited number of crop raiders in the area. Only crested porcupines and mole rats are crop raiding animals in the area. Other crop raiders particularly medium to large−bodied mammals are pushed out from the forest fragments.

According to Mesele Yihune *et al*. (2009), crop raiders have less crop damaging impact due to their low population size in northern Ethiopia. Potatoes and enset were the most preferred and vulnerable crops to these crop raiders. Such differential vulnerability of crop types towards crop raiders is widely documented in Ethiopia (Amare Yilmato & Serekebirhan Takele, 2019; Seyoum Kiros & Afework Bekele, 2021a). These crops are preferred mainly because they are widely grown in the area, have high nutritional qualities (Seyoum Kiros & Afework Bekele, 2021a), and the raiders are also specialized to feed tuber crops.

Clearing of natural vegetation and replacements by exotic commercial plants (*Eucalyptus* spp.) and their expansions was commonly observed in the uplands of Lake Wenchi. This may have a negative impact on the vegetation structure of the area and its biodiversity. The same threatening factor was observed in Entoto Natural Park and Escarpments (Kalkidan Esayas & Afework Bekele, 2011). According to Sefi Mekonen *et al*. (2017), the flora and fauna of Ethiopia are facing an ongoing pressure from the replacement of local varieties. Exotic invasive species like *Parthenium hysterophorus*, *Prosopis juliflora* and *Eucalyptus* spp. are widely distributed even in PAs (Mengistu Wale *et al*., 2017; Seyoum Kiros & Afework Bekele, 2021a) and outside these areas (Kalkidan Esayas & Afework Bekele, 2011; Kumar & Chhaya, 2015). The expansion of commercial exotic plants may be related to the rising in the market demand and better market pricing than the native *Erica* plants.

There was aggressive land grabbing and encroachments around the lakeshores. This expels and shifts the natural communities, and break natural resources conservation and management traditions, and jeopardise the durability of the biological diversity of the area. Similar problems have been reported by Fasil Degefu & Schargel (2015) from the same area.

In the present study, majority of the respondents had a positive attitude towards the conservation of Wenchi montane forests and their wildlife. Those individuals who had a positive attitude towards the conservation of Wenchi montane forests and their wildlife see the economical, ecological, aesthetic and scientific value of the area. Kabeta Legese *et al*. (2019) also documented positive attitudes of the local community towards the mammals and their willingness to participate in the future conservation efforts of Wabe forest fragments. Those individuals who had a negative attitude may consider the challenges associated with the scarcity of land for farming, human settlement and livestock grazing in the area and the prohibition of resource exploitation such as cutting of live trees. Similar problems are also documented from Gibe Sheleko National Park (Seyoum Kiros & Afework Bekele, 2021a).

In contrast, Mosissa Geleta & Afework Bekele (2016) reported a negative local community attitude towards wildlife and their conservation in western Ethiopia. This attitudinal discrepancy might be because of the differences in the awareness level, and costs incurred by study participants linked with wildlife. Local people develop negative perceptions towards conservation efforts may be due to lack of awareness, crop damage and livestock depredation, lack of benefit sharing, prohibition or punishments imposed due to illegal activities (Aberham Megaze *et al*., 2017; Azmeraw Alemkere, 2018; Seyoum Kiros & Afework Bekele, 2021a).

The attitudes of the local community towards conservation efforts and wildlife are shaped by several intricate factors that the local people see and experience locally. It is principally based on the costs and benefits they experience (Abebe Tufa *et al*., 2022). Local people in Wenchi highlands generate some benefits and incomes from the natural resources as a tour guide, renting horses, selling firewood, sharing ecotourism revenues and in the form of recreation and enjoyment. Thus, they developed positive attitudes towards the natural resource protection and development projects. Similar findings are documented by other reports from different PAs in Ethiopia (Ayenew Biset *et al*., 2019; Seyoum Kiros & Afework Bekele, 2021a), and the same study area (Abebe Tufa *et al*., 2022).

According to Abebe Tufa *et al*. (2022), the length of stay in the study site and the residence place from ecotourism attraction centre may perhaps shaped the attitudes of the local community towards ecotourism projects. A relatively low human–wildlife conflict in the area may also have contributed to the positive attitudes of the local community. Studies have also documented that younger and educated individuals have positive attitudes towards conservation efforts than other groups of the community (Aberham Megaze *et al*., 2017; Azmeraw Alemkere, 2018; Seyoum Kiros & Afework Bekele, 2021a; Abebe Tufa *et al*., 2022).

