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Abundance and microhabitat use of rodent species in crop fields and bushland in Ethiopia

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Abstract. The abundance and microhabitat use of rodents were investigated in four different habitats: two rain-fed crop fields with differing stone bund density, an irrigated field and bushland. A total of 444 individual small mammals belonging to six rodent and one shrew species were recorded in trapping grids and line transects. Of these, 230 individuals (52%) belonged to three pest rodent species of crop fields in northern Ethiopia: *Stenocephalemys albipes* (65%), *Mastomys awashensis* (25%) and *Arvicanthis niloticus* (10%). Population abundance of the three species was higher in the early dry season compared to the rainy season. While the bushland was significantly ($p < 0.05$) favoured by *S. albipes* and *M. awashensis* in both seasons, the irrigated field was preferred by *Arvicanthis niloticus* in the early dry season. In the early dry season, the microhabitat use of *A. niloticus* was strongly associated with the type of ground cover (herb) ($R^2_{adj} = 0.152$, $P < 0.01$). While *M. awashensis* was associated with vegetation density ($R^2_{adj} = 0.13$, $P < 0.01$), *S. albipes* was associated with vegetation cover ($R^2_{adj} = 0.102$, $P < 0.001$). The findings indicate that co-occurring pest rodent species prefer different microhabitats. Understanding their co-occurrence particularly in crop fields is vital for crop protection as they are known serious agricultural pests in northern Ethiopia.

Key words: small mammals, pest species, ground cover, pest management, Tigray

Introduction

Characterizing landscape features and environmental factors that best explain variation in the presence and abundance of organisms in particular habitats is one of the main focuses of ecological studies (Turner 2005). Within the same landscape and specific habitat, organisms often differ in their sensitivity to the degree of heterogeneity and as a result may show differences in habitat use (Orrock & Pagels 2003, Coppeto et al. 2006). Habitat use depends on the features of the habitat and individual responses in terms of dispersal ability, habitat affinities and habitat quality in terms of

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resource availability and predation risk (Williams et al. 2002, Sullivan et al. 2017). Habitat preference in an area may also reflect home ranges or the allocation of shelter and foraging sites within a given habitat (Hodara & Busch 2010). Species may be more widely distributed and abundant in some habitats compared to others (Cramer & Willig 2005).

Small mammals are often the target for studies on habitat use because they are characterized by relatively small home ranges (Hodara & Busch 2010) and are capable of rapid population growth allowing them to respond quickly to habitat change (Bagne & Finch 2010). They show strong relationships and interactions with plant communities (Bowers et al. 1996) and are associated with seed dispersal (Hollander & Vander Wall 2004, Schnurr et al. 2004) and predator population dynamics (Zielinski et al. 1983). Numerous previous studies have examined patterns of segregation of coexisting rodent species into structurally distinct microhabitats (e.g. Dueser & Shugart 1978, Harper et al. 2005, Hodara & Busch 2010). Microhabitats are distinct portions of the available space that meet the niche requirements and have been explained in terms of environmental variables affecting individual behaviour, determining which specific microhabitats within the home range are more intensively used (Morris 1987). This selection of distinct microhabitat is a basic mechanism that allows different species of small mammals to cohabit (Dalmagro & Vieira 2005, Freitas et al. 2005). Therefore, their overall characteristics including complex behaviour make small mammals a good subject for evaluating habitat use.

The Tigray Region in northern Ethiopia is mostly semi-arid with the landscape characterized by highland (area above 2000 m a.s.l.) and agricultural fields around human settlements. In some places protected areas, either bush or scrubland, have been established near human settlements and crop fields as part of soil and water conservation measures. The protected areas are free from animal grazing and other human-related disturbance. The typical Tigray landscape used by humans is thus a mosaic of rain-fed and irrigated fields, fallow lands, bush and scrubland. These habitats show seasonal changes in ground vegetation cover and resource availability, which could influence the occurrence and microhabitat use of small mammals such as rodents and shrews.

Three rodent species, *Arvicanthis niloticus*, *Mastomys awashensis* and *Stenocephalemys albipes* (Muridae) have been reported as the major crop pests in Tigray Region (Meheretu et al. 2014, Meheretu & Leirs 2019). Previous studies on rodent assemblages in Ethiopia have focused on species distribution, relative abundance and composition (e.g. Kasso et al. 2010, Takele et al. 2011, Datiko & Bekele 2014, Kostin et al. 2018), systematics and taxonomy (Bryja et al. 2014, 2018, 2019a) and population dynamics (Gebresilassie et al. 2006, Meheretu et al. 2014). Few detailed investigations have been conducted on habitat use by rodents in Ethiopia (Wube & Bekele 2001, Gebresilassie et al. 2006). The current study aimed at investigating the abundance and microhabitat use of rodent species in four habitats, namely bushland, crop fields with low densities of stone bunds (low stone walls constructed in the fields to prevent soil erosion by runoff and retain moisture) crop fields with high densities of stone bunds and irrigated crop fields. The study further aimed to identify seasonal variations in rodent abundance among the habitats during the rainy and early dry seasons.

Material and Methods

Description of the study area

The study was conducted in the Klte-Awla'elo District of Tigray Region in northern Ethiopia (Fig. 1, Fig. S1). The altitude of the study area ranged from 2000 to 2400 m a.s.l. Data were collected from June to December 2018 in the three crop fields, namely (i) a crop field with low density of stone bunds (CFL), (ii) a crop field with high density of stone bunds (CFH) and (iii) an irrigated crop field (IF), and in a bushland habitat (BL) (also called exclosure), in order to investigate rodent abundance and microhabitat characterization (Table 1, Fig. S2). The rainy season runs from mid-June to mid-September while the early dry season runs from October to December. We excluded data from June and the analysis covered six months (three in the rainy season and three in the early dry season). In the rain-fed crop fields, wheat (*Triticum* spp.), barley (*Hordeum vulgare*) and teff (*Eragrostis tef*) are mainly grown during the rainy season. The irrigated field is cultivated with vegetables such as cabbage (*Brassica* spp.), carrot (*Daucus carota*), orange (*Citrus sinensis*) and guava (*Psidium guajava)* and cereal crops such as maize (*Zea mays*) at least twice a year, during the rainy (rain-fed) and dry (October to May) seasons. The bushland habitat

