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Land use determinants of small mammal abundance and distribution in a plague endemic area of Lushoto District, Tanzania

PROCHES HIERONIMO[1*], DIDAS N. KIMARO[1], NGANGA I. KIHUPI[1], HUBERT GULINCK[2], LOTH S. MULUNGU[3], BALTHAZAR M. MSANYA[4], HERWIG LEIRS[5] and JOZEF A. DECKERS[2]

[1]*Department of Agricultural Engineering and Land Planning, Sokoine University of Agriculture, P.O. Box 3003, Morogoro, Tanzania*
[2]*Department of Earth and Environmental Sciences, University of Leuven, Celestijnenlaan 200E, Leuven, Belgium*
[3]*Pest Management Centre, Sokoine University of Agriculture, P.O. Box 3110, Morogoro, Tanzania*
[4]*Department of Soil Science, Sokoine University of Agriculture, P.O. Box 3008, Morogoro, Tanzania*
[5]*Evolutionary Ecology Group, Universiteit Antwerpen, Groenenborgerlaan 171, B-2020 Antwerpen, Belgium*

Abstract: Small mammals are considered to be involved in the transmission cycle of bubonic plague, still occurring in different parts of the world, including the Lushoto District in Tanzania. The objective of this study was to determine the relationship between land use types and practices and small mammal abundance and distribution. A field survey was used to collect data in three landscapes differing in plague incidences. Data collection was done both in the wet season (April-June 2012) and dry season (August-October 2012). Analysis of variance and Boosted Regression Trees (BRT) modelling technique were used to establish the relationship between land use and small mammal abundance and distribution. Significant variations ($p \leq 0.05$) of small mammal abundance among land use types were identified. Plantation forest with farming, natural forest and fallow had higher populations of small mammals than the other aggregated land use types. The influence of individual land use types on small mammal abundance level showed that, in both dry and wet seasons, *miraba* and fallow tended to favour small mammals' habitation whereas land tillage practices had the opposite effect. In addition, during the wet season crop types such as potato and maize appeared to positively influence the distribution and abundance of small mammals which was attributed to both shelter and food availability. Based on the findings from this study it is recommended that future efforts to predict and map spatial and temporal human plague infection risk at fine scale should consider the role played by land use and associated human activities on small mammal abundance and distribution.

Keywords: land use, small mammals, abundance, distribution, plague, infection risk, Tanzania

Introduction

Land use determines the spatial distribution of vectors and hosts according to their food and habitat preference (Linard *et al*., 2007). Like other animals, small mammals must obtain sufficient energy, nutrients and vitamins and escape predators to survive and reproduce. Their patterns of distribution may thus be influenced by the distribution and abundance of habitat resources. The most critical factors that have been found to influence small mammal distribution are thought to be food and shelter (Cooney *et al*., 1982). Total rodent abundance has been found to increase with increasing shrub cover in Kalahari in Namibia (Blaum *et al.,* 2007) and the Kibale Mountains of Uganda (Isabirye-Basuta & Kasenene, 1987). In the West Usambara Mountains of north-eastern Tