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Home range size and survival probability of two major rodents (*Rhabdomys dilectus* and *Lophuromys aquilus*) on slopes of Mount Kilimanjaro, Tanzania

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Abstract

Home range and survival are important parameters influencing abundance and distribution of rodent species. Therefore, understanding the factors affecting them is crucial for conservation and management of the species. This study was aimed to determine home range size and survival probabilities of two dominant rodent species (*Lophuromys aquilus and Rhabdomys dilectus*) found in western slopes of Mount Kilimanjaro, Tanzania. Trapping was done in moorland and fallow habitats across both dry and wet seasons, using Sherman live traps in four CMR grids. Home range size of *Rhabdomys dilectus* was influenced by habitat type. It was significantly higher in moorland than in fallow habitat. Whereas, home range size of *Lophuromys aquilus* was influenced by the variations in habitat, season and sex. It was significantly higher in moorland than in fallow. Also, male *L. aquilus* had larger home range size than females but the difference was not significant. Moreover, there were significant differences in survival of the two species and sex. Survival of *L. aquilus* was higher than that of *R. dilectus* indicating that *L. aquilus* could be more adapted to live on Mt. Kilimanjaro than *R. dilectus*. This was evident from its lower capture probability compared to *R. dilectus*. Low capture probability indicates trap shy behavior which could serve as a mechanism of predator avoidance. Furthermore, for both species female's survival was higher than that of males. This was probably due to that females spend most of their time inside the nest during breeding season, hence reduces the risk to encounter predators. The study concludes that, species type, sex, habitat type and quality influence home range size and survival probability of rodents, which are attributed to variations in resources availability, mating behavior and reproductive fitness. Therefore, rodent conservation and management interventions should be species and sex specific taking other factors into consideration.

Keywords: *Capture probability; Home range; Lophuromys aquilus; Reproductive fitness; Rhabdomys dilectus; Survival*

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Introduction

A home range is a specific area traversed by an animal for day-to-day activities such as foraging, nesting, resting and mating (Burt, 1943; Powell, 2000; Powell and Mitchell, 2012; Cooney *et al.*, 2015). A home range provides resources and conditions necessary for animal's survival such as food, water, shelter/cover, mates and nesting grounds. It is always difficult for the animal to protect its home range (a territory) from other conspecifics, however, if the benefits of protecting it outweighs the costs, an individual will incur the costs to protect it (Burt, 1943). Home range of small mammals are dynamics, changing in size and position over time and space due to changes in resource distribution and availability at spatial-temporal scales (Orland and Kelt, 2007; Powell and Mitchell, 2012). Moreover, home ranges may vary between individuals, species, sex, age class, season and breeding activity (Burt, 1943; Powell, 2000; Schmidt, 2002; Powell and Mitchell, 2012; Cooney *et al.*, 2015; Lee and Rhim, 2016). For example, home range differences and may be overlap between individuals of same species or sympatric species might occur as a result of competition or coexistence through resource partitioning at spatial-temporal scales (Fieberg and Kochanny, 2005; Chuyong *et al.*, 2011; Morris *et al.*, 2011; Casula *et al.*, 2019; Manlick *et al.*, 2021).

Variations in habitat type and seasonality results into seasonal food availability and cover which in turn affects habitat selection and home range size of small mammals. For example, wood mice (*Apodemus sylvaticus*) shows seasonal differences in home range size and habitat selection (by extending the size in cultivated areas) due to change in food and cover (Flavicollis, 2006). Also, home range size of female striped mice (*Rhabdomys pumilio*) is reported to change due to seasonal variations in food resources (Schradin and Pillay, 2006). In addition, reproducing individuals have large home range size due to required food and extra energy for reproduction and caring of juveniles (Mlyashimbi *et al.*, 2019; 2020). On the other hand, survival of small mammals is influenced by variations in seasonality and vegetation structure (Ademola *et al.*, 2021) which affects abundance of food resources such as grains, plant materials and insects/termites (Ademola *et al.*, 2022; Kennis *et al.*, 2012). Likewise, survival of small mammals including rodents have been found to vary with sex and age class (Eccard *et al.*, 2002; Previtali *et al.*, 2010).

In addition, both home range size and survival are important parameters influencing behavioral and ecological characteristics of small mammals. Home range measures the space an animal uses in a habitat that reflects the energy spent to acquire food or mates and the likelihood to encounter predation (Koshev *et al.*, 2005; Flavicollis, 2006). In rodent community ecology, home ranges are important factors for species breeding activity, foraging, distribution and habitat selection (Powell and Mitchell, 2012; Sabuni *et al.*, 2015). Survival on the other hand, is related with reproductive fitness of an individual. The higher the survival rate the higher the chances of reproductive fitness and higher population size (Ademola *et al.*, 2021). However, human activities like agricultural land preparation practices and deforestation affect rodent species home range, survival and distribution through habitat destruction and fragmentation, which reduces habitat area and resource availability (Gehring and Swihart, 2004; Lambert *et al.*, 2006; Greenberg *et al.*, 2011; Nelson *et al.*, 2019). Fragmentation can result into extinction of species especially for those with restricted distribution range through inbreeding depression (Gehring and Swihart, 2004). For that case, understanding home range size and survival probability of rodents is crucial for conservation of endangered/vulnerable species which has restricted home range size and distribution in a particular habitat or ecosystem (Sabuni *et al.*, 2015).

Generally, home range size (Monadjem and Perrin, 1998; Gebresilassie *et al.*, 2006) and survival probabilities (Julliard, *et al.*, 1999; Sluydts *et al.*, 2007; Mulungu *et al.*, 2016; Mlyashimbi *et al.*, 2020; Mayamba *et al.*, 2020; Ademola *et al.*, 2021) of rodents have been well studied in east Africa. However, there is scanty information on home range size and survival of rodents from the genus Lophuromys and Rhabdomys (Schradin, 2009). As reported earlier two species *Lophuromys aquilus* (endemic) and *Rhabdomys dilectus* are sympatric species predominating habitats of Mt Kilimanjaro (Verheyen *et al.,* 2007; Thomas *et al.,* 2022a; 2022b). Their home range size and survival probabilities and the factors affecting them have not been well documented. Also, the increasing rate of human activities in unprotected areas of Mount Kilimanjaro might be of great threat to their home range and survival. Therefore, this study was aimed to determine home range size of the two species, their survival and capture probabilities as well as the influencing factors for conservation and management purpose. We hypothesized that, home range and survival probability of the two species would vary across habitats and seasons, and with sex (Schradin and Pillay, 2006). It was expected that, home range and survival of species would markedly differ between males and females due to different requirements for reproduction and response to change in resource availability such as food, cover and mates (Schradin and Pillay, 2006).