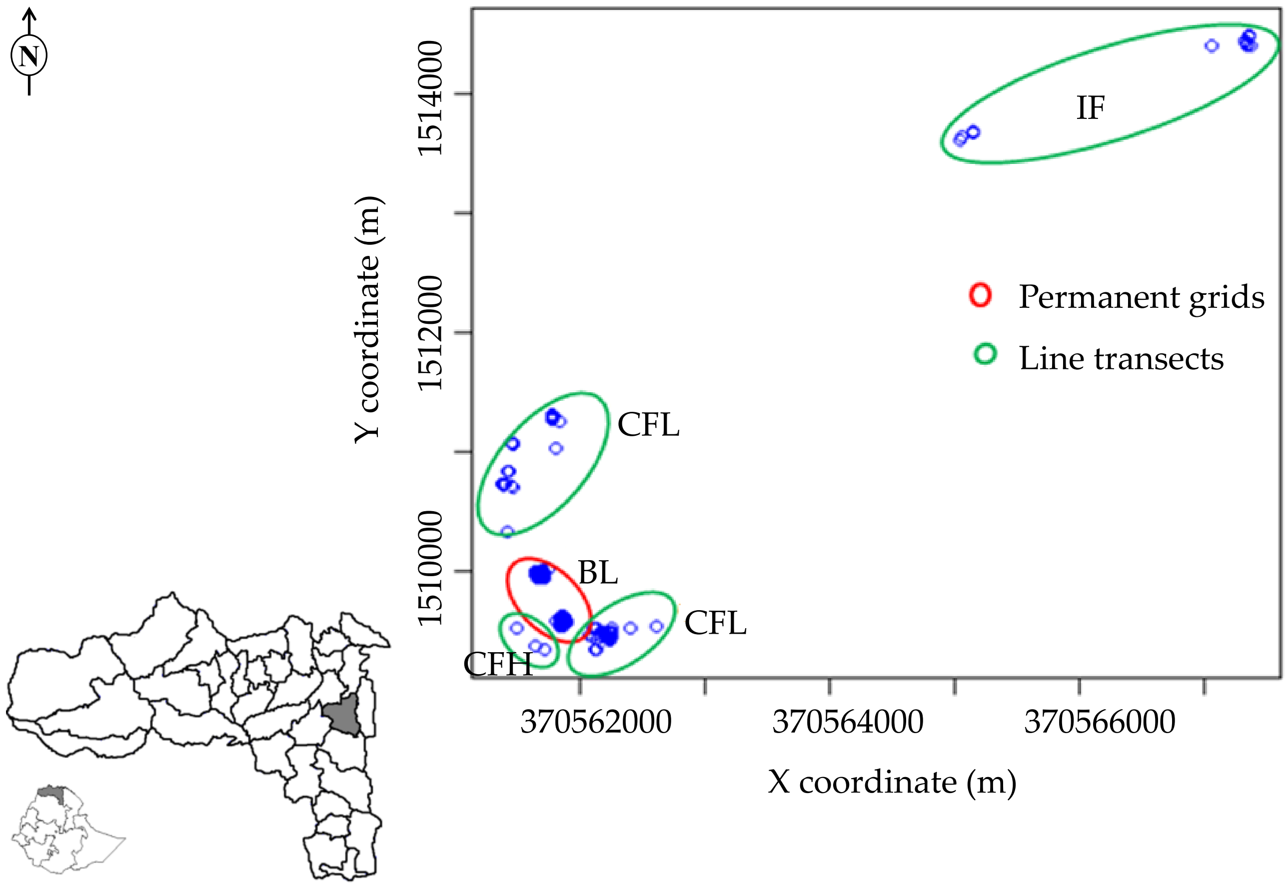

Fig. 1. Study area and geographic coordinates of successful trap stations for the three rodent species in each of the four habitat types in Klte-Awla'elo District, 2018 (map is not to scale).

Table 1. Description of the four habitat types (see Fig. S2). The local Tigrigna names are in brackets.

Habitat types	Description
1. Bushland (BL)	This is an "area enclosure" protected for more than 20 years as part of water and soil conservation programs in the Tigray Region. It is free from animal grazing and has limited human disturbance. Vegetation is mainly dominated by *Acacia ethbaica* (seraw) with *Hyparrhenia hirta* (Sa'eri-geza). A number of indigenous plants are recovering including *Aloe* spp. ('ere), *Rhus* spp. (TeTa´lo), *Eucleas himperi* (Kli´ow), *Rumex nervosus* (H´eh´ot), *Mytenus senegalensis* (Arugudi), *Dodonea angustifolia* (Tahses), *Solanum incanum* (´Ngule), *Leucas abyssinica* (Swa-qerni), *Carissa edulis* ('Egam) and *Cynodon dactylon* (Tahag). Exotic plants in this habitat include *Acacia saligna* (Akacha).
2. Crop field with low stone bunds (CFL)	Rain-fed crop fields with low stone bunds density are those with stone bunds spaced approximately 30 m apart. During the rainy season (June-September) barley and wheat are the only vegetation cover.
3. Crop field with high stone bunds (CFH)	Crop fields with high stone bunds density. Stone bunds are spaced approximately 10 m apart. Stone bunds area either in a natural setting or terraced and contour bounded. The stone bunds are set within the crop field for water and soil conservation.
4. Irrigated crop field (IF)	Irrigated crop fields are mainly for cash crops during the dry season. They are surrounded by many permanent fruit plants and herbaceous vegetation on the edges of the fields. Crops include tomato, onion, potato, carrot and cabbage. The vegetation composition is completely different from the three other habitats and includes *Citrus sinensis* (Aranshi), *Psidium guajava* (Zeytuhun), *Pennisetum purpureum* (Sa'eri-harmaz), *Nicotiana glauca* (Men-gededo) and *Datura stramonium* (Mesten'agr).

consists of steep degraded slopes where trees and vegetation are left to regenerate naturally and protected by the community from free livestock grazing and uncontrolled woodcutting (Jacob et al. 2019). Natural bushland vegetation comprises *Acacia ethbaica* and *Hyparrhenia hirta* and a number of indigenous plants are recovering including *Aloe* spp., *Rhus* spp., *Eucleas himperi*, *Rumex nervosus*, *Mytenus senegalensis*, *Dodonea angustifolia*, *Solanum incanum*, *Leucas abyssinica*, *Carissa edulis* and *Cynodon dactylon*. We defined low density of stone bunds as an inter-bund distance of about 15 m and high density of stone bunds when the inter-bund distance of about 10 m (see Meheretu et al. 2014 for more detail). This is important because significantly more rodent captures were reported in fields with higher density of stone bunds than fields with lower density of stone bunds (Meheretu et al. 2014).

