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Ecological correlates of population abundance of a pest small mammal species (*Mastomys natalensis*) inhabiting a protected area-farmland landscape in western Serengeti, Tanzania

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ABSTRACT

There is growing recognition of the negative impacts pest mammal species have on food security and the human health. Strategies to reduce these impacts could benefit from results of association of population of the pests to ecological aspects. We assessed how environmental and habitat attributes were associated population abundance of *Mastomys natelensis* in a landscape interspaced with farmland and protected areas in Western Serengeti. Rodents were trapped through Capture-Mark-Release method between April, 2020 and March, 2021 and estimated density of *M. natalensis* using the Minimum Number of Animals Known to be Alive (MNA) method. We found density to be significantly higher during dry season and in active farmlands; Both active farmlands and areas with sandy-clay-loam soils were strongly positively associated with higher abundance perhaps because of the increased species activity patterns during searching for food and favourable nesting soils thereby exposing the rodents to the traps. Also, the density tended to be significantly lower in areas with high plant species richness probably because *M. natalensis* is a pestrous species often in high abundance in areas cleared of vegetation for agricultural activities. These results provide useful inputs towards control strategies to reduce impacts associated with these pests in the rural landscapes.

Key words: Minimum number known alive - pest species - population abundance – rodents – Serengeti - soil texture.

INTRODUCTION

Most rodent species exhibit spatial and temporal fluctuations in numbers, attributed to ecological and environmental factors (Massawe *et al.* 2011). For example, when investigating the effects of land preparation methods and cropping systems on population abundance of the Multimmate rat *Mastomys natalensis*, Massawe and others (2005) found higher rodent population peaks in dense vegetation cover practiced with slash and burn relative to tractor ploughed fields. Also, when investigating the influence of soil type on population abundance of rodents in crop fields with attention to *Mastomys natalensis,* Massawe and others (2008) found higher abundance of the species in loam-textured soils with a high percentage of sand, but lower abundance in the sandy–clay- soils. Moreover, a study on attributes for prediction of rodent burrows in the western Usambara Mountains exhibited comparatively more rodent burrows in hill-shades and slopes in higher elevations (Meliyo *et al*. 2014) whereas rainfall has been found to have an indirect effect on abundance of rodents due to increased availability of food during the rainy season (Mayamba *et al.* 2020, Jordão *et al.* 2010). Empirically, the species inhabits diverse habitats from natural grassland, bushes, thickets to treed and disturbed areas including human settlements (Mulungu *et al.* 2011), but absent in rainforest (Happold 2013) hence one of the commonest species in savannah habitats with densities reaching up to 1000 rats/ha in disturbed areas (Happold 2013).

Further, rodents are well known for their economic and social ecological importance to man and other species. But, while they provide food to other species including man, thus important in the food web in many ecosystems (Fiedler 1990), they are known to cause damages to food crops (Milan 1990), and are host of flea parasites that are vectors of diseases (Kilonzo *et al.* 1992). Also, some harbour bacteria that cause zoonotic diseases such as leptospirosis caused by *Leptospira* bacterium, and toxoplasmosis caused by *Toxoplasma gondii* (Machang'u *et al.* 1997). Consequently, periodic outbreaks of some rodent populations pose concern to humans due to their pest and health impacts. For example, population outbreak of *M. natalensis* has been associated with the increased food loss (up to 80%), therefore, posing food insecurity in rural areas of Tanzania (Mdangi 2009). On the other hand, plague disease outbreak in some parts of Tanzania such as Iringa, Singida, Kondoa, Rombo, Hai, Arumeru, Mbulu and Same Districts has been a threat to public health (Kilonzo *et al.* 2006). Understanding the factors that affect abundance of a rodent population is germane to the effective population management of species that are considered as serious pest. This is especially important in sub-Saharan Africa where food insecurity is threatening development of most rural human populations due to crop devastation by various crop pest species (Milan 1990). Regular and up to date monitoring of the rodent population trends is vital so as to predict when the rodent population outbreaks are likely to ensue, thereby enable relevant authorities to prepare with the potential control measures required in preventing their impacts. Such monitoring information is missing in many parts of Tanzania including the western Serengeti ecosystem and surrounding villages posing risks of continued post-harvest and on-farm crop losses.