Attitudes of the local community towards wildlife and their habitat conservation may also vary among men and women. According to Seyoum Kiros & Afework Bekele (2021a), women develop more negative attitudes to conservation efforts than males. This is related to the presence of frightening or dangerous wild animal species in the natural forests. In general, the existing socio–economic difficulties, benefits generated, educational background, gender, residence place, and belief in the ownership of the forests contributed in shaping the attitudes of local communities in Wenchi highlands.

Several conservation threats are putting the wildlife in Wenchi montane forests in danger of local extinction. The present study has identified five potential opportunities for the conservation of Wenchi montane forests and its wildlife that could halt local extinction threats. These included the unique natural topographic beauty, rich flora and fauna, government led ecotourism development project, a recent national and global recognition of the area, and positive attitudes of the local community for the conservation of this area.

A naturalistic beauty of Wenchi highlands is excelled by the presence of the volcanic crater highland lake, Lake Wenchi. Recent studies have identified that Wenchi Lake watershed forests alone host a significant number of indigenous plants and mammals including country endemics (Gemechu Shale *et al*., 2014; Abebe Tufa *et al*., 2020). According to Abebe Tufa *et al*. (2020) ninety one percent of the woody plant species in Wenchi watershed were native plants, from which nearly one fourth of them were endemic to Ethiopia.

The present study has also identified 9 endemic small mammals in these montane forests. Such floral and faunal richness of the area could serve as another input and impetus for the conservation of the area. More importantly, there are also significant number of birds including the country endemics, Yellow−fronted parrot (*Poicephalus flavifrons*) and Blue-winged goose (*Cyanochen cyanoptera*), and many more that need further identifications.

The government of Ethiopia is doing an incredible and praiseworthy ecotourism and conservation efforts especially in areas that were previously ignored as part of Gebete Lehager projects − an approach to sustainably manage lands, conserve biodiversity and improve local livelihoods (Abebe Tufa *et al*., 2022). This could be a turning point in shaping the attitudes of the community towards the conservation of the area, and alert the scientific communities to conduct holistic researches that can scientifically solve the prevailing problems in the area. This in turn has a paramount role to conserve the small mammals and other wildlife that these natural forests harbours.

Wenchi Lake has recently attracted both national and international attentions. The area has attracted more recognition now than ever. This global and national recognition of the area can be a best opportunity to devise strategies to conserve the natural resources and wildlife of this area. The government ecotourism initiative has also opened another door that could lead to the mitigation of biodiversity threats to the forests and wildlife in the highland. For instance, the local administration has taken legal measures on land grabbers and demolished houses built along the lake shores. This problem has been reported for a long time (Fasil Degefu *et al*., 2014; Fasil Degefu & Schagerl, 2015), but no corrective measures have been taken until the ecotourism development initiative is launched in the area. These measures are encouraging efforts in tackling the threats on the Lakeshore Forests and the wildlife it hosts and could further contribute to their conservation.

On the other hand, development projects are also risky and may end up in unwanted results unless they are carefully planned and executed. For example, Musyoki *et al*. (2012) have reported that irresponsible tourism is a challenging factor in the conservation of cheetahs and wild dogs. Legal measures should not also limit to demolishing the built house in the lakeshores, but should be proactive, consistent and durable to maintain the natural beauty and the composition of the area. It should also involve the local community and the low–level government sectors so that the problem will dry out from its base and won't relapse in the future.

The interviews of the local community on their perceptions and attitude of conservation of the forests and wildlife of the area have revealed that they have positive attitudes toward its conservation. They also have a willingness in collaborating and supporting the conservation efforts that will be in place if needed. Such conservation friendly attitudes of the public have a paramount importance for the success and sustainability of the conservation efforts in the area. The positive attitudes of the local community might be associated with the absence of wildlife threats that could incur costs to them, the deceptive response of the locals for image building, and to escape from government hassles, and the financial benefits they are gaining from the existing ecotourism activities in the area.