Small mammals sampling and microhabitat use

Small mammals were sampled using a combination of capture-mark-recapture (CMR) and removal trapping (RT). Two permanent CMR grids were set in the BL, while two line transects were set in each of the four habitats (BL, CFL, CFH and IF) (Table 1 and Fig. 1).

The CMR grids each measured 70 × 70 m and were spaced 300 m apart. Each grid consisted of seven parallel trapping lines spaced 10 m apart. Each trapping line consisted of seven trapping stations also 10 m apart. A single Sherman live-trap was set at each trapping station, making a total of 49 traps per grid. The traps were set for three consecutive days every month. Traps were baited with peanut butter mixed with barley flour and captures were inspected in the morning (06:00-07:00 h) and late in the afternoon (17:00-18:00 h). Captures were identified to species, marked with toe-clipping codes, weighed, sexed and their reproductive status (perforated or closed vagina in females and scrotal or non-scrotal testes in males) recorded, before being released at the trap stations where they were captured.

Line transects for RT consisted of 50 trapping stations spaced 2 m apart. A single Sherman live-trap was set at each trapping station, making a total of 50 traps per trapping line. The two line transects in each habitat type were spaced about 200 m apart. The traps were set for three consecutive days every month, baited with peanut butter mixed with barley flour, and captures were inspected in the morning (06:00-07:00 h). Captures were moved to the lab at Mekelle University in Ethiopia, identified to species level, weighed, sexed and their reproductive status were recorded. Then, the specimens were euthanized and standard external body measurements (body, tail, foot and ear lengths) were recorded.

Microhabitat use

A wooden frame measuring 1 × 1 m was used to demarcate a quadrant centred at trap stations where animals were caught in both the grids and line transects. The quadrant was divided into 16 small squares (25 × 25 cm each) using a rope. Microhabitat characterization was conducted using the quadrant for three purposively selected rodent species, namely *A. niloticus*, *M. awashensis* and *S. albipes*. We considered these three species because they are important agricultural pests and the most abundant rodent species co-occurring in crop fields in the region (Meheretu et al. 2014, Meheretu & Leirs 2019). Microhabitat characterization was carried out for each capture of the three species. First, the quadrant was laid at the trap station of capture, a GPS reading was taken and the presence and absence of cracks (Cr) and stone bunds (St) inside the quadrant was recorded. The type of ground cover was characterized and coded as bare soil, herb, grass, crop (barley or wheat), mixed-1 (50% grass + 50% stone bund) and mixed-2 (50% grass + 50% herb). A visual estimate of percentage vegetation cover (PVC) was made for each quadrant. Average height of vegetation (AVH), density of vegetation cover (VD) visual estimate of percentage tree canopy cover (CVC), diameter at breast height (DBH) and distance to the nearest shrub (DNS) (≥ 2 m height within ≤ 3 m radius from a successful trap station) were recorded based on standard methods described in the literature (Dueser & Shugart 1978, Cerqueira & Freitas 2005, Vieira et al. 2005, Smith et al. 2005, Smith & Fox 2017).

Data analysis

We calculated sampling effort in terms of trap-nights. A trap-night refers to one trap set for a 24-hour period. Accordingly, we computed total trap nights as a product of number of traps in use for a 24-hour period, number of trapping days per month and number of trapping months. A Chi-squared test was used to test for differences in the proportions of habitat used by each species. Redundancy analyses (RDA) (Borcard et al. 2011) was used to establish significant microhabitat characteristics as environmental predictors of species abundance by generating estimates of adjusted R^2 (R^2_{adj}), using the R package *vegan* (Oksanen et al. 2019), and the package *packfor* in R (Dray et al. 2009) to run a forward selection procedure in RDA (Blanchet et al. 2008) for both rainy and early dry seasons.