This study, therefore, aimed at assessing abundance of *M. natalensis* and how its population is influenced by the local-scale vegetation and soil characteristics as the key habitat correlates that could be among the targets for rodent population control measures. We hypothesised that, the abundance of *Mastomysis natalensis* will be influenced by habitat type, vegetation ground cover, tree diameter at breast height (DBH), plant species richness, soil textures and seasonality. This information will be useful to the reserve management during preparation of the reserve ecological management plans. Also, it will be utilized during the development of pest control plan in the neighbouring villages as this species is a potential pre-harvest pest.

MATERIALS AND METHODS

Study area

The study was conducted within Kijereshi Game Reserve and neighbouring village land in western Serengeti in Busega and Bariadi Districts. The game reserve covers 65.7 km^2 (Fig 1) and borders Serengeti National Park (SENAPA) on the northern side, and is surrounded by six villages: Lukungu, Mwabayanda, Mwakiloba, Kijilishi, Senta and Nyamikoma.

The study landscape receives an annual rainfall of about 750–850 mm (McSherry 2015) characterized by bimodal rainfall pattern with short rains from November to January and long rains from March to May (Campbell and Hofer 1995). Further, the reserve is characterized of three vegetation types: the riverine forest (RRF-covering 9.4% of the reserve area), grassland (GL-25.1%) and wooded grassland (WG-65.5%) (Gunda 2020). For this study we used the WG found in Kijereshi Game Reserve, and the fallow land and maize crop fields randomly selected from Nyamikoma village with varying soil types of clay, sand and loamy (McSherry 2015).

In the Nyamikoma village, the fallow lands surround cultivated fields, which during wet season, are planted with maize (*Zea mays*) intercropped with legumes (Leguminosae), sorghum (*Sorghum bicolor*) and sunflower (*Halianthus* spp.) (Egidius J. Rwebuga, pers. obs., 2020). There are two types of cropping seasons; the major season starting March to July and the minor season from September/October (depending on the commencement of short rainfall) to end of February before the start of long rains.

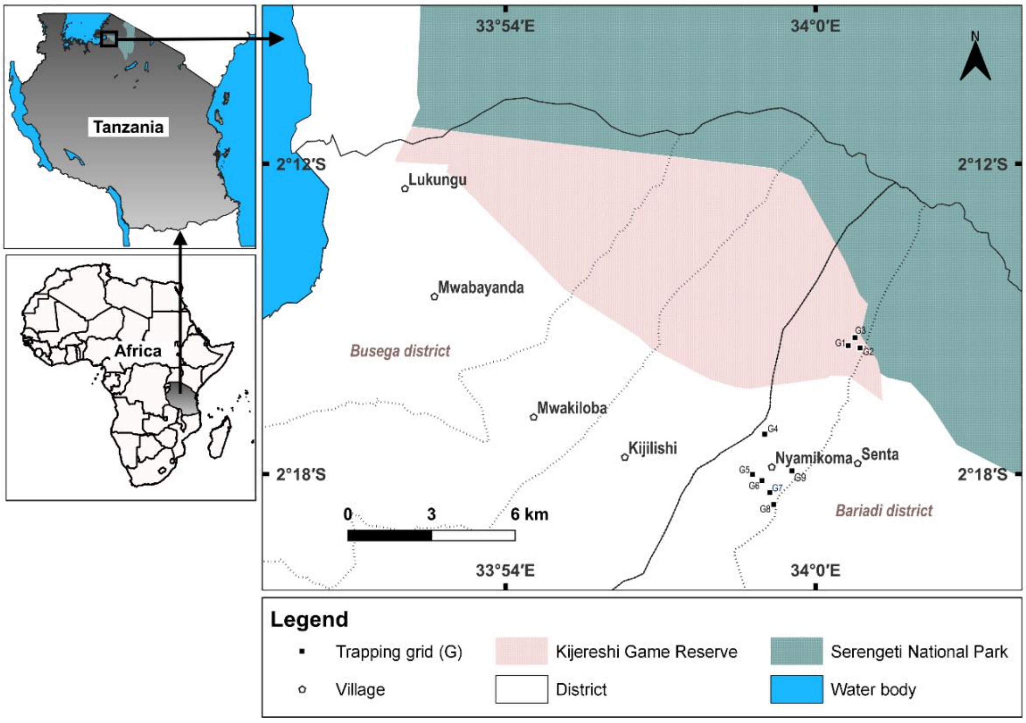

Figure 1: Location of study sites within Kijereshi Game Reserve and Nyamikoma village that surround the western Serengeti ecosystem

