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Original Study

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Abstract: Considering climate change and high population increase, the conversion of natural habitats into arable land is rising at an alarming rate in the Ethiopian highlands. The impact on the diversity of rodents and shrews is difficult to measure since historical data are often unavailable. However, the relative effects of such land-use changes could be contemplated by comparing with data from similar natural habitats in adjacent areas. Between October to November 2018, we randomly setup 20 infrared camera traps in wheat fields located near Mount Guna at about 3350 m elevation, as part of a large research project investigating the efficacy of rodent repellent botanicals. We recorded six rodent species (*Arvicanthis abyssinicus*, *Dendromus lovati*, *Dendromus mystacalis*, *Hystrix cristata*, *Mus mahomet* and *Stenocephalemys albipes*) and two shrew species (*Crocidura* cf. *baileyi* and *Crocidura olivieri*). *A. abyssinicus*, *H. cristata* and *S. albipes* are known to occur in agricultural fields. *D. lovati* was recorded from anthropogenic habitat for the first time in this study. The species has been described as rare or difficult to capture with conventional traps. We call for rigorous biodiversity studies and conservation measures in agroecosystems in the Ethiopian highlands to avert further losses in biodiversity and ecosystem services.

Keywords: camera trap; Ethiopia; Mount Guna; pest; rodents; shrew.

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1 Introduction

Infrared digital camera traps are widely used to investigate mammalian diversity in natural and anthropogenic habitats and can be particularly effective at capturing rare and elusive species which may otherwise be missed or under-detected by conventional trapping methods (De Bondiet et al. 2010; Dundas et al. 2019). Furthermore, a growing body of literature indicates that camera traps are more effective than conventional traps in detecting even common, but trap-shy (or trap-adverse) species with low impact on both target and non-target species (De Bondiet et al. 2010; Rendall et al. 2014). Still, the most commonly employed methods to survey the occurrence and demography of non-volant small mammals (e.g., rodents and shrews) involve the capture of individuals by conventional live traps (Gray et al. 2017).

For most of Ethiopia, the diversity of pest rodents and their impact on agriculture is documented in isolated accounts. Of the 104 species of rodents recorded for the country (Bryja et al. 2019b), about a dozen are believed to be agricultural pests. The most common pest rodents with widespread distributions in Ethiopian highland agroecosystems belong to three genera: the African Grass Rat (*Arvicanthis*), Ethiopian White-footed Rat (*Stenocephalemys*) and Multimammate Mouse (*Mastomys*) (Meheretu et al. 2015; Meheretu and Leirs 2019; Welegerima et al. 2020). Unfortunately, except for the Tigray Region (e.g., Meheretu et al. 2014, 2015), reliable long-term data on rodents in agroecosystems is unavailable for most of the Ethiopian highlands, including the Amhara Region where this study was conducted. The Amhara Region is the second largest region in Ethiopia with a predominantly rainfed agrarian population of about 22 million inhabitants. Ethiopia is an agrarian economy and poor knowledge and investment in crop protection is a major impediment to the development of robust pest rodent management and surveillance systems (see e.g., Hengsdijk and de Boer 2017). In the light of the absence of baseline information on pest rodents in the Amhara Region, this study aims to provide an insight into the local pest species occurring in agroecosystems in Ethiopian highlands using camera traps. Such information is vital for agricultural pest control experts for further in-depth studies, ultimately leading to the development of proactive, sustainable management techniques.

2 Materials and methods

This study was part of a larger research initiative investigating the efficacy of rodent repellent botanicals and their acceptance by farmers in rural Ethiopia. We conducted this study in the agrarian village of Mowecha near Mount Guna, located in Farta Woreda, Amhara region, Ethiopia (Figure 1). Here we deployed a total of 20 motion detector infrared camera traps spaced 10 m apart in the surrounding wheat fields. Specific placement of camera traps was based on investigator discretion, influenced primarily by microhabitat features and suitable areas. The centre point of the collective fields is located at approximately 11.743546°N and 38.172789°E at an elevation of 3352 m above sea level (a.s.l.). The fields were selected upon the recommendation of local pest control experts for a high incidence of rodent infestation and crop loss. The cameras were mounted on poles at a height of