Local people that obtained some benefits have developed positive attitudes towards conservation efforts (Ayenew Biset *et al*., 2019; Seyoum Kiros & Afework Bekele, 2021a). In this regard, Wanchi Ecotourism Association (WETA) policy states that the community acquire profits about 10% from those provide services, and 50% from the payment made for an entry by tourists (Abebe Tufa *et al*., 2022). These opportunities are powerful in implementing conservation efforts. Therefore, now it is a right time to use and synchronise these opportunities as an input and driving force to safeguard the biodiversity of the area, and bring meaningful results.

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

The present study played its fair share in providing scientific information about non-volant small mammal's abundance and diversity, spatiotemporal changes and prevailing conservation challenges and opportunities in Wenchi montane forests. The study registered a high number of endemic non-volant small mammals that could serve as a triggering point and additive factor to consider the area for small mammal conservation.

The diversity and abundance of non-volant small mammals showed spatiotemporal variations supporting the seasonal and inter−annual changes in the diversity and abundance of small mammals. The community structure of non-volant small mammals in the area is principally associated with the seasonal abundance and widespread nature of bracken fern. The population density and the biomass of rodents in Wenchi montane forests very low and showed variations in habitats, seasons and species.

Non-volant small mammals in Wenchi montane forests displayed varying distributional patterns in species richness, diversity and abundance across altitudinal ranges. Some of them are more abundant in lower altitudes, while others are at higher altitudes. Still, few of them were restricted to particular altitudinal range. Most rodents in Wenchi highlands were omnivorous except Yellow spotted brush−furred rat and Ethiopian forest brush−furred rat that were insectivorous. Omnivorous rodents were reliant more on plants than animal matters. There were also seasonal fluctuations in the feeding habits of rodents of the area.

Rodents cause considerable damage to agricultural crops and properties of small farm holders of Wenchi highlands. The farmers perceived rodents as pests to their crops, and are a nuisance to them. The farmers declined to manage rodent damage in the crop fields. Owning cats, rodent trapping and rodenticides were employed as indoor management strategies.

Wenchi montane forests and the non-volant small mammals therein are severely threatened by several anthropogenic activities. Land grabbing, overgrazing, human settlement and farmland expansions, replacement of native species by exotics, and a seasonal burning of the ericaceous belts are some of the prevailing conservation threats in Wenchi highlands. On the other hand, recent global and regional recognitions, positive attitudes of the local people, topographic beauty, rich flora and fauna in the area, and ecotourism development project in the area are the potential opportunities that could serve as a springboard for the conservation of the area and its wildlife.

6.2. Recommendations

In accordance to the findings of the present study, the following recommendations are forwarded.

- Wenchi montane forests and the small mammals found within these forests are highly threatened by several mounting anthropogenic factors. Conservation of these habitats should be, therefore, a priority for the continued survival of these diverse and endemic small mammals.
- The regional and/or national wildlife conservation and management authority should give full attention in considering the area as a conservation area, and enforce conservation laws needed for sustainability of the wildlife from local extinction, and the natural environments of the area from degradation.
- The current results are exclusively based on morphological identification, and require corroboration by genetic studies (validation through molecular works). This is, in particular, imperative for *Lophuromys* species complex and *Murid* spp. A, and could also add more endemism to the area.
- The findings are also relatively from the higher grounds, and expanding the survey to the lower grounds could further bolster the small mammal species diversity and the level of small mammal endemism in the highlands.
- Regular ecological assessments are required to evaluate the changes of small mammals and other wildlife species in the area as continuous monitoring and time−based conservation responses.
- Local people considerably depend on the natural resources in the montane forests suggesting a need of awareness creation, facilitating for alternative income sources through integrated conservation and development project options such as the ongoing

ecotourism initiatives, re−engagement to honey bee production and other available options.

- Strict and educative legal measures should be in place on individuals that are directly participated on impacting the natural environments.
- There should be area wide restrictions on destructive resource utilizations from the natural forests, and the replacement of natural vegetation by commercial exotic plants.
- Rodent pests are a risk to food safety in the area, and conducting on−field damage assessment and community level education programmes are critical to estimate the actual damage rodents inflict in the field and to awaken the farmers for rodent management.
- There is a big knowledge gap about the biological and ecological values of small mammals and on the use of traps and rodenticides in the area implying a need for a community wide education and training program on these problems and possible solutions.
- Unless further study differentiates priority areas in Wenchi highlands, any conservation measures in the area should incorporate all the available natural forest remnants for conservation.