Results

Abundance

A total of 444 small mammals belonging to seven species were captured in 4,158 trap nights from the four habitats. Six of the species were rodents, namely *Acomys caharinus, Arvicanthis niloticus, Mastomys awashensis, Mus proconodon, Myomyscus brockmani* and *Stenocephalemys albipes*, and the remaining one species was the shrew (*Crocidura olivieri*) (Table 2). The three target species (*A. niloticus, M. awashensis* and *S. albipes,* rodent species hereafter) accounted for 52% (230/444) (Fig. S3), while the other species (*A. caharinus, M. proconodon, M. brockmani* and *C. olivieri*) accounted for 48% (214/444) of the total captures (Table 2). The Ethiopian white-footed rat (*S. albipes*) accounted for the largest proportion of the target species (65%, 151/230) followed by *M. awashensis* (25%) and *A. niloticus* (10%). About 54% (125/230) of the rodent species were captured in the early dry season and the remaining about 46% (105/230) were in the rainy season (Table 3).

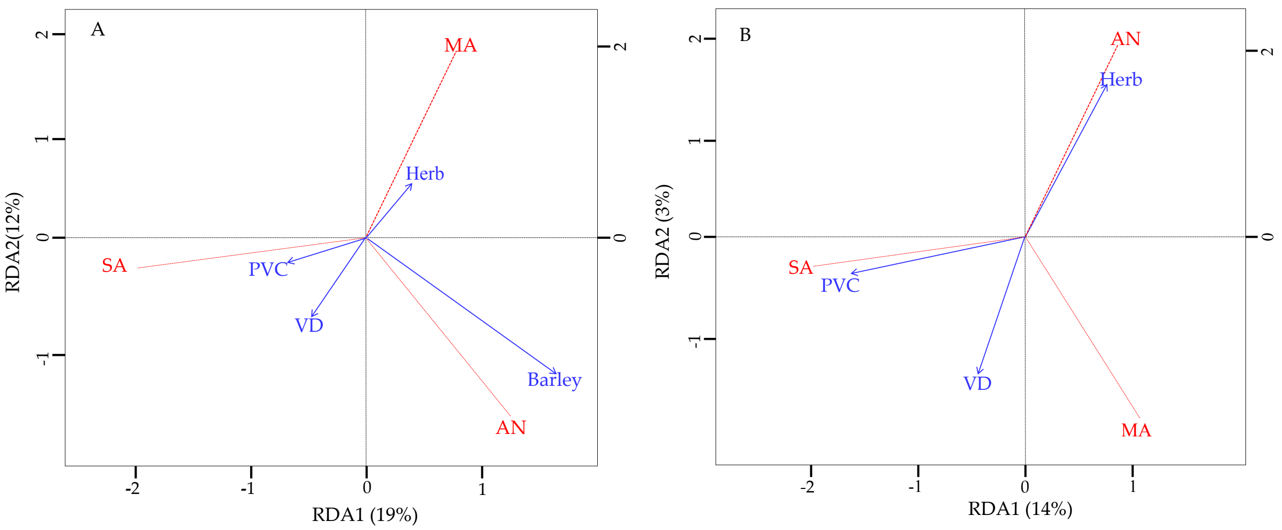

Fig. 2. RDA axes summarizing microhabitat variation and the position of each rodent species relative to these variables (A) during the rainy season and (B) during the early dry season. Arrows correspond to the contribution of each variable on the three rodent species and represented by *S. albipes* = SA, *M. awashensis* = MA and *A. niloticus* = AN, Percentage vegetation cover = PVC, Vegetation density = VD, Herb and Barley. During the rainy season (A), the two canonical axes explain together 31% of the total variance of the data, the first axis alone explaining 19%. During the dry season (B), the two canonical axes explain together 17% of the total variance of the data while the first axis alone explaining 14% of the variation.

Table 2. Number of rodent species recorded in the grids and trap lines. Rodent species with the symbol * are target species of this study for characterizing habitat and microhabitat use because of their importance as agricultural pests and co-occurring in crop fields in Tigray.

	Method						
	Grid			Line Transect			
Species	Male	Female	Total/grid	Male	Female	Total/transect	Total
*A. niloticus**	2	-	2	11	9	20	22
*M. awashensis**	13	23	36	10	11	21	57
*S. albipes**	77	33	110	23	18	41	151
Sub total			148			82	230
A. cahirinus	63	38	101	71	29	100	201
C. olivieri	2	3	5	3	3	6	11
M. proconodon	-	-	-	-	1	1	1
M. brockmani	-	-	-	-	1	1	1
Sub total			106			108	214
Total							444

Table 3. Seasonal abundance of the three target species of rodents captured in the four habitat types.