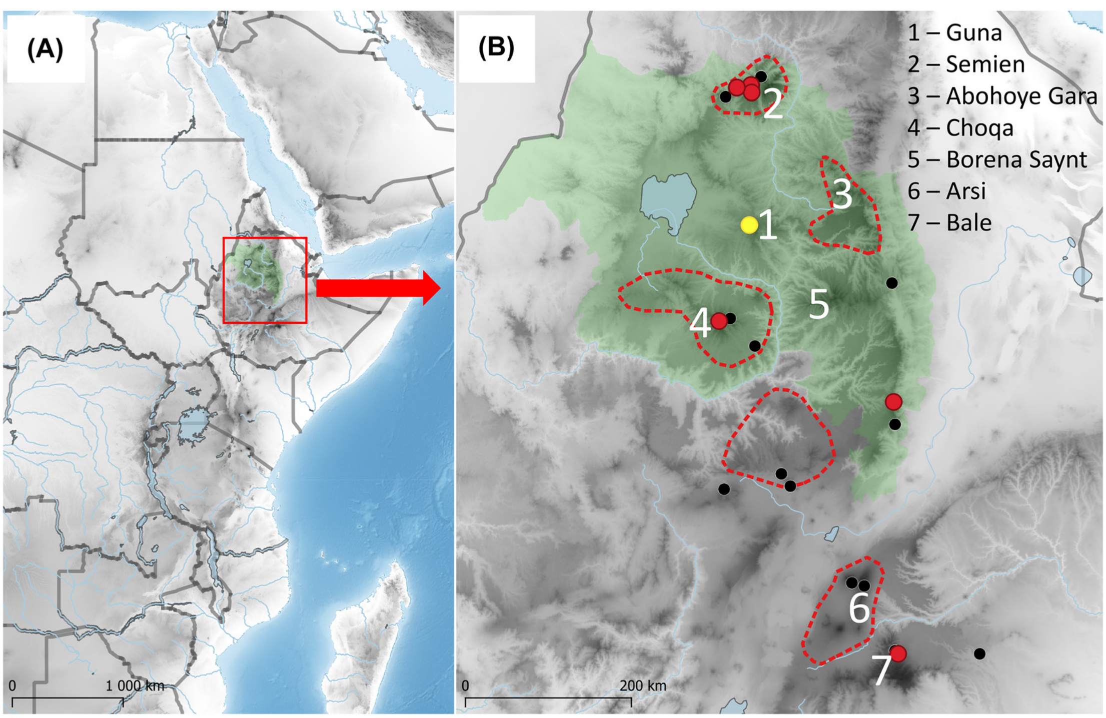

Figure 1: (A) Map of Eastern Africa, red frame is zoomed on the right panel. (B) Distribution of *Dendromus lovati* (circles) in the Ethiopian highlands. Yellow circle indicates the locality on Mt. Guna, explored in this study. Red circles show localities of genotyped specimens (Bryja et al. 2019a; Kostin et al. 2020), smaller black circles show localities from GBIF database (see Bryja et al. 2019a) and those reported by Yalden et al. (1976). Note that the population on Mt. Choqa, separated by the Blue Nile valley, are genetically very distinct and might represent a separate species (Kostin et al. 2020). Red dashed lines delimit the predicted distribution of the species according to the IUCN red list (Lavrenchenko 2016b). The numbers mark the most important mountain ranges mentioned in the text (the legend is in the right upper corner). The Amhara regional state is shown by the green background.

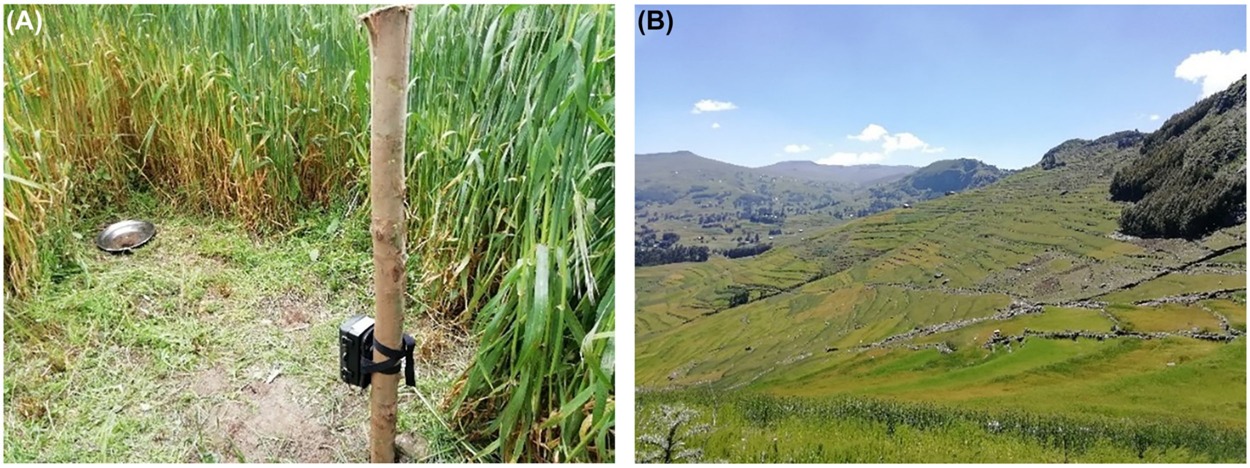

Figure 2: (**a**, **b**) A set-up of camera trap (right) and a glimpse of the agroecosystem in Mowecha village, Farta Wereda, in the Amhara region of Ethiopia. We cleared approximately one square meter of the crop at each camera location to reduce the risk of camera triggers caused by moving vegetation.

about 40–50 cm from the ground (Figure 2). Camera traps were operational for a near 16 h period each for a total of 42 experimental days between October to November 2018 (within the dry season). The cameras time delay setting was set at 10 s to minimize the risk of missing animals between captures. The same camera locations were generally maintained throughout the study and each camera was checked on a daily basis. Images were recovered from individually labelled memory cards installed on each camera and stored on the computer in separate files named after the label number of the memory cards.

Mowcha village is situated along a steep slope leading to Mount Guna which rises to an elevation of 4120 m a.s.l. at its summit (11.705985°N, 38.237103°E; Figure 1). Rainfall in the area is unimodal and the main wet season runs from March to September (Yenealem 2019). The wettest month is June with mean monthly maximum rainfall of 346 mm while the driest month is January with mean monthly maximum rainfall of 9 mm. The hottest month is March with mean monthly maximum temperature of 25 °C while the coldest month is December with mean monthly minimum temperature of 8 °C. Livelihood here depends on small-scale agriculture and the main crops grown are barley (*Hodeum vulgare*), wheat (*Triticum* spp.), potato (*Solanum tuberosum*) and different types of beans. The crops are sown shortly after a few rains early in the main wet season and harvested around November.

About 500 images of rodents and shrews were obtained from the camera traps. We first analysed all images taken by each camera each day, disregarding incomplete, unclear and blank images, as well as those belonging to other animals (e.g., insects, toads), and keeping only those images with complete views of the animals. In the last round, we considered three to four images per species with good resolution showing morphological features such as body size, shape and size of the snout, relative tail and body length and fur colour, which are useful to unambiguously discriminate species. We also supplemented the identification with our prior knowledge of trapping in similar habitats.

3 Results and discussion

3.1 Camera captured species

The cameras provided images of six rodent species (*Arvicanthis abyssinicus*, *Dendromus lovati, Dendromus mystacalis, Hystrix cristata, Mus mahomet* and *Stenocephalemys albipes*) and two shrew species (*Crocidura* cf. *baileyi* and *Crocidura olivieri*) (Figure 3). Three of the rodent species (*A. abyssinicus*, *H. cristata* and *S. albipes*) are known from agricultural fields (Lavrenchenko 2016a; Shenkute et al. 2006; Tamrat et al. 2020; Welegerima et al. 2020). Interestingly, *D. lovati*, which is easily distinguishable by its fur colouration, was detected in agricultural fields for the first time. Previously, it was only known from natural habitats, with a localized distribution on the highest mountains of Ethiopia, and for being particularly difficult to capture using conventional trapping methods (Bryja et al. 2019b; Craig et al. 2020).