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APPENDICES

Appendix 1: Questionaries

Dear respondent, this questionnaire is made to assess the local community knowledge and experiences on the resource uses, threats and conservation measures of Wenchi montane forests and their wildlife. You will also be asked on the damage and management practices of major vertebrate pests in your locality. Your response will have a huge impact on the outcome of this study, and ultimately on the future management measures of these pests. Hence, you are kindly requested to provide the answer that you are only sure about and what you have really experienced. Your response will be used for this study only. Thank you for your participation and invaluable responses! It is highly appreciated!

Part I: Socio-Economic Profiles

Name: __________________ Sex: __Age: __ Village: ______ Family size: ___ Farm size: ____

Education: □ No formal education □ Attended <5 grade □ Attended < 8 grade □ 10th complete □ College and above □

Years spent in farming: ___________________ Annual crop yield: _________

Part II: Resource Uses, Threats and Conservation

1. Do you and/or your community use the natural resources from the forests? Yes □ No □
2. If your answer is "**Yes**", please rank the following possible resource uses

Item	Rank	Item	Rank
Firewood collection		Timber production	
Charcoal production		Mineral Water	
Wild honey		Edible and medicinal plants	
House construction materials		Other (specify)	
Grazing land for livestock			

3. Is there any restriction of natural resource utilization from the forests? Yes □ No □. If "**Yes**", mention the type of resource and describe the reason why?
4. Do you think the presence of forest fragments have any importance to you and the people?

Yes □ No □

5. If **"<u>Yes</u>"**, what is the importance? Attract tourists □ Protect the soil □ Regulate climate □ Source of recreation □ Source of construction materials □ Bee keeping □Timber □ Fire wood □ Grazing □ Protect the lake□
6. Do you notice any change in the size and amount of these forests through time? Yes □ No □
7. If your answer is **"<u>Yes</u>"**, what is the change you observed? Increasing □ slightly decreasing □ decreasing greatly □
8. What do you think brought this change? Human population increase □Shortage of farmland □ Free access of the resources □ Overgrazing □ other
9. Rank the following possible conservation challenges to Wenchi forests on the basis of their severity (1= Very high, 2= High, 3= Medium, 4= Low, 5 = Very low)

<u>No</u>	Possible challenges	Level of severity				
		1	2	3	4	5
1	Overgrazing by livestock					
2	Human encroachment					
3	Agricultural expansion					
4	Firewood collection					
5	Charcoal production					
6	Exotic plantation					
7	Road construction					
8	Human induced fire					
9	Poor attention by government					
10	Human population increase					
11	Illegal land grabbing					
	Other (specify)					

10. Is it possible to tackle these threats to the forests and its animals? Yes □ No □. If **"<u>Yes</u>"**, how?
11. Who do you think is responsible to conserve them? Government□ Society □ Both □ Other
12. Is there any conservation practices put in place before for these forest fragments? Yes □ No □
13. Do you think these forest remnants need further conservation? Yes □ No □
14. What are your recommendations to retain these forest fragments?

15. If requested, are you willing to cooperate in the future conservation process? Yes □ No □

Part III: Pest Animals

1. Mention and rank crops grown in your area____
2. Rate problematic animals in your area by putting tick mark (√) (1= Very high, 2= High, 3= Medium, 4= Low, 5 = Very low)

No	Animals	Level of severity				
		1	2	3	4	5
1	Monkeys					
2	Rats					
3	Mole rats					
4	Porcupine					
5	Birds					
6	Termites					
	Other (specify)					

3. Which one needs further study and control? Rodents □ Monkeys □ Birds □ Other (specify)?
4. Do you think all rodents are equally problematic animals? Yes □ No □
5. What are the damage rodents cause to you? Damage crops in fields □ Damage crops in stores□ Transmit diseases □ Bite on human □ Contaminate food □ Damage properties □
6. Is the damage before harvest or after? Before □ After □ Both □
7. In what frequency rodents occur? Regular □ Frequent □ Irregular □ Rare □
8. Which crop is more susceptible to rodent damage? Barley □ Wheat □ Enset □ Potato □
9. During which season rodents heavily infest your house? Dry □ Wet □ Both □
10. In which month do you think rodent causes more damage to the crop? July to August □ August to September □ July to September □ August □ September □
11. At which developmental stage of crops rodents cause critical damage? Just after sowing □ Booting □ Germination □ Maturation □ Threshing □
12. Estimate crop damage in the field. <100 kg ha^{-1}□ 100–500 kg □ >500 kg ha^{-1} □ difficult to estimate □