Materials and methods

Study area description

The study was conducted on Mount Kilimanjaro which is located in northeastern, Tanzania. The study was a continuation of previous studies by Thomas *et al.,* (2022a; 2022b) conducted at the same study area. The study area lies between 3°07S and 37°35E on the western slopes of Mt Kilimanjaro in Siha district of Kilimanjaro region. The mountain has zonation of habitats along altitudinal gradients ranging from 1,500 to 5,895 m.a.s.l. (Hemp, 2006; Mulungu *et al.,* 2008). There is plantation forest, fallows and cultivated habitats in the lower zone from 1,500 to 2,400 m.a.s.l. (Mbonile *et al.,* 2003). It has homogenous vegetation dominated by Pines, Cyprus and Eucalyptus tree species together with cultivated crops such as carrots, cabbage green peas and irish potatoes as explained in Thomas *et al.,* (2022a). Moreover, the mid elevation zonation ranging from 1,800 m.a.s.l. up to 2,800 m.a.s.l. which includes lower and higher (evergreen) montane forests predominated by indigenous Podocarpus, Ficus and Hagenia tree species. Also, a third zonation in higher altitudes with alpine heath/ecotone habitat from 2,800 to 3,200 m.a.s.l. Alpine heath/ecotone habitat is characterized by sparse and dry vegetation predominated by erica grasses, philippia shrubs and bearded lichens hanging from trees. Another zonation is from 3,200 m.a.s.l. up to 4,500 m.a.s.l which has the moorland habitat dominated by Erica and Helichrysum bushes. Above the moorland there is rocky and bare land (Hemp, 2006).

Moreover, the mountain is characterized by a tropical montane climate with two rainy and two dry seasons (Mulangu and Kraybill, 2013). Rainy season is from March to May and from October to December. Whereas, the dry season is from January to February and from June to September (Thompson *et al.,* 2003). The mean annual rainfall is around 1,300 mm, 2,200 mm and 700 mm in low, mid and high elevations respectively. With temperatures reaching up to -6^{0}C and 29^{0}C in the highlands and lowlands respectively.

Trapping

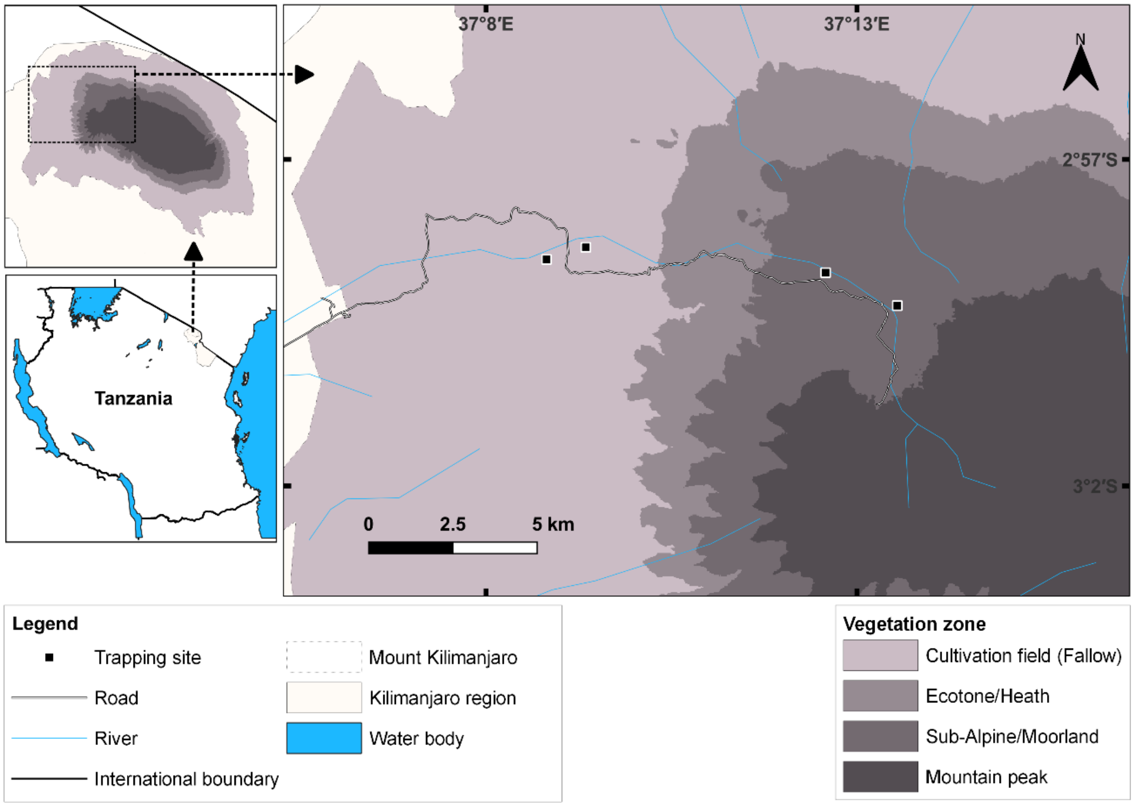
Trapping was done using Capture-Mark-Recapture (CMR) technique following similar procedures described in Thomas *et al.,* (2022b) and Leirs *et al.,* (2023). Four live trapping grids; two in each of the moorland and fallow habitat were established at approximately 500 m apart. Each grid consisted of 49 traps placed in 7 lines each with 7 traps placed at 10 m trapping station. Traps were baited with peanut butter and inspected in next morning before 10:00 a.m. Trapping was done for three nights consecutively in each trapping session (month). Continuous monthly live trapping was conducted for two years; commenced in April 2020 and terminated in March 2022 covering both dry and wet seasons. Trapped animals were marked by toe clipping which has been scientifically tested and found not to affect animal's behavior (Borremans *et al.,* 2015). Data on the date, trap station number, grid number, habitat type, toe clip code, weight, species, sex and sex condition (if whether the animal was sexually active/breeding or not) of each trapped animal were recorded before it was released at the point of capture. Rodent species were identified in the field following Happold (2013) and confirmed with molecular technique. Traps were washed and packed for the next trapping session.

Data analysis

Sex was determined using distance between the anus and urogenital opening (shorter in females and longer in males) and presence of secondary sexual characteristics such as testis and nipples for males and females respectively (Searle, 1985; Kay and Hokestra, 2008). Rodents were grouped into two age classes: adults and juveniles. Age of an individual was determined based on body weight and maturation status (Kay and Hokestra, 2008; Kingdon, 2015). Maturation in adults was assessed through growth of secondary sexual characteristics in both males and females, which was evident during reproductive activity (Searle, 1985; Monadjem and Perrin, 2002).

Figure 1

Map of west Mount Kilimanjaro, showing four grids in selected habitats (moorland and fallow)



Homer range size

Home range size was estimated as the total area travelled in a Minimum Convex Polygon (MCP) by individuals, within five different trap relocations. For that case, estimation of home range size using MCP was not applicable to other rodent species because they had few trap relocations from CMR capture history. Home ranges of only two species; *Lophuromys aquilus* and *Rhabdomys dilectus* were estimated. AdehabitatHR package in R program (R Core Team, 2020) was used to estimate individual's home range as MCP at 95% of relocation points. Non-parametric Wilcoxon/Mann-Whitney test was used to determine differences in home range between species. Moreover, home range data were log transformed and simple linear regression models were fitted to determine the relationship between home range size of individual species with respect to season, habitat, sex and sex conditions, and the interactions between them. We used AIC model selection to distinguish among a set of possible linear regression models describing the relationship between home range size, habitat, season, sex and sex condition. Model with lowest AIC score carrying higher % of cumulative weight was selected as best model. For example, for *Rhabdomys dilectus* analysis; the best-fit model included habitat and season with interaction effects. Whereas, for *Lophuromys aquilus*, the best-fit model, included habitat and season with no interaction effects. After model selection we conducted model validation through checking model assumptions i.e use of Q-Q plots and residuals, and results presented in model summary. Two-way Anova was used to determine the differences in home range size of individual species across habitats, seasons and sex.