A review of the literature on evidence of rodents and shrews occurring at Mount Guna and ecologically similar adjacent high mountains (Simien Mountains, Choke (or Choqa) and Abohoy Gara) at comparable elevations, but in natural habitats, yielded a list of 13 rodent and five shrew

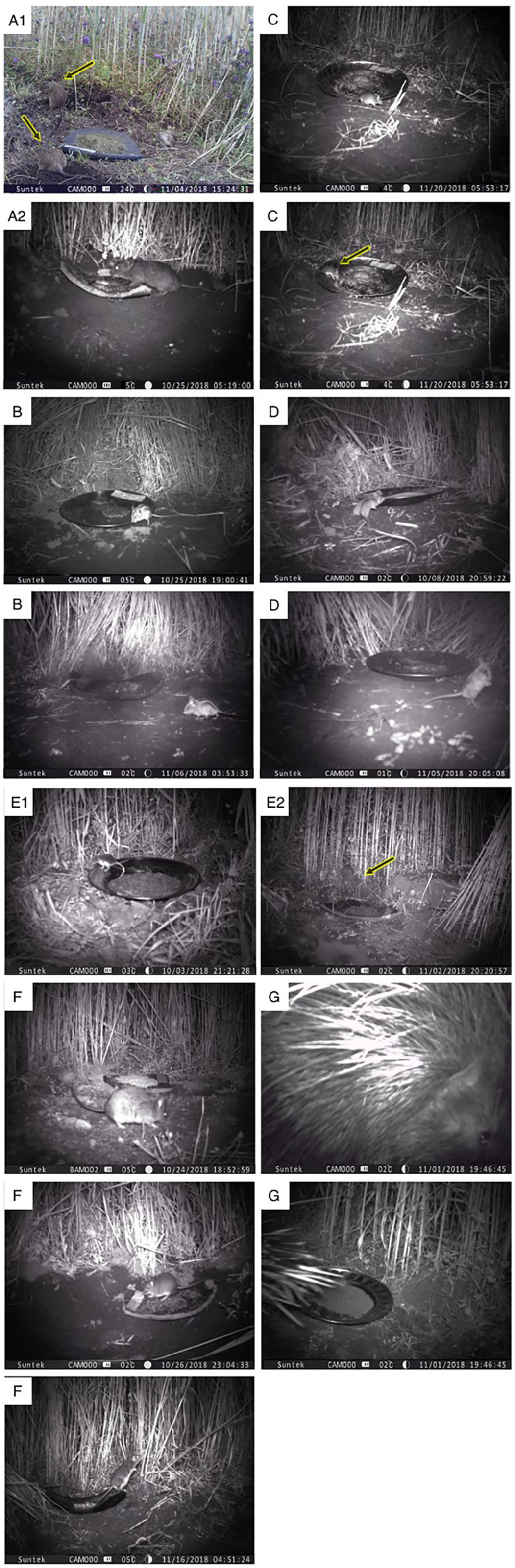

Figure 3: Rodents and shrews caught with camera traps in agricultural fields in Mowecha village, Amhara region in Ethiopia. (A) *Arvicanthis abyssinicus* [(A1) daytime (15:34 h), (A2) dusk (05:19 h)]. (B) *Dendromus lovati*. (C) *Mus mahomet* (D) *Dendromus mystacalis*. (E1) *Crocidura* cf. *baileyi*. (E2) *Crocidura olivieri*. (F) *Stenocephalemys albipes*. (G) *Hystrix cristata*.

species that could potentially be shared among them (Table 1) (see e.g., Bryja et al. 2019b; Bulatova and Lavrenchenko 2005; Craig et al. 2020; Kostin et al. 2020; Lavrenchenko and Bekele 2017). With the exception of African Giant Shrew, *C. olivieri*, the rodents and shrews recorded in this study are indeed a subset of those recorded on the adjacent mountains.