13. How do you assess crop damage in the field? Stems cut of standing crops □ Rodent tracks and runways in crop fields □ Observation of rodents □
14. How do you assess crop damage in storage? Hearing sounds made by the rodents □ Observation of damaged seeds □ Observation of damaged seed stores □ Observation of rodents dropping □ Observation of rodents □

Part III: Management Practices

1. Do you control rodent damage? Yes □ No □
2. If your answer is **"Yes"**, where do you control them? In crop fields (outdoor) □ In the house (Indoor) □ Both □
3. How do you control outdoor rodent damages? Rodenticide □ Traps □ Field sanitation □ Flooding burrows □
4. What initiates you for rodent management in the field? Noticing damaged crops in the fields□ Noticing rodent movement □ Part of routine farming practice □ When instructed by extension staff □
5. Which crop stage is suitable for effective rodent management? After sowing □Booting □ Germination □ Maturation □ Threshing □
6. How do you manage indoor rodent damages? Rodenticides □ Traps □ Physical killing □ Keep domestic cats'□ Other □
7. What initiates you for rodent management in the house? Noticing damaged crops □ Noticing rodent movements □ Noticing damaged properties □Rodent noises and disturbances
8. Why don't you use IPM? Use a single effective method □No other options □ Lack knowledge □ Other □
9. Do you manage rodents in cooperation with your neighbours? Yes □ No □
10. If "**No**", do you think you will be re-infested as a result? Yes □ No □. If **"Yes"**, why don't you cooperate?
11. How do you obtain rodenticide? Freely from district agricultural office □ Purchased from agricultural office □ Purchased from local market/shop □Purchased from local pharmacy
12. Do you think rodenticides have any side effect? Yes □ No □
13. If your answer is **"Yes"**, what are these effects? Water pollution □ Killing untargeted organisms □ Don't know □

Part IV: Effects of overgrazing

1. Do you have livestock? Yes □ No □. If **"Yes"**, what are they? Cattle __ Sheep __ Goat__ Horse __Donkey___
2. Where do these livestock grazes? In private pasture lands □ In nearby forests □ Other
3. If your answer is in nearby forests, in which season? Summer □ winter □ Both □
4. Do you think continuous grazing has negative impacts on the forest? Yes □ No □
5. If **"Yes"**, how and why do you use it in such a way? No other options □ It is a better place □
6. Do you think small mammals can be impacted by such land use? Yes □ No □

Appendix 2: Supplementary materials

2.1. Some of the anthropogenic threats in Wenchi highlands

a) Firewood collection

b) Systematic exploitation of forest resources

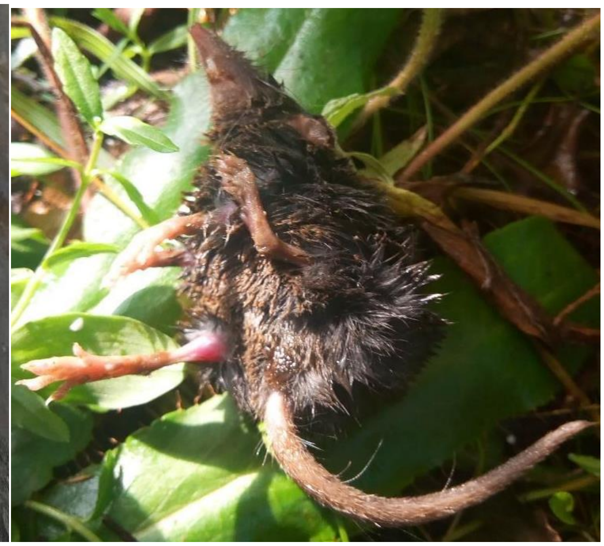
c) Farmland expansions

d) Soil erosion and fragmentation e) *Eucalyptus* spp. Plantations

2.2. Some small mammals of Wenchi highlands (Photo by: Kabeta Legese)

M. natalensis *S. albipes*

C. oliveiri



C. bailey

D. yaldeni

L. brevicaudus

L. chryopus

L. flavopunctatus

M. awashensis (top) and *M. natalensis* (bottom)

Field inspections

Murid spp. A.

D. lovati

Embryo count

Stomach content