	Rainy season				Early dry season				Total/habitat
Habitat	SA	MA	AN	Total/habitat /season	SA	MA	AN	Total/habitat /season	
BL	39	16	-	55	70	20	2	92	147
CFL	13	2	8	23	-	-	-	-	23
CFH	16	8	3	27	8	5	1	14	41
IF	-	-	-	-	5	6	8	19	19
Total				105				125	230

S. albipes = SA, *M. awashensis* = MA and *A. niloticus* = AN, Bushland = BL, Crop fields with low stone bunds = CFL, Crop fields with high stone bunds = CFH, Irrigated crop field = IF.

Table 4. RDA calculated for the microhabitat variables and overall variation in microhabitat use in both seasons by the three rodent species at Klte-Awla'elo, Tigray.

Season	Global RDA (environmental variables)	R^2	R^2_{Adj}	*P* value
Rainy	Barley	0.155	0.146	0.001***
Dry	PVC	0.109	0.102	0.001***
	VD	0.144	0.13	0.009**
	Herb	0.173	0.152	0.004**

This table summarizes the contribution of the significant microhabitat variables, which quantifies the contribution of each variable. ****P* < 0.001; ***P* < 0.01.

Habitat use

While the bushland was significantly ($p < 0.05$) favoured by *S. albipes* and *M. awashensis* in both seasons, the irrigated field was preferred by *A. niloticus* in the early dry season. The crop field with high density of stone bunds supported relatively more rodent species (18%, 41/230) than the low stone bund density field (10%, 23/230). In the bushland habitat, *S. albipes* accounted for the greatest proportion of the captures in the early dry (76%, 70/92) and rainy (70%, 39/55) seasons and *M. awashensis* was second (Table 3, Table S1). No rodent was captured in the crop field with low density of stone bunds during the early dry season or in the irrigated field during the rainy season. *A. niloticus* accounted for 42% (8/19) of the captures in the irrigated field during the early dry season (Table 3).

Microhabitat use

There was a clear association between the occurrence of rodent species and three variables at microhabitat level. Percentage vegetation cover (PVC), type of vegetation cover (barley and herb) and density of vegetation cover (VD) contributed significantly to explaining the variation in rodent species in both seasons (Table 4). During the rainy season, the RDA showed that the microhabitat predictors explained about 31% of the total variance in rodent microhabitat use (Fig. 2A). The first axis alone explained 19% of the variance and *A. niloticus* was strongly associated with the type of vegetation cover (barley) which supported 14.4% ($R^2_{adj} = 0.146$, $P < 0.001$) (Table 4). However, *M. awashensis* and *S. albipes* were not significantly correlated with any of the variables during the rainy season.

For the early dry season, the RDA sowed that the microhabitat predictors explained about 17% of the total variance in rodent microhabitat use, while the first axis alone explained 14% of the variance (Fig. 2B). In this season, the microhabitat use of *A. niloticus* was strongly associated with the type of vegetation cover (herb) which supported 15.2% ($R^2_{adj} = 0.152$, $P < 0.01$). While *M. awashensis* was associated with vegetation density (13% supported) ($R^2_{adj} = 0.13$, $P < 0.01$), *S. albipes* was associated with percentage vegetation cover (10.2% supported) ($R^2_{adj} = 0.102$, $P < 0.001$) (Table 4).

When data from both seasons were pooled, the RDA revealed that three microhabitat variables, percentage vegetation cover, type of vegetation cover (wheat, barley and herb) and distance to the nearest shrub (DNS), contributed significantly to variation at microhabitat level and accounted for differences in microhabitat use among the three rodent species (Fig. S4, Table S2). The first two

RDA axes explained 26% of the variation at the microhabitat level and were strongly associated with the three species (R^2_{adj} = 0.2614, $P < 0.001$) (Fig. S4). The first axis alone explained 19% of the variation by percentage vegetation cover and associated with *S. albipes*. The second axis explained an additional 7% of the variation due to type of vegetation cover (wheat, barley and herb) and distance to the nearest shrub. While *M. awashensis* was significantly associated with wheat and distance to the nearest shrub, *A. niloticus* was associated with herb and barley. The other variables showed shorter projections in the graph indicating that they do not obviously explain the variation in microhabitat use for the three rodent species in either season and were excluded from the RDA graph.