3.2 Brief species distribution and ecological account

3.2.1 Abyssinian grass rat (*A. abyssinicus*, Rüppell 1842)

A. abyssinicus was the rodent species most frequently caught by the camera traps. All captures were during the day, with one exception where it was captured at 5:19 a.m (Figure 3A1, A2), suggesting that the species is predominantly diurnal. A recent taxonomic revision of the genus using genetic markers revealed that the species represents the grass rat occupying the highest elevations in five mountain blocks west of the GRV, namely Guna, Choke, Abohoye Gara, Simien Mountains and Borena Saynt National Park (see Figure 1 for the geographic location of these mountains adjacent to Mount Guna) (Bryja et al. 2019a, b). Its geographic range extends to neighbouring Eritrean Highlands (Lavrenchenko 2016a), but genetic data for these populations are not available. Although it is predominantly a grassy Afroalpine meadow and heath species that lives between 3600 and 4000 m a.s.l. (Craig et al. 2020), the species is no stranger to anthropogenic habitats, including farmlands (Lavrenchenko 2016a; Shenkute et al. 2006). *A. abyssinicus* contributes to a significant portion of the diet of the Ethiopian wolf (*Canis simensis*) where the two species co-occur in Abohoye Gara, Simien Mountains and Borena Saynt National Park at this elevation (Atickem et al. 2017; Gutema et al. 2019; Yihune and Bekele 2014; our unpublished data). Unfortunately, the Ethiopian wolf population at Mount Guna has become locally extinct since 2010 due to habitat loss and fragmentation (Gottelli et al. 2013).

3.2.2 Lovat's climbing mouse (*D. lovati*, de Winton 1900)

D. lovati was captured on cameras only a handful of times (Figure 3B), and only at night, suggesting that the species is predominantly nocturnal. Its occurrence in farmland was unexpected, as there are no previous records associating the species with anthropogenic habitats (Lavrenchenko 2016b). *D. lovati* is easily recognized by its characteristic three dark stripes across its back and rump, while all other Ethiopian *Dendromus* taxa have at most one stripe (Bryja

Table 1: Rodents and shrews recorded from agroecosystem in this study and in natural habitats in Mount Guna and adjacent high mountains (Simien Mountains, Choke and Abohoy Gara), west of the Great Rift Valley (GRV).

Taxa	This study	Mount Guna (elevation not specified; Bulatova and Lavrenchenko 2005; Yenealem 2019)	Simien Mountains (3250 m and 3600 m; Craig et al. 2020)	Mount Choke (3421 m and 3510 m; Kostin et al. 2020)	Mount Abohoy Gara (3200–3600 m; Bryja et al. 2019b)
Order Rodentia					
Family Muridae					
Arvicanthis abyssinicus	X	X	X, at 3600	X	X
Desmomys harringtoni	–	–	X, only at 3250	X, but at lower elevation 2372 a.s.l	–
Lophuromys simensis	–	X, but as *Lophuromys* sp. or *L. flavopunctatus*	X	X	X
Mus mahomet	X	–	X, only at 3250	–	X
Mus imberbis	–	–	X	–	–
Stenocephalemys albipes	X	X, but as *S. griseicauda*	X, only at 3250	X, but at 2342, 2372 and 3421	X
Stenocephalemys zimai	–	X, but as *S.* sp. or *S. griseicauda*	X, but as *S.* sp. *A* at 3600	X, but as *S. sp. A* at 3, 421	X
Otomys simiensis	–	X, but as *Otomys* sp.	X only at 3250 m	–	X
Otomys typus	–	X, but as *Otomys* sp. or *Otomys typus*	X, only at 3600	–	X
Family Nesomyidae					
Dendromus lovati	X	–	X	X, but genetically distinct	–
Dendromus mystacalis	X?	–	X, only at 3250	–	X, genetically *D.* sp. indet 1, sensu Voelker et al. 2021)
Family Hystricidae					
Hystrix cristata	X	–	–	X (Teme et al. 2018)	–
Family Spalacidae					
Tachyoryctes splendens	–	X	? Indirect observation	X, but only at 3510	–
Order Eulipotyphla					
Family Soricidae					
Crocidura olivieri	X	–	–	–	–
Crocidura makeda	–	–	–	–	X
Crocidura cf. *baileyi*	X	X at 3800 (Bannikova et al. 2021)	X	–	–
Crocidura sp. indet.	–	–	X	–	–
Crocidura cf. *thalia*	?	X	–	–	–

"X", species recorded; "–", species not recorded in that particular study; "?", not identified to the species level hence not possible to compare with similar species under the same genera.

et al. 2019b). It occurs in grasslands in Afromontane forests, ericaceous heaths and Afroalpine meadows (Craig et al. 2020) on both sides of the Rift Valley between 2500 and 3550 m a.s.l. (Yalden et al. 1976, 1996), but Craig et al. (2020) extended its highest altitudinal distribution to 4000 m a.s.l by sampling several individuals of the species in the Simien Mountains north of our study area (Figure 1). The species has been described as very rare with localized distributions in natural habitats on only the highest mountains of Ethiopia and is particularly difficult to capture using conventional trapping methods (see e.g., Dieterlen 2009). The majority (12 of 17, i.e., 71%) of the individuals of *D. lovati* sampled by Craig et al. (2020) came from pitfall traps. Craig et al. (2020) therefore argue that the supposed rarity of the species in previous sampling within its range may be due to this sampling bias.