Survival and capture probability

Survival was defined as the probability of individual rodents to survive/persist from one month to the next. It refers to mean length of time an individual persists in the grid/study site within a trapping session, usually assigned to 1 (Mayamba *et al.,* 2020; Ademola *et al.,* 2021). Survival expresses the occurrence of animals that are captured in one trap session and a subsequent one. Whereas the capture probability is fully time and trap dependent as a result of trap awareness and unawareness behavior of individual rodents. Both survival and capture probabilities were estimated for each trapping session according to Pollock's closed robust design, in which the population is assumed to be closed within each trapping session and open between the trap sessions. Also, it is assumed that there is no immigration or emigration of individuals from the population.

Prior to analysis, goodness-of-fit (GOF) test was carried out with the U-CARE software (Pradel *et al.,* 2003; Choquet *et al.,* 2009a) to assess trap dependence and transience individuals (the ones trapped only once during the entire study period). GOF test followed the assumption on transience. It did not indicate any effect of trap dependence, meaning that capture probability of individuals was independent of their previous capture (Pradel and Sanz-Aguilar, 2012).

Survival and capture probability modelling

Survival of the two species were modelled and estimated using the multi-event capture-recapture models in E-SURGE (Pradel, 2005; Lebreton and Pradel, 2002; Choquet *et al.,* 2009a; 2009b) in which the number of states might be greater than the number of events. The multi-event capture-recapture models incorporated detection heterogeneity into our models (Pradel and Sanz-Aguilar, 2012). For capture probability, modified methods of analysis by Sluydts *et al.,* (2007) and Mayamba *et al.,* (2020) were used. To minimize trap dependence, capture probability of the two species was varied between trap aware individuals (captured during the previous trap session), trap unaware individuals (not captured during the previous trap session) and dead/not captured individuals. Initially, over 20 different models were constructed to test whether survival and capture probabilities of the two species is different and if whether sex has a significant impact on the differences as conducted by Mlyashimbi *et al.,* (2020), hence all the models that were run included species and sex (Table 1). In further analysis, survival and capture probabilities of individual species were allowed to vary between sex (male and female), season (dry and wet) and between habitats (moorland and fallow). Corrected Akaike information criterion (AICc) for smaller sample size was used for ranking the models and selection (Burnham *et al.,* 1995). Model with lowest AICc was considered as best fit (better describes distribution of data). Also, all models with a difference of delta AICc < 2.0 were considered as equally good.

Results

Home range size

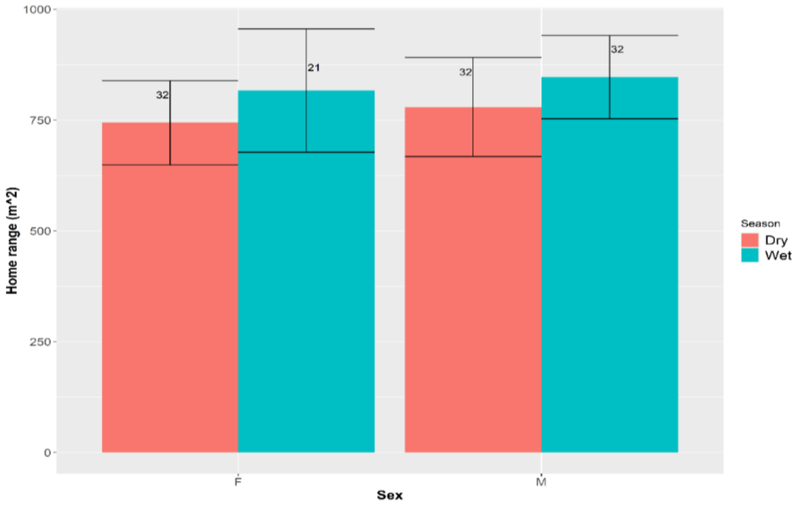
In general, mean home range size was not significantly different between the species (Mann-Whitney U = 2292.5, p = 0.217) however, *Lophuromys aquilus* had a relatively larger mean home range size (842.06 m^2) than *Rhabdomys dilectus* (729.05 m^2).

For individual species analysis; home range size of *Rhabdomys dilectus* was influenced by the variation in habitat (F1, 115 = 4.61, p = 0.034, R^2 = 0.03). Mean home range significantly differed between habitats, as it was significantly larger in the moorland than in fallow habitat (Estimate ± Standard error SE and P-value) (0.30 ± 0.14, p= 0.034). Moreover, home range was significantly influenced by the interaction between habitats and seasons (F3, 113 = 2.95, p = 0.04, R^2 = 0.05). Whereby, mean home range significantly decreased (-0.66 ± 0.27, p = 0.01) during wet season in the moorland.

Moreover, linear regression modeling indicated that, home range size of *Lophuromys aquilus* was influenced by habitats (p = 0.001), season (p = 0.062) and sex (p = 0.16) (F3, 65 = 6.22, p = 0.0, R^2 = 0.19). Moreover, mean home range size significantly differed between habitats, whereby, it was significantly larger in moorland than in fallow habitat (0.73 ± 0.2, p < 0.001). Mean home range size did not differ significantly between season and sex; however, mean home range size was relatively larger during wet season (0.25 ± 0.16, p = 0.12). Also, male's home range size was relatively larger than that of females (0.28 ± 0.16, p = 0.09). (Figure 2).

Figure 2

Variations in mean home range size of Lophuromys aquilus between males (M) and females (F) across dry and wet seasons



Survival Probability

Comparatively, the best model indicated that survival probability was influenced by species and sex, whereas capture probability was influenced by species (Table 1). Also, the next best models which were well supported with (Delta AICc less than 2) indicated that survival probability was influenced by species and sex (Table 1).

Table 1

The candidate models used to estimate survival of the two species. Survival estimates (Phi) and capture probabilities (p) of the two species were modelled with respect to time and sex (male or female)

SN	Model	df	AICc	ΔAICc	Weight	Deviance
16	Phi(~spec + sex)p(~spec)	5	1947.472	**0**	3.27E-01	1937.472
12	Phi(~spec)p(~spec)	4	1948.204	**0.732**	2.27E-01	1940.204
10	Phi(~spec)p(~spec + sex)	5	1949.15	**1.676**	1.41E-01	1939.148