Discussion

Species composition and season

Of the seven species of small mammals captured, the three target rodent species comprised about 52%, supporting our initial assertion that these are most abundant pest rodent species co-occurring in agroecosystems in Tigray (also see Meheretu et al. 2014, Meheretu & Leirs 2019). Furthermore, more (about 54%) rodents were captured during the early dry season than the rainy season (46%), in agreement with earlier reports in northern Ethiopia (Meheretu et al. 2014) and Tanzania (Massawe et al. 2011), where rodent species abundance peaks after the rain stops. It was argued that the end of the rain marks increased availability of food and cover as vegetation and crop growth advances, with no risk of burrows becoming flooded. Further, the rodent breeding season corresponds to the rainy season so the population peaks at the end of the rain. Most of the small mammal species captured in the study area have been reported from several localities in northern Ethiopia. Two species, however, are rare members of the Ethiopian fauna of open habitats and their findings are interesting from a biogeographical point of view. *Mus proconodon*, an Ethiopian endemic, has only been reported from Hagere Selam and *Myomyscus brockmani* from Grakahsu forest near Alamata, both in the Tigray Region, northern Ethiopia (Bryja et al. 2019b).

Microhabitat preference of sympatric rodents

The abundances of the three rodent species varied among the four habitat types. The bushland habitat supported the highest abundance of all species in both seasons. Furthermore, the crop field with a high density of stone bunds supported relatively more rodents than the crop field with a low density of stone bunds in both seasons. This could be attributed to the overall strong association of the rodent species with high ground cover. The relatively high ground vegetation cover in the bushland might have contributed to greater availability of food and cover against potential predators (Manning & Edge 2004, Jacob 2008, Van Deventer & Nel 2012). Rodents may prefer stone bunds built close to each other because they feel safe to easily move around and hide nearby before being spotted by predators (Meheretu & Leirs 2019) compared to when the stone bunds are built far apart. This observation agrees with an earlier report from Tigray which found a higher abundance of rodents in fields with a higher density of stone bunds (Meheretu et al. 2014).

The Ethiopian white-footed rat (*S. albipes*), a possible endemic to Ethiopia (some reports suggest its presence in neighbouring Eritrea), occurred in all four habitat types investigated (not considering seasonal difference). Previous reports indicated that the species predominantly occurs in montane forest habitats (Bekele 1996, Bryja et al. 2018, 2019b). However, as Bryja et al. (2019b) indicated the species also occurs in other habitats and likely is rapidly spreading across most of the Ethiopian highlands. The current study extends the occurrence of the species to semi-arid bushland, rain-fed crop fields and irrigated fields in northern Ethiopia. Furthermore, the species co-occurred with the other two rodent species in all the four habitats investigated. Additionally, in northern Ethiopia, *S. albipes* has also been reported from peri-domestic and domestic areas (Meheretu et al. 2012).

The Awash multimammate mouse (*M. awashensis*), also an Ethiopian endemic, was the second most abundant rodent species in the bushland, crop field with a high density of stone bunds and irrigated field. The species is the sister taxon of the Natal multimammate mouse (*M. natalensis*), a widespread species in sub-Saharan Africa and known as a serious agricultural pest throughout its distribution (Martynov et al. 2020). *Mastomys awashensis* has also been reported as an agricultural pest in northern Ethiopia (Nyssen et al. 2007, Meheretu et al. 2014).

The grass rat (*A. niloticus*) occurred only in the two crop fields with stone bunds during the rainy season and mostly in the irrigated field during the early dry season. This suggests that the species occurs in the crop fields during the rainy season when crop cover is available and leaves the crop fields during the early dry season when the crops are harvested. As a diurnal species, *A. niloticus* requires a significant amount of cover against potential predators (Wube 2005, Meheretu & Leirs 2019). In northern Ethiopia, the species has been reported to occur more often in irrigated fields with monocot plants (Gebresilassie et al. 2004) and wheat and barley fields with a high density of stone bunds (Meheretu et al. 2014). During the rainy season, *S. albipes* was not significantly correlated with any of the microhabitat variables measured. However, it showed a significant correlation with a higher percentage of vegetation cover during the early dry season. Likewise, *M. awashensis* was not significantly correlated with any of the microhabitat variables measured during the rainy season but showed a significant correlation with a higher density of vegetation cover during the early dry season. These results are not unexpected since vegetation cover was not a major concern in the rainy season and although both rodents are nocturnal species, they are expected to require more cover during the early dry season than the wet season where vegetation cover dwindles. On the other hand, the diurnal *A. niloticus* was strongly associated with the type of vegetation cover (barley and herb) in both seasons. It was interesting to note that *A. niloticus* showed a tendency to shift its microhabitat preference from barley fields during the rainy season to herbaceous cover during the early dry season, after the harvest. This is in agreement with earlier reports in general, many animal species tend to choose their foraging sites based on particular microhabitat characteristics within their habitat (Thornton & Hodge 2008).