3.2.3 Chestnut climbing mouse (*Dendromus mystacalis*, Heuglin 1863)

Until recently *D. mystacalis* was thought to have a disjunct distribution in Eastern and Southern Africa (e.g., Child and Monadjem 2016; Wilson et al. 2017). However, a recent systematic assessment of the genus based on genetic data confirmed Dieterlen's (2009) claim that the species is endemic to Ethiopia (Bryja et al. 2019b; Voelker et al. 2021). Compared to *D. lovati*, the species is widespread in Ethiopia and occurs on both sides of the GRV, typically between 2000 and 3000 m a.s.l. (although populations east of the GRV have not yet been genetically confirmed; Bryja et al. 2019b). We camera trapped this single-striped species (Figure 3D) in the same farmland as *D. lovati*, suggesting that the species co-occur at some elevations, as they did in the Afromontane forest/ericaceous heathland belt in the Simien Mountains between 2900 and 3300 m a.s.l. (Craig et al. 2020). Furthermore, as with *D. lovati*, all images of *D. mystacalis* were captured during the night, suggesting that both species were active at the same time. Note that we do not rule out possible misidentification of the species with *D.* sp. indet. 1 (sensu Voelker et al. 2021) which is also a single-striped Afromontane species (Bryja et al. 2019b).

3.2.4 Mahomet pygmy mouse (*Mus mahomet*, Rhoads 1896)

Eight species of the African pygmy mice of the subgenus *Nannomys* occur in Ethiopia, six of which are endemic to the country (Bryja et al. 2014). Among them, the most abundant and widespread across the Ethiopian highlands is *M. mahomet* (Bryja et al. 2014, 2019b). It can be relatively easily recognized by its whitish belly separated from the greyish upper part by a narrow orange band (Figure 3C). The species occurs in montane forests, scrublands and grasslands on either side of the GRV, between 1500 and 3400 m a.s.l. It can easily adapt to grasslands that have recently been cleared for agriculture (Lavrenchenko 2016c).

3.2.5 White-footed Ethiopian rat (*S. albipes*, Rüppel 1842)

S. albipes was the second most captured species by camera traps during the study, and only at night, suggesting that the species is predominantly nocturnal (Figure 3F). It is widespread on both sides of the GRV from 800 to 3300 m a.s.l. (Bryja et al. 2018) and may co-occur with its congener *Stenocephalemys zimai* on Mount Guna (Mizerovská et al. 2020). We cannot rule out a possible misidentification of the two species, however, the two can easily be differentiated based on their relative tail length proportions, which is always higher in *S. albipes* (tail length ca. 125% of head and body length in *S. albipes* compared to just 83% in *S. zimai;* Mizerovská et al. 2020). *S. albipes* inhabits primary montane forest and forest patches, but it can also occur in mosaic habitats including bushlands and shrublands in Ethiopian highlands, especially in their northern part (Welegerima et al. 2020). A growing number of recent studies have shown that the species is thriving undoubtedly in agricultural fields (Meheretu and Leirs 2019; Welegerima et al. 2020) and peri-domestic areas (Meheretu et al. 2012, 2013). The species accounted for 65% (151/230) of pest rodent species trapped from wheat and barley fields in northern Ethiopia from 2000 to 2400 m a.s.l (Welegerima et al. 2020). Both *S. albipes* and *S. zimai* are known hosts of the Tigray orthohantavirus (TIGV) as detected from populations in natural habitats in the Simien Mountains (Meheretu et al. 2019). Orthohantaviruses are emerging zoonotic negative-sense RNA viruses belonging to the family Hantaviridae, order Bunyavirales (see Noack et al. 2020). TIGV was first discovered in 2012 in the neighbouring Tigray Region from synanthropic *S. albipes* trapped from 2600 to 2700 m a.s.l (Meheretu et al. 2012). Recently, orthohantavirus-reactive IgG antibodies have been detected in humans (seroprevalence = 5.26%) and *S. albipes* (seroprevalence = 8.69%) in the same villages where the virus was first detected (Meheretu et al. 2021). The widespread occurrence of *S. albipes* in anthropogenic habitats in the Ethiopian highlands, therefore, remains a potential public health concern. Note that the pathogenicity of the virus to humans has yet to be established, an interesting area for future research.