SN	Model	df	AICc	ΔAICc	Weight	Deviance
14	Phi(~spec + sex)p(~spec + sex)	6	1949.306	**1.833**	1.31E-01	1937.306
20	Phi(~spec * sex)p(~spec)	6	1949.434	**1.962**	1.23E-01	1937.256
18	Phi(~spec*sex)p(~spec + sex)	7	1951.256	3.783	4.93E-02	1937.256
28	Phi(~time+spec)p(~spec)	22	1958.554	11.081	1.28E-03	1914.55
26	Phi(~time+spec)p(~spec + sex)	23	1959.8	12.327	6.88E-04	1913.8
13	Phi(~spec + sex)p(~1)	4	1962.458	14.985	1.82E-04	1954.458
9	Phi(~spec)p(~1)	3	1963.145	15.673	1.29E-04	1957.145
17	Phi(~spec*sex)p(~1)	5	1964.427	16.954	6.80E-05	1954.427
15	Phi(~spec +sex)p(~sex)	5	1964.437	16.965	6.77E-05	1954.437
11	Phi(~spec)p(~sex)	4	1964.488	17.015	6.60E-05	1956.488
19	Phi(~spec*sex)p(~sex)	6	1966.408	18.936	2.53E-05	1954.408
32	Phi(~time *spec)p(~spec)	40	1972.824	25.352	1.02E-06	1892.824
25	Phi(~time + spec)p(~1)	21	1973.38	25.907	7.74E-07	1931.38
30	Phi(~time *spec)p(~spec+ sex)	41	1974.036	26.563	5.60E-07	1892.036
27	Phi(~time + spec)p(~sex)	22	1974.981	27.508	3.50E-07	1930.981
29	Phi(~time*spec)p(~1)	39	1987.722	40.25	5.95E-10	1909.722
31	Phi(~time*spec)p(~sex)	40	1989.226	41.753	2.80E-10	1909.226
5	Phi(~sex)p(~1)	3	1992.151	44.679	6.50E-11	1989.151
8	Phi(~sex)p(~spec)	4	1993.111	45.638	4.02E-11	1985.111
7	Phi(~sex)p(~sex)	4	1994.116	46.644	2.43E-11	1986.116
1	Phi(~1)p(~1)	2	1994.979	47.507	1.58E-11	1990.979
6	Phi(~sex)p(~spec + sex)	5	1995.054	47.582	1.52E-11	1985.054
3	Phi(~1)p(~sex)	3	1995.742	48.269	1.07E-11	1989.742
4	Phi(~1)p(~spec)	3	1996.168	48.695	8.72E-12	1990.168
2	Phi(~1)p(~spec + sex)	4	1996.815	49.342	6.31E-12	1988.815
21	Phi(~time)p(~1)	20	2005.238	57.766	9.35E-14	1965.238
24	Phi(~time)p(~spec)	21	2006.287	58.815	5.54E-14	1964.287
23	Phi(~time)p(~sex)	21	2006.291	58.818	5.52E-14	1964.291
22	Phi(~time)p(~spec +sex)	22	2007.215	59.742	3.48E-14	1963.215

Note. Table columns includes number of parameters (df), AICc Corrected Akaike Information Criterion due to small sample size and Delta Δ AICc, model weight and Deviance.

There were significant differences in survival probability between the species. Survival probability of *Lophuromys aquilus* was significantly higher than that of *Rhabdomys dilectus* (Figure 3). However, there were no significant differences between sex, the survival of females of both species was relatively higher than that of males, (Mean ± SE) 0.486 ± 0.031 for female *Rhabdomys dilectus* and 0.713 ± 0.235 for female *Lophuromys aquilus* (Figure 3). In addition, survival probability of both species (*L. aquilus* and *R. dilectus*) was significantly influenced by the variation in season when their capture probability was varied with time (Tables 2a and 2b). Capture probability of *Rhabdomys dilectus* was significantly higher than that of *Lophuromys aquilus*. It was (Mean ± SE) 0.429 ± 0.03 for *Lophuromys aquilus* and 0.655 ± 0.045 for *Rhabdomys dilectus* (Figure 4).

Figure 3

Survival probability between the species (Lph = Lophuromys aquilus and Rbd = Rhabdomys dilectus) and sex (F = female, M = male).

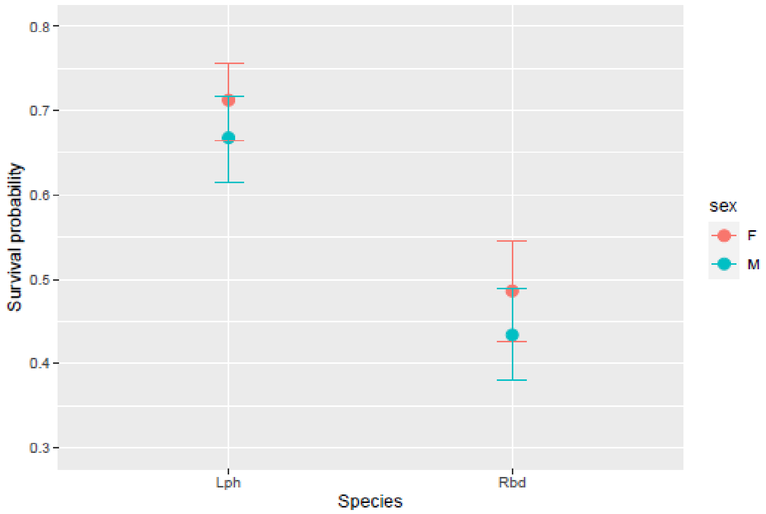
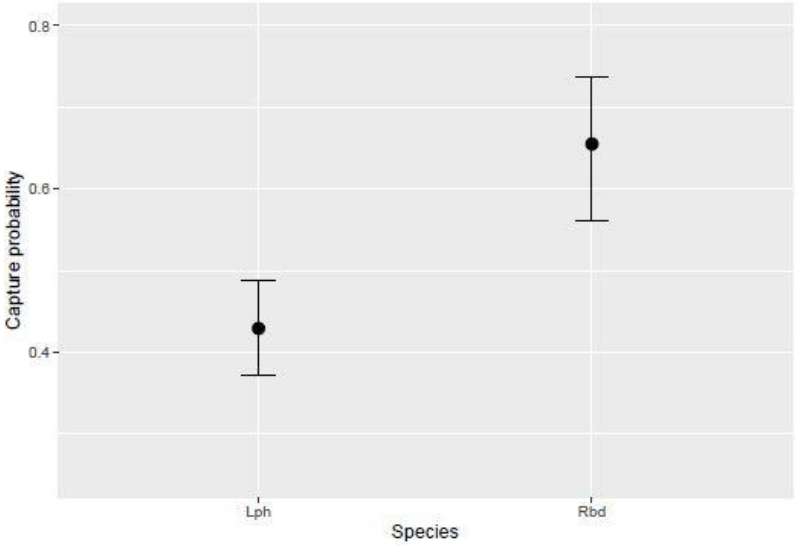


Figure 4

Capture probability between species (Lph = Lophuromys aquilus, Rbd = Rhabdomys dilectus).



In analysis of individual species, the models with the lowest AICc describing survival and capture probabilities for *Rhabdomys dilectus* showed that; survival probability varied with season and sex and constant capture probability (p(~1)) However, these models were not significantly different from the third and fourth best models that describes survival probability (Phi) with varying season and sex, and capture probability varying with time (p(~time)) (Table 2a). For *Lophuromys aquilus*, The model with the lowest AICc describing survival and capture probabilities showed; constant survival probability (Phi(~1)) and constant capture probability (p(~1)) (Table 2b). The model was not significantly different from the second best model that showed constant survival probability (Phi(~1)) and capture probability varying with time (p(~time)). However, the third and fourth best models that describes survival (Phi) varying with varying season and sex, and constant capture probability were equally good.