Note that, with the exception of a new association of *M. awashensis* with the type of vegetation cover (wheat) and distance to nearest shrub, the overall results of the pooled data were comparable to the seasonal data showing that the three rodent species are more likely to be associated with good vegetation cover at the microhabitat level. This is also supported by the numerical output in both analyses. The findings are in agreement with several reports elsewhere. Dalmagro & Vieira (2005) indicated that many Neotropical rodent species have a strong association with vegetation variables at the microhabitat level. The occurrence of two South American rodents *Necromys lasiurus* and *Oryzomys scotti* in Brazilian Cerrado was associated with the availability of greater grass height (Vieira et al. 2005). Some studies indicated that predation pressure is a key factor determining differential habitat use by small mammals (Norrdahl & Korpimäki 2000). Therefore, even though it was most critical for the diurnal *A. niloticus*, the strong association of the three rodent species with vegetation cover in the current study can be attributed to avoidance of predators and food availability. Although we did not investigate predation, carnivores such as the spotted hyena (*Crocuta crocuta*), black-backed jackal (*Canis mesomelas*) and birds of prey, black kite (*Milvus migrans*), black-shouldered kite (*Elanus caeruleus*) and augur buzzard (*Buteo augur*) were often observed in the study area. This suggests the possibility of perceived predation risk by the rodents when the habitats had poor vegetation cover, particularly in crop fields after harvest and the fallow period. Some of these carnivores have already been identified as potential rodent predators in agroecosystems in northern Ethiopia (Meheretu & Leirs 2019). Bushlands and crop fields with a high density of stone bunds, which supported the majority of the rodent species, are likely to offer better food availability and cover against predators even at the microhabitat level.

In conclusion, this study represents the first demonstration of microhabitat use of three coexisting rodent species in bushland, crop fields with stone bunds and irrigated fields in northern Ethiopia. Understanding their habitat preferences and microhabitat use, particularly in crop fields, has important agricultural implications as the three species are known agricultural pests. We suggest further study to understand how other environmental and ecological factors, such as microclimate, soil type and predation, influence the rodent community and microhabitat use in the different habitat types.

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Supplementary online material

Fig. S1. Photographic view of the study area and surrounding landscape structure of Adi-azab'o in Klte-Awla'elo district (13°39′14.4″ N and 39°34′19.4″ E) in eastern zone of Tigray regional state, Northern Ethiopia. (photo Kiros Welegerima 2018).
Fig. S2. Description of the four habitat types from left to right, A) Bushland, B) Crop field with low stone bunds, C) Crop fields with high stone bunds and D) Irrigated crop field. (photo Kiros Welegerima 2018).
Fig. S3. The three focus species of the study, (A) *Arvicanthis niloticus;* (B) *Mastomys awashensis*; (C) *Stenocephalemys albipes* recorded during the study. (photo Kiros Welegerima 2018).
Fig. S4. RDA axes summarizing microhabitat variations and the position of each rodent species relative to these variables when data from both seasons was pooled. Arrows correspond to the contribution of each variable on the three rodent species and represented by *S. albipes* = SA, *M. awashensis* = MA and *A. niloticus* = AN, Percentage vegetation ground cover = PVC, Distance nearest shrub = DNS, Barley, Herb & Wheat.
Table S1. Number of individual rodent species across habitat type, grid/line transect and rainy/dry season during the entire study.
Table S2. RDA result calculated for the microhabitat variables to the overall variation in microhabitat use by the three rodent species at Klte-Awla'elo, Tigray. (Percentage vegetation ground cover = PVC, Distance nearest shrub = DNS, Wheat, Herb & Barley).

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