3.2.6 Crested porcupine (*H. cristata*, Linnaeus 1758)

H. cristata is a large rodent with a body mass reaching up to 17 kg (Mori and Lovari 2014). Recent studies indicate that the species is in threat of extinction throughout most of its sub-Saharan African range (Viviano et al. 2020). While the main threats are hunting for bushmeat and traditional medicine practices, the species is also subject to persecution as it is widely reported to be a crop pest (Viviano et al. 2020). Likewise, it has been reported as being a crop pest in Ethiopia (Alemayehu and Tekalign 2020; Datiko et al. 2007; Tamrat et al. 2020).

H. cristata was captured by a camera trap only at one night (Figure 3G) in the crop fields. Note that the camera did not capture the full view of the species likely because the camera position was set to capture rodents with smaller size than this species. Little is known about the ecology and distribution of the species in Ethiopia despite its occurrence across most of the country at a wider range of elevations; exceptions include the arid regions of Afar and Somali, northeast and southeast of the country respectively (Amori et al. 2016).

3.2.7 Bailey's shrew (*Crocidura* cf. *baileyi*, Osgood 1936)

Crocidura baileyi is a medium-sized shrew with a distinctively bicoloured pelage and tail, reddish-brown dorsally contrasting with white beneath (Yalden et al. 1976; 1996). The species can be differentiated by its distinct white belly which is evident in Figure 3E1. It prefers a humid locality with tall grasses in Afroalpine moorland and humid heather forest distributed west of the GRV between 2700 and 3300 m a.s.l. (Craig et al. 2020; Lavrenchenko et al. 2016).

3.2.8 The African Giant Shrew (*C. olivieri*, Lesson 1827)

C. olivieri is easily recognizable by its relative size compared to other shrews in Ethiopia. It is the largest shrew species in Africa with a body mass of up to 65 g and a body length reaching up to 240 mm, including the tail which is about 80% of the body length (Churchfield and Hutterer 2013). Besides, it is one of the most common and abundant insectivorous small terrestrial mammals in sub-Saharan Africa where it occurs in many habitats, including agricultural fields and domestic/peri-domestic habitats up to 2680 m a.s.l. Our record from Mowcha village probably indicates its highest elevational limit (Figure 3E2). It is not the first time that the species has been recorded in anthropogenic habitats in Ethiopian highlands, including crop fields and peri-domestic habitats (see Meheretu et al. 2012, 2013). The most recent report on the diversity of Ethiopian shrews by Konečný et al. (2020) has elevated the country's species list to 31 (29 *Crocidura* and two *Suncus* species) with 13 of the *Crocidura* species endemic to the country.

4 Conclusions

This brief study has undoubtedly demonstrated the ability of camera traps to rapidly document rodent and shrew communities in agroecosystems. In doing so, it also provides insight into the community of pest rodents that pest management professionals should expect to find in farmlands in the Ethiopian highlands at a given elevation. *A priori* baseline information is important to enabling rapid intervention should a significant pest infestation occur in the future, or a rodent-associated zoonosis flare-up in the region. Nevertheless, we believe that this study has only covered a fraction (even if significant) of the rodents and insectivores present in the agroecosystem. Therefore, detailed studies that spatially focus on different cropping patterns and patchy vegetation and temporally encompass both the wet and dry seasons are needed to gain better insight into the diversity, demography and habitat use of small mammals.

Research ethics: Permission to conduct the research was obtained from the Amhara Bureau of Agriculture, Bahir Dar, Ethiopia. Verbal consent was obtained from the farmers who volunteer their farms to deploy the camera traps.

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Conflict of interest statement: The authors declare no conflicts of interest regarding this article.

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