Table 2

***(2a** and **2b):** The candidate models used to estimate survival (Phi) and capture (P) probabilities of Rhabdomys dilectus (2a) and Lophuromys aquilus (2b) were modelled with respect to time, sex (male or female), habitat type (moorland and fallow) and season (dry and wet).*

2a

SN	Model	df	AICc	Δ AICc	Weight	Deviance
5	Phi(~season)p(~1)	3	1896.999	0	0.276	1890.98
7	Phi(~sex)p(~1)	3	1896.999	0	0.276	1890.96
6	Phi(~season)p(~time)	4	1898.282	1.283	0.145	1890.216
8	Phi(~sex)p(~time)	4	1898.282	1.283	0.145	1890.216
1	Phi(~1)p(~1)	2	1900.789	3.789	0.042	1896.769
3	Phi(~habitat)p(~1)	6	1901.155	4.156	0.035	1889.016
9	Phi(~sex*season)p(~1)	6	1901.509	4.509	0.029	1889.37
2	Phi(~1)p(~time)	3	1902.002	5.003	0.023	1895.962
4	Phi(~habitat)p(~time)	7	1902.729	5.729	0.016	1888.544
10	Phi(~sex*season)p(~time)	7	1903.094	6.095	0.013	1888.909

2b

SN	Model	df	AICc	Δ AICc	Weight	Deviance
1	Phi(~1)p(~1)	2	1499.966	0	0.311	1495.935
2	Phi(~1)p(~time)	3	1501.007	1.041	0.185	1494.946
5	Phi(season)p(~1)	3	1501.544	1.578	0.141	1495.483
7	Phi(~sex)p(~1)	3	1501.544	1.578	0.141	1495.483
6	Phi(~season)p(~time)	4	1502.604	2.638	0.083	1494.501
8	Phi(sex)p(~time)	4	1502.604	2.638	0.0831	1494.501
3	Phi(habitat)p(~1)	6	1505.179	5.213	0.023	1492.963
9	Phi(sex*season)p(~1)	6	1506.299	6.334	0.013	1494.083
4	Phi(~habitat)p(~time)	7	1506.4	6.434	0.012	1492.111
10	Phi(~sex*season)p(~time)	7	1507.501	7.535	0.007	1493.212

Note. Table columns includes number of parameters (df), AICc Corrected Akaike Information Criterion, Delta Δ AICc, model weight and Deviance.

Discussion

Home range size

A non-significant difference in home range size of *Lophuromys aquilus* and *Rhabdomys dilectus* indicate that the two species have overlapping home ranges and sharing of resources. However, a relatively larger home range size of *L. aquilus* than *R. dilectus* suggest higher accessibility to food resources and varieties, which support its generalists/opportunistic behavior. Our results support findings by Thomas *et al.,* (2022a) which reported an overlap in niche breadth among the two species due to sharing of food resources. Moreover, home range size of *Lophuromys aquilus* differed between sex and season. Males had relatively larger home range size compared to females (however not significant), probably because males move longer distances especially during wet season to search for mates (Mulungu *et al.,* 2013; Cooney *et al.,* 2015). Unlike females who spend most of their time in the nests to nurture for the juveniles. Our findings coincide with other studies which reported significant differences in home range sizes between males and females whereby, males moved longer distances to maximize the chances of meeting sexually active females (Kennis *et al.,* 2012; Borremans *et al.,* 2014; Leirs *et al.,* 1997). However, the results contradict those of Mlyashimbi *et al.,* (2020), which reported large home range size in female *Mastomys natalensis* during breeding season due to high food requirements for reproduction.

The mean home range sizes of both species significantly differed across habitats probably due to vegetation structure and climate variability between the two habitats. Larger home range sizes of both species in moorland could be attributed to poor vegetation (ground cover) which affects food availability. Similarly, Gebresilassie *et al.,* (2006) suggested that rodents have larger home ranges in habitats with limited food resources to maximize search for food to meet body requirements. Whereas small home ranges in fallow was probably due to dense vegetation and ground cover which provide food and protection from predators. Also, it could be due to crop remains from surrounding agricultural fields. Fallows are said to serve as refuge to rodents inhabiting farm-fallow mosaics, providing them with supplementary food and breeding sites (Mulungu *et al.,* 2013; 2016).

In addition, seasonality has been reported as the major factor influencing home ranges of small mammals including rodents as it affects vegetation structure and food availability (Powell and Mitchell, 2012; Cooney *et al.,* 2015). In most cases rodents tend to have smaller home ranges during wet season when food is abundant than in dry season when food is limited (Schradin and Pillay, 2006; Mulungu *et al.,* 2011). Interestingly, in this study home range size of *Rhabdomys dilectus* significantly decreased during wet season (especially in the moorland) whilst that of *Lophuromys aquilus* relatively increased during wet season. An interaction between seasonality and habitat explains the variation and inconsistence in home range size between the two species in both dry and wet season. Extremely cold temperatures in moorland and behavioral adaptation of the species could be the possible explanation for a significant decrease in home range size of *R. dilectus* and an increase in home range size of *L. aquilus*. Cold temperatures during wet season are reported to affect movements and activity patterns of *Rhabdomys dilectus* (Clausnitzer, *et al.,* 2003), unlike for *L. aquilus* which prefers wet conditions and is actively moving during wet season (Happold, 2013; Kingdon, 2015).

Survival and capture probabilities

In the current study, best models for comparative and individual species analysis included species, sex, and season, indicating that survival and capture probabilities varies between species, sex and season. *Lophuromys aquilus* had higher survival probability but lower capture probability. Whilst *Rhabdomys dilectus* had lower survival probability but higher capture probability. Higher survival of *Lophuromys aquilus* is because it is reported to be a nocturnal rodent species in a previous study by Thomas *et al.,* (2022a). Being nocturnal could be a reason for high survival probability due to less susceptibility to predators (Ebensperger and Blumstein 2006). Moreover, the significantly lower capture probability of *L. aquilus* over time could suggest it is a trap shy species. Trap shy behavior could serve as a mechanism of avoiding predation. This is because the species spend longer time to acclimatize to the traps and normally hide in areas with dense cover. In addition, higher survival of *L. aquilus* support the fact that it is a habitat generalist that is more adapted to live across a range of habitats and altitudinal gradients. This is evident from the distribution of species of genus Lophuromys on Mt Kilimanjaro (Thomas *et al.,* 2022b) and elsewhere (Clausnitzer *et al.,* 2003; Bantihun and Bekele, 2015). Lophuromys species are reported to colonize disturbed and less suitable habitats, and are opportunistically able to utilize resources in vicinity resulted from human disturbance (Happold, 2013; Gitonga *et al.,* 2015; Monadjem *et al.,* 2015). Similarly, Ademola *et al.,* (2021) reported high survival rate of *Praomys delectorum* in disturbed forest due to high food resources because of anthropogenic disturbance. High survival probability improves individual's fitness through successful reproduction which results into stable populations (Ademola *et al.,* 2021; Mulungu *et al.,* 2016; 2013). Hence, survival is a vital component and important factor that influences rodent population size (Mulungu *et al.,* 2016; Mlyashimbi *et al.,* 2019; 2020). Moreover, it is reported that, rodent population size is directly dependent on rain fall patterns whereby, breeding occurs during the rainy season (Leirs *et al.,* 1994; Mulungu *et al.,* 2013). Rainfall influences food resources and ground cover which provides protection to newly recruited juveniles from predators and harsh weather (Leirs *et al.,* 1997). For that case, rodents' survival is higher in high quality habitats which has stable conditions and high food resources than in poor quality habitats (Kennis *et al.,* 2012).