Data collection

To address the research objectives, we applied several techniques. First, in order to understand the rodent abundance, we used the Capture-Mark-Recapture technique. The procedure involved placing three replicas of grids (70 x 70 m) in three different habitats; WG within Kijereshi Game Reserve, in the active Maize farmland and farm-fallow in the village land. The grids were spaced at a distance not less than 300 m from each other. This distance was deliberately made larger than the average known home range of the study species; 800 m^2 (Monadjem and Perrin 1998) to avoid potential double counting of individuals from any two adjacent trap stations. Each grid consisted of seven parallel lines spaced 10 m apart, with seven trapping stations per line also spaced 10 m apart, making a total of 49 trapping stations per grid (Leirs *et al.* 1996). Further, at each trapping station, one Sherman LFA live trap (H.B. Sherman Traps Inc., Tallahassee, FL, U. S.A) was positioned to trap rodents (Leirs *et al.* 1996). To improve catchability, the traps were baited with peanut butter mixed with maize flour as commonly used in similar studies (Mulungu *et al.* 2012).

Rodents were trapped for three consecutive days each month for a 12-month period (April 2020 to March 2021). Throughout the trapping period, traps were checked twice a day, in early morning (between 06:00 and 07:00 hours) and late afternoon (between 17:00 and 18:00 hours) (Monadjem & Perrin 1998). From each trap catch, we identified and recorded species name of the animals caught, body mass, sex, and reproductive status (this demographic information are not reported here). Species identification of the trapped individuals was done using field guides (Happold 2013). When data recording was completed from any captured individual, one toe was clipped and the animal was released at the trapped site to facilitate monitoring of subsequent recaptured individuals (Mulungu *et al* 2005). A total of 441 (49 x 90) traps were used during the sampling period accounting to a total of 15867 trap nights.

Second, to understand the role of habitat characteristics on the rodent abundance, several variables were recorded within a grid where rodent trapping occurred. We measured diameter at breast height-DBH, determined plant species richness and vegetation ground cover, within each grid by establishing five nested plots, one at each corner and the center of the grid, and DBH for trees and shrubs was determined using a diameter tape (Hays *et al.* 1981). Quadrats of 1 m x 1 m were used for herbs and grasses while those of 10 m x 10 m were used for trees and shrubs (Hays *et al.* 1981). Determination of vegetation ground cover (i.e., the bird's-eye view of how much ground is obscured by vegetation) was done visually (Kennedy & Addison 1987). Species identification of rodents and plants was done in the field by use of plant field guides and experts. Furthermore, to understand how rodent abundance was related to the soil type and characteristics, we collected five soil core samples from each corner of the grid at a depth of 30 cm, packed in plastic bags (Massawe *et al.* 2008) and took them to the soil science laboratory at the Sokoine University of Agriculture for particle size analysis using the hydrometer method (Gee and Bauder 1986). Soil types were characterized using a soil texture triangle to determine the percentage of sand, silt and clay (Gee and Bauder 1986). Finally, we recorded season: wet (December to May) or dry (June to November) of each collected field data, to understand the effect of seasonality on the abundance of the rodent species. Seasons were defined as wet and dry periods. Thus, there was one wet and one dry period that had six trapping sessions each.

The fieldwork was, without some limitations that are worthy pointing out in connection with the Capture -Mark–Recapture trapping technique, which engaged 70 m x 70 m grids using the Sharman live traps. The shortcoming of this technique is that traps set within home ranges of many individuals of rodents are likely to have higher capture rates compared to the ones outside the home ranges of these animals (Harkins *et al.* 2019). However, this effect was rectified by replicating our trapping grids three times and pooling the capture data before analysis. Also, a few traps were destroyed by animals or stollen particularly in the fallow land and crop fields, which could have interfered with the trapping probability of rodents. We therefore replaced any lost or destroyed trap any time this incidence was detected.

Data Analysis

Data were analyzed in several steps to address each objective of this study. First, we used field collected abundance data to compute the density of the study species using the Minimum Number of Animals

Known to be Alive (MNA) for each hectare (i.e., surveyed rodent trapping grid), every month throughout the sampling period. MNA was computed by enumerating the number of individuals caught in a capture session, plus those that were not caught at that time, but were caught both previously and subsequently (Krebs 1966) as follows:

$$MNA = Nu + Ns$$

Where:

MNA = Minimum number of animals known to be alive during a particular period (i.e., month) in a given plot (i.e., 70 m x 70 m plot used in a Capture –Mark-Recapture technique);

Nu = Unique individuals captured in a particular capture session;

Ns = Number of individuals not caught at that particular time, but were caught previously and subsequently.

Further, we investigated how the rodent density varied across the surveyed habitat types, sampling seasons and soil types using non-parametric tests as data failed a normality Shapiro–Wilk test at p > 0.05 test. Differences in rodent density between seasons were determined using Wilcox test, and between habitat types using Kruskall-Wallis test (Mwasapi and Rija 2021).

Second, to understand the effect the measured habitat characteristics haves on the rodent abundance, we built a negative binomial generalized linear model (GLM), implemented in the package MASS after detecting data over dispersion in the poison GLM. The binomial generalized linear model consisted of six independent variables (plant species richness, soil type, habitat type, DBH, ground cover and sampling season, all known to influence the biology of most rodent species elsewhere (Mwasapi and Rija 2021), and the rodent abundance as a dependent variable. To determine most influential explanatory variables in the model, we performed a backward stepwise single deletion of non-significant terms (Rija 2022). Additionally, chi-square test was used at every step of removing non-significant model terms, to examine the model significance (Kamil 2018). Hence only four variables that were found significant were considered for modeling (ie seasonality, soil class, plant species richness and habitat types). Thereafter, prediction models were built using the predict function under the “ggplot2” package to examine the predictive power of each variable in the final GLM model.

RESULTS

Abundance of *Mastomys natalensis* in different habitats

We found rodent density ranging from 5.5±1.6/ha to 20.56±3.6/ha across various habitat characteristics (Table 1) with the Maize fields recording significantly higher mean density (20.56±3.6/ha) than all other habitat types (χ^2= 79.393, df = 2, p < 0.001).

Effect of habitat characteristics and seasonality on abundance of *M. natalensis*

The density of *M. natalensis* was significantly influenced by the measured variables (Table 2) as it showed dissimilar responses to season, habitat type, soil structure and plant species richness. Examining abundance of the *Mastomys natalensis*, we found significantly higher density record for all habitats during the dry season than the wet season (W = 2159.5, p< 0.001; Fig. 2a). Also, the species density positively and significantly associated with Maize habitat as compared to Fallow and WG habitats (Table 2; Fig. 2b) as well as sand-clay-loam soils, but decreased in sandy-clay soils (Table 2; Fig. 2c). Furthermore, the *M. natalensis* density was positively and significantly associated with the dry season, but decreased in the wet season and with increasing plant species richness (Fig. 2 a & d).

Table 1: Summary of vegetation properties, soil texture classes (with associated mean % clay, mean % silt and % mean sand) and density of *M. natalensis* in different habitats.

Habitat type	Soil texture classes	Mean % clay (±SDE)	Mean % silt (±SDE)	Mean % sand (±SDE)	Mean plant species richness (±SDE)	Mean DBH (±SDE)	Mean vegetation ground cover (±SDE)	Mean MNA/ha (±SDE)
Fallow	SCL	31.9±0.0	9.82±0.0	58.32±0.0	23.00±0.35	2.0±0.06	73.77±3.0	12.9±2.1
	SC	35.6±0.0	5.64±0.0	58.8±0.0	23.00±0.35	2.0±0.06	27.61±1.07	16.46±3.5
WG	SCL	15.9±0.0	8.86±0.0	75.32±0.0	25.92±1.28	1.99±0.27	27.61±1.07	5.5±1.6
	SC	35.6±0.0	11.6±0.0	52.80±0.0	25.92±1.28	1.99±0.27	27.61±1.07	5.58±1.3
Maize	SCL	26.9±02	7.4±0.2	66.65±0.4	22.00±0.14	0.83±0.11	24.44±2.02	20.56±3.6

Fallow= fallow land, WG=wooded grassland, Maize=active maize crop fields, SCL= sandy-clay-loam soils, SC= sandy - clay soils

Table 2: Effect of various ecological variables on abundance of *Mastomys natalensis* basing on the density (MNA/ha) as revealed in the final plausible GLM model.

Model type	Parameter	Estimates +SE	Z-value	P (Z)
MNA/ha	Intercept	2.979 ± 0.206	14.481	0.000***
	Maize habitat	0.249 ± 0.200	2.268	0.023*
	WG habitat	0.701 ± 0.092	- 7.611	0.000 ***
	Wet season	- 0.866 ± 0.071	-12.208	0.000 ***
	Sandy- clay-loam	0.280 ± 0.103	2.709	0.007 **
	Plant species richness	- 0.038 ± 0.009	- 4.180	0.000***

*, ** and *** indicate significant at p < 0.05, 0.01 and 0.001, respectively

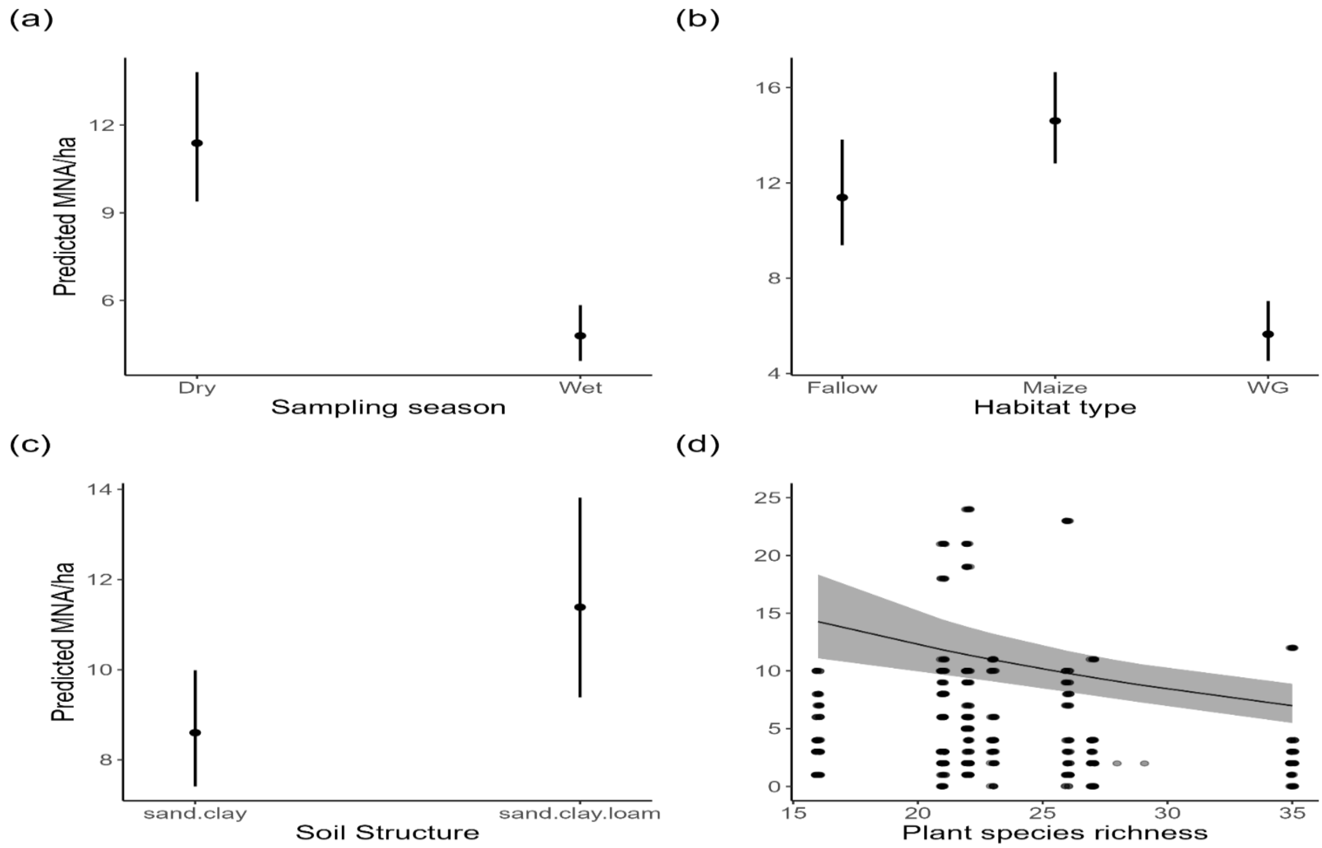

Figure 2: Effect of sampling season (a), habitat type (b), soil structures(c), and plant species richness (d) on the density (MNA/ha) of *M. natalensis* in the study areas. [Black dots (in d) represent raw data on plant species richness at each sampling point whereas the grey shade indicates 95% CI of the estimated mean effect size.]

Discussion

Abundance of *Mastomys natalensis* varied across habitats, leading to highest density in the Maize field followed by fallow land, and least in the WG habitat. The results were attributed to more availability of food resources in the maize field before and after harvesting compared to fallow land and the wooded grassland, which may have enhanced their reproductive capacity thus the positive association between the species density and the Maize fields. The findings correspond with Makundi (1999) and Magige (2016) who also reported higher densities of the species in cultivated than in non-cultivated habitats. However, when investigating population dynamics and breeding patterns of *M. natalensis* in irrigated rice fields, Mulungu *et al*. (2013) had most individuals of the species captured in fallow land, which in the present study ranked second. According to Stuart and others (2012), rodent pests of rice tend to nest on field edges, rice bunds and in adjacent habitats rather than within the rice field itself, especially during flooded conditions. So, in avoiding the wet/dump soils, most rodents tend to be resting and feeding long distances away from their nest sites (Ylonen *et al*. 2002), consequently getting trapped in surrounding areas, i.e., fallow lands, before they reach intended rice fields (Monadjem and Perrin 1998).

Additionally, density of *Mastomys natalensis* varied between wet and dry seasons. In all three habitats, months of dry season experienced higher abundance than those of wet season. Large part of our study site is a low land, and becomes flooded during the wet season, probably contributing to the subsequent observed lower abundance. According to Jacob (2003), deaths of rodents due to flooding, and migration to other non-flooded areas during the rainy season is a common experience, a phenomenon that underscore our results. The higher abundance of *M. natalensis* in the dry season reported by the current study is in agreement with the findings by Mulungu and others. (2013). Rodents breed during the long rains starting one month after the usual peak rainfall, lasting until the dry season, contributing to increase in numbers of the rodents (Leirs *et al*. 1996).

Moreover, results regarding the positive association between abundance of *M. natalensis* and sandy-clay-loam soils are similar to Massawe and others (2008). Odhiambo (2005) and Massawe (2008) pointed out that abundance of rodents in soils of different textures and moisture content is associated with the suitability of the soils for creating nesting places since soil texture influences many properties including drainage, moisture-holding capacity and rates of water infiltration (Marina and Zubaid 2015) and weather in rodent holes. As such, soils containing loamy texture has low water holding capacity (Hodnett and Tomasella 2002), which keeps burrow holes dry most of the time hence more stable and stronger (Laundre and Reynolds 1993). Large part of our trapping sites had a sandy-clay texture, suggesting unsuitability for rodent burrowing and nesting particularly during the rainy season. This explains the negative association between abundance of the species and sandy-clay soils, results that are in line with Massawe and others (2008) who reported low abundances of rodents in the sandy-clay soils especially during the wet season

However, according to our results, plant species richness showed negative association with the abundance of *M.natalensis*. A comparatively far more numbers of *M.natalensis* were found in mono-cropped maize fields, which are cleared of all other vegetation types except the maize crop plant, yet, like other cereal crops attract pestrous rodent species like *M.natalensis* (Shenkut 2006). Our results were similar to those reported by Makundi and others (2007) who found higher densities of the species in areas cleared for agriculture at even much higher elevation of the Usambara Mountains, Tanzania.

CONCLUSION AND RECOMMENDATIONS

Our results indicate that the rodent density varied between habitats and seasons. It ranged from 5.5±1.6/ha to 20.56±3.6/ha, and was significantly higher during the dry season and in active maize crop farmlands than in the wet season and protected areas ($\chi 2= 79.393$, df = 2, $p < 0.001$). Further, rodent density was strongly positively associated with active farmlands ($p = 0.023$) and sandy-clay-loam soils ($p = 0.007$) but negatively correlated with the plant richness ($p < 0.0001$). These results are useful for developing the potential strategies to reducing impacts associated with this rodent species in the rural landscapes.

Since the target species exhibits seasonal variation in abundance in all three habitats especially in the maize crop fields, trapping to reduce its population especially when their densities are low and use of rodenticides could optimise prevention of the rodents' outbreaks during farming season and hence leading to reduced maize crop loss in the fields.

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