On the other hand, a significantly lower survival probability of *Rhabdomys dilectus* could be due to high predation risk since the species is diurnal and moderately associated with ground cover. It preferably inhabits areas with patchy and sparse vegetation such as open grasslands which might expose it to predation (Schradin and Pillay, 2006; Clausnitzer *et al.,* 2001; 2003). It is reported that, diurnal rodent species are conspicuous and susceptible to mammalian and avian predators than nocturnal rodents (Ebensperger and Blumstein 2006). Moreover, high capture probability of *R. dilectus* could suggest that it is a trap loving species. Trap loving behavior put the species at high risk of predation because it quickly gets familiar with the traps.

Furthermore, our results indicate that survival probability differed between sexes, however, we could not find significant differences in survival probabilities between the sexes. Survival was relatively higher for females of both species than males, and was relatively higher in wet season than in dry season. Survival probability between the sexes could be attributed to observed movement patterns (home range sizes), time and energy invested in reproduction by the two sexes. However, home range size differences were not statistically supported and we lacked strong evidence on time and energy spent. Females are believed to spend more time inside the nests nurturing for their newborn juveniles hence are less likely to encounter predation (Norrdahl and Korpimäki, 1998) and mortality from extreme weather conditions (Clausnitzer *et al.,* 2003). Whereas, males have high risks of predation due to moving longer distances searching for mates (Norrdahl and Korpimäki, 1998). Also, high females' survival during wet season could be a result of high availability of food resources. Food resources and high ground cover results into improved growth and protection of the rodents during wet season (Powell and Mitchell, 2012; Cooney *et al.,* 2015). However, our findings are contrary to studies by Meheretu *et al.,* (2015) and Oli and Dobson, (1999) which found lower survival of females compared to males due to post-natal stress. It is reported that, reproduction success of females depends on spatial-temporal availability and distribution of food resources (Ostfeld, 1985).

Conclusion

Results of this study indicated that, home range size and survival varied between the species whereby *Lophuromys aquilus* had larger home range size and higher survival probability than *Rhabdomys dilectus*. Moreover, home range size and survival probabilities of the two species were influenced by habitat type, season and sex. The study concludes that, habitat types with distinct vegetation structure and seasonality are major factors influencing home range size and survival probability of rodents through provision of food and cover, which in turn influences rodents' movement and reproduction.

Furthermore, this is a very first study on Mt Kilimanjaro and East African region to document on home range size and survival of *Lophuromys aquilus* (endemic to Mt Kilimanjaro) and *Rhabdomys dilectus* which is widely distributed. The study revealed large home range size and high survival probability of *L. aquilus,* suggesting it is a well-adapted species to live on Mt Kilimanjaro. However, its survival could be threatened by increasing climate change, habitat destruction and fragmentation caused by anthropogenic activities. This is because, the species prefers dense and moist montane vegetation. Since, conservation status of *L. aquilus* remains uncertain/unknown in the IUCN Red List due to data deficiency, this study has shed light on demography of the species and calls upon conservation interventions. Moreover, it is recommended that further studies with prolonged trapping (for at least five years) should be conducted for better understanding of demography and behavioral adaptations of the other rodent species.

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Data availability

Authors agree to provide the data associated with this study (to be deposited in a public repository) upon request by the Editor in Chief once manuscript is accepted for publication.

Ethical Approval statement

A proposal to conduct this research was approved by postgraduate committee of Sokoine University of Agriculture SUA, Tanzania (Ref no: SUA/DPRTC/PFC/D/2019/0002/ 13). The research was registered and provided a permit (No: 2020-163-NA-2020-127) by the Tanzania Commission for Science and Technology (COSTECH) and by Tanzania Wildlife Research Institute (TAWIRI) to research on rodents. A permit to enter into Mount Kilimanjaro National Park was provided by Tanzania National Parks (TANAPA).

References

Ademola, O. J., Massawe, A. W., Mulungu, L. S., & Makundi, R. H. (2022). Dietary composition of rodents across different habitats in the Ukaguru Mountains, Tanzania. *African Journal of Ecology*, *60*(4), 958-968.

Ademola, O. J., Vanden Broecke, B., Leirs, H., Massawe, A. W., Mulungu, L. S., & Makundi, R. H. (2021). Effects of forest disturbance on the fitness of an endemic rodent in a biodiversity hotspot. *Ecology and Evolution*, 11(5), 2391–2401.

Bantihun, G., & Bekele, A. (2015). Diversity and habitat association of small mammals in Aridtsy forest, Awi zone, Ethiopia. *Zoological Research*, *36*(2), 88–94. Burnham, K. P., White, G. C., & Anderson, D. R. (1995). Model selection strategy in the analysis of capture-recapture data. *Biometrics*, 888-898.

Borremans, B., Hughes, N.K., Reijniers, J., Sluydts, V., Katakweba, A.A.S., Mulungu, L.S., Sabuni, C.A., Makundi, R.H. & Leirs, H. (2014) Happily together forever: temporal variation in spatial patterns and complete lack of territoriality in a promiscuous rodent. P*opulation Ecology*. 56, 109–118.

Borremans, B., Sluydts, V., Makundi, R. H., & Leirs, H. (2015). Evaluation of short-, mid- and long-term effects of toe clipping on a wild rodent. *Wildlife Research*, 42: 143–148.

Burt, W. H. (1943) Territoriality and home range concepts as applied to mammals. *Journal of Mammalogy*. 24:346–352.

Casula, P., Luiselli, L., & Amori, G. (2019). Which population density affects home ranges of co-occurring rodents?. *Basic and Applied Ecology*, *34*, 46-54.

Choquet, R., Lebreton, J.-D., Gimenez, O., Reboulet, A.-M., & Pradel, R. (2009a). U-CARE: Utilities for performing goodness of fit tests and manipulating CApture REcapture data. *Ecography*, 32(6): 1071–1074.

Choquet, R., Rouan, L., & Pradel, R. (2009b). Program E-Surge: A Software Application for Fitting Multievent Models. In D. L. Thomson, E. G. Cooch, and M. J. Conroy (Eds.): Modeling Demographic Processes In Marked Populations (pp. 845–865).

Chuyong, G. B., Kenfack, D., Kyle E. Harms, K. E., Thomas, D. W., Condit, R., & Comita, L. S. (2011). Habitat specificity and diversity of tree species in an African wet tropical forest. *Journal of Plant Ecology*: 212:1363–1374.

Clausnitzer, V., Churchfield, S. & Hutterer, R. (2003). Habitat occurrence and feeding ecology of Crocidura montis and *Lophuromys* flavopunctatus on Mt. Elgon, Uganda. *African Journal of Ecology*, 41(1): 1-8.

Clausnitzer, V., Denys, C., Granjon, L., & Poulet, A. (2001). Rodents of the afro-alpine zone of Mt. Elgon. *African small mammals*, 427-443.

Cooney, S. A., Schauber, E. M. & Hellgren, E. (2015). Ranging Behavior of Marsh Rice Rats in a Southern Illinois Wetland Complex. *Journal of Mammalogy* 96, No. 4: 732-741.

Core Team. R (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. http://www.R-project.org/.

Ebensperger, L. A., & Blumstein, D. T. (2006). Sociality in New World hystricognath rodents is linked to predators and burrow digging. *Behavioral Ecology*, *17*(3), 410-418.

Eccard, J. A., Klemme, I., Horne, T. J., & Hannu, Y. (2002). Effects of competition and season on survival and maturation of young bank vole females. *Evolutionary Ecology*, 16: 85–99.

Fieberg, J. & Kochanny, C.O. (2005) Quantifying home-range overlap: the importance of the utilization distribution. *Journal of Wildlife Management*, 69, 1346–1359.

Flavicollis, O. A. (2006). Spatial organization and home range of Apodemus flavicollis and A. agrarius on Mt. Avala, Serbia. Acta Zoologica Academiae Scientiarum Hungaricae, 52(1), 81-96.

Gebresilassie, W., Bekele, A., Belay, G. & Balakrishnan, M. (2006). Home Range and Reproduction of Rodents in Maynugus Irrigation Field, Northern Ethiopia. *Ethiopian Journal of Science*. 29(1):57–62.

Gehring, T. M., & Swihart R. K. (2004). Home Range and Movements of Long-Tailed Weasels in a Landscape Fragmented by Agriculture. *Journal of Mammalogy*, 85(1):79–86, 2004.

Gitonga, J., Simbauni, J., & Oguge, N. (2015). Effect of habitat fragmentation on food habits and gastrointestinal tract of *Praomys delectorum* sub-populations in the Taita and Kyulu hills, Kenya. *International Journal of Current Research*, 4(1): 63–72.

Greenberg, C. H., Perry, R. W., Harper, C. A., Levey, D. J., & Mccord, J. M. (2011). The role of young, recently disturbed upland hardwood forest as high quality food patches. In Greenberg, C. H., Collins, B and Thompson III, F. (Eds.): Sustaining young forest communities: ecology and management of early successional habitats in the Central Hardwood Region, USA. pp. 121–141.

Happold, D. C. D. (2013). Mammals of Africa. Volume III: Rodents, Hares and Rabbits. London, United Kingdom: Bloomsbury Publishing, London. 784pp.

Hemp, A. (2006). Continuum or zonation? Altitudinal gradients in the forest vegetation of Mt. Kilimanjaro. *Plant ecology, 184*(1): 27-42.

Julliard, R., Leirs, H., Chr, N., Yoccoz, N. G., Caroline, A., Vot, P. R. E., Julliard, R., Leirs, H., Chr, N., Yoccoz, N.G., Caroline, A., Vot, P.R.E., Verhagen, R.O.N. & Verheyen, W. (1999). Survival-variation within and between functional categories of the

African multimammate rat. *Journal of Animal Ecology*, 68: 550–561.

Kay, E.H. & Hoekstra, H.E., 2008. Rodents. Current Biology, 18(10), pp. R406-R410.

Kennis, J., Laurent, C., Amundala, N. D., Migimiru, A., & Leirs, H. (2012). Survival and movement of the Congo forest mouse (Deomys ferrugineus): a comparison of primary rainforest and fallow in Kisangani, Democratic Republic of Congo. *African Zoology*, 47(1): 147–159.

Kingdon, J. (2015). The Kingdon Field Guide to African Mammals. Second Edition. Bloomsbury Publishing Plc, 50 Bedford Square London WC1B 3DP. 640pp.

Koshev, Y., Atanassov, N. & Kocheva, M. (2005). Relation between Body Mass and Home Range Size of Small Mammals. Proceedings of the Balkan Scientific Conference of Biology in Plovdiv (Bulgaria) from 19 – 21 May, 2005 (Eds B. Gruev, M. Nikolova & A. Donev), 2005 (P. 437–444).

Lambert, T. D., Malcom, J. R., & Zimmerman, B. L. (2006). Amazonian small mammal abundances in relation to habitat structure and resource abundance. *Journal of Mammalogy*, 87(4): 766–776.

Lebreton, J.D., & Pradel, R., 2002. Multistate recapture models: modelling incomplete individual histories. *Journal of Applied Statistics*, 29 (1–4), 353–369.

Lee, E. & Rhim, S. (2016). Seasonal home ranges and activity of three rodent species in a post-fire planted stand. *Journal of Folia Zooligica*. 65(2): 101- 106.

Leirs, H., Kirkpatrick, L., Sluydts, V., Sabuni, C., Borremans, B., Katakweba, A., & Mariën, J. (2023). Twenty-nine years of continuous monthly capture-mark-recapture data of multimammate mice (Mastomys natalensis) in Morogoro, Tanzania. *Scientific Data*, *10*(1), 798.

Leirs, H., Stenseth, N. C., Nichols, J. D., Hines, J. E., Verhagen, R., & Verheyen, W. (1997). Stochastic seasonality and nonlinear density-dependent factors regulate population size in an African rodent. *Nature*, 389(September): 176–180.

Leirs, Herwig, Verhagen, R., & Verheyen, W. (1994). The basis of reproductive seasonality in Mastomys rats (Rodentia: Muridae) in Tanzania. *Journal of Tropical Ecology*, 10: 55–66.

Manlick, P. J., Maldonado, K., & Newsome, S. D. (2021). Competition shapes individual foraging and survival in a desert rodent ensemble. *Journal of Animal Ecology*, *90*(12), 2806-2818.

Mayamba, A., Broecke, B. V., Leirs, H., Isabirye, B. E., Byamungu, R. M., Nakiyemba, A., ... & Mulungu, L. S. (2020). Fitness of the pestiferous small rodent Mastomys natalensis in an agroecosystem in Mayuge district, Lake Victoria Crescent, Uganda. *Mammalia*, *84*(4), 344-353.

Mbonile, M. J., Misana, S., and Sokoni, C. (2003). Land use change patterns and root causes of land use change on the southern slopes of Mount Kilimanjaro, Tanzania. *LUCID Working Paper*.

Meheretu, Y., Welegerima, K., Sluydts, V., Bauer, H., Gebrehiwot, K., Deckers, J., & Leirs, H. (2015). Reproduction and survival of rodents in crop fields: the effects of rainfall, crop stage and stone-bund density. *Wildlife Research*, *42*(2), 158-164.

Mlyashimbi, E. C., Broecke, B. V., Mariën, J., Kimaro, D. N., Tarimo, A. J., Machang'u, R. S., & Mulungu, L. S. (2019). Soil type influences population dynamics and survival of the Multimammate rat (Mastomys natalensis) in semi-arid areas in Tanzania. *Crop Protection*, *124*, 104829.

Mlyashimbi, E. C., Mariën, J., Kimaro, D. N., Tarimo, A. J., Machang'u, R. S., Makundi, R. H., & Mulungu, L. S. (2020). Home ranges, sex ratio and recruitment of the multimammate rat (Mastomys natalensis) in semi-arid areas in Tanzania. *Mammalia*, *84*(4), 336-343.

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

Monadjem, A. & Perrin, M. (1998). The effect of supplementary food on the home range of the multi-mammate mouse Mastomys natalensis. S. Afr. J. Wildl. Res. 28, 1–3.

Monadjem, A., Taylor, P. J., Denys, C., & Cotterill, F. P. D. (2015). Rodents of Sub-Saharan Africa. A biogeographic and taxonomic synthesis. Berlin/Munich/Boston: Walter de Gruyter.

Morris, G., Hostetler, J. A., Conner, L. M., & Oli, L. K. (2011). Effects of prescribed fire, supplemental feeding and mammalian predator exclusion on hispid cotton rat populations. *Oecologia*, 67:1005-1016. DOI 10.1007/s00442-011-2053-6.

Mulangu, F., & Kraybill, D. (2013). Climate change and the future of mountain farming on Mt. Kilimanjaro. In *The future of mountain agriculture* (pp. 73-88). Springer, Berlin, Heidelberg.

Mulungu, L. S., Mahlaba, T., Massawe, A. W., Kennis, J., Crauwels, D., Eiseb, S., Monadjem, A., Makundi, R. H., Katakweba, A.S., Leirs, H., & Belmain, S. (2011). Dietary differences of the multimammate mouse, Mastomys natalensis (Smith, 1834), across different habitats and seasons in Tanzania and Swaziland. *Journal of Wildlife Research*. 38: 640–646.

Mulungu, L. S., Makundi, R. H., Massawe, A. W., Machang'u, R. S. & Mbije, N. E. (2008). Diversity and distribution of rodent and shrew species associated with variations in altitude on Mount Kilimanjaro, Tanzania. *Journal of Mammalia* 72(3): 178-185.

Mulungu, L. S., Ngowo, V., Mdangi, M. E., Katakweba, A. S., Tesha, P., Mrosso, F. P. & Belmain, S. R. (2016). Survival and recruitment of the multimammate mouse, Mastomys natalensis (Smith 1834), in a rice agro ecosystem. *Mammalia*, 80(2), 205-210. doi:10.1515/mammalia-2014-0150

Mulungu, L.S., Ngowo, V., Mdangi, M., Katakweba, A. S., Tesha, P., Mrosso, P., Mchomvu, M., Sheyo, P., & Kilonzo, B. S., (2013). Population dynamics and breeding patterns of multimammate mouse, Mastomys natalensis (Smith 1834), in irrigated rice fields in Eastern Tanzania. *Pest Management Science*, 69, 371–377.

Nelson, D. L., Kellner, K. F., & Swihart, R. K. (2019). Rodent population density and survival respond to disturbance induced by timber harvest. *Journal of Mammalogy*, *100*(4), 1253-1262.

Norrdahl, K., & Korpimaki, E. (1998). Does mobility or sex of voles affect risk of predation by mammalian predators? *Ecology*, 79(1): 226–232.

Oli, M. K., & Dobson, F. S. (1999). Population cycles in small mammals: the role of age at sexual maturity. *OIKOS*, (86): 557–565.

Orland, M. C., & Kelt, D. A. (2007). Responses of a heteromyid rodent community to large- and small-scale resource pulses: diversity, abundance, and home-range dynamics. *Journal of Mammalogy*, *88*(5), 1280-1287.

Ostfeld, R. S. (1985). Limiting resources and territoriality in microtine rodents. *The American Naturalist*, 126(1): 1–15.

Powell, R. (2000). Animal home range and territories and home range estimators. Research Techniques in Animal Ecology. Controversies and Consequences. Columbia University Press.

Powell, R. A. & Mitchell, S. M. (2012). What is home range? *Journal of Mammalogy*, 93(4): 948–958, 2012.

Pradel, R. (2005). Multievent: An Extension of Multistate Capture-Recapture Models to Uncertain States. *Biometrics*, 61(2): 442–447.

Pradel, R., & Sanz-Aguilar, A. (2012). Modeling Trap-Awareness and Related Phenomena in Capture-Recapture Studies. *PLoS ONE*, 7(3): 1–4.

Pradel, R., Wintrebert, C. M. A., & Gimenez, O. (2003). A proposal for a goodness-of-fit test to the Arnason-Schwarz multisite capture-recapture model. *Biometrics*, 59(1): 43–53.

Previtali, M. A., Lehmer, E. M., Pearce-Duvet, J. M. C., Jones, J. D., Clay, C. A., Wood, B. A., Ely, P.W., Laverty, S.M. & Dearing, D. M. (2010). Roles of human disturbance, precipitation, and a pathogen on the survival and reproductive probabilities of deer mice. *Ecology*, 91(2): 582–592.

Sabuni, C. A., Sluydts, V., Mulungu, L. S., Maganga, S. L., Makundi, R. H., & Leirs, H. (2015). Distribution and ecology of lesser pouched rat, Beamys hindei, in Tanzanian coastal forests. *Integrative Zoology*, 10(6), 531-542.

Schmidt, N. M., Berg, T. B., & Jensen, T. S. (2002). The Influence of Body Mass on Daily Movement and Home Range of the Collared Lemming (Dicrostonyx Groenlandicus). *Canadian Journal of Zoology*. 80: 64-69.

Schradin, C. & Pillay, N. (2006) Female striped mice (Rhabdomys pumilio) change their home ranges in response to seasonal variation in food availability. *Behavioral Ecology*, 17, 452–458.

Schradin, C., Schneider, C., & Yuen, C. H. (2009). Age at puberty in male African striped mice: the impact of food, population density and the presence of the father. Functional *Ecology*, 23(5), 1004-1013.

Searle, J.B., 1985. Methods for determining the sex of common shrews (Sorex araneus). *Journal of Zoology*, 206(2), pp.279-282.

Shilereyo, M., Magige, F. J., Ogutu, J. O., & Røskaft, E. (2020). Small mammal community demography and reproductive seasonality under protection, pastoralism and agriculture in the Serengeti Ecosystem, Tanzania. *International Journal of Biodiversity and Conservation*, 12(4), 253-269.

Sluydts, V., Crespin, L., Davis, S. & Lima, M. (2007). Survival and maturation rates of the African rodent, Mastomys natalensis: density-dependence and rainfall. *Integrative Zoology*, 2: 220–232.

Thomas, S.M., Soka, G.E. & Mulungu, L.S. (2022b). Influence of vegetation structure, seasonality, and soil properties on rodent diversity and community assemblages in west Mount Kilimanjaro, Tanzania. *Ecology and Evolution*, 12(9), p.e9211.

Thomas, S.M., Soka, G.E., Mulungu, L.S. & Makonda, F.B. (2022a). Spatial-Temporal Variations in Dietary Consumption of Two Dominant Rodent Species (Rhabdomys dilectus and Lophuromys aquilus) on Mount Kilimanjaro, Tanzania. *Diversity*, 14(8), p.659.

Verheyen, W. N., Hulselmans Jan, L. J., Dierckx, T., Mulungu, L., Leirs, H., Corti, M., & Verheyen, E. (2007). The characterization of the Kilimanjaro Lophuromys aquilus true,1892 population and description of five new Lophuromys species (Rodentia, Muridae). Bulletin L'Insitut Royal des Sciences Naturalles de Belgique, Biologie, 77, 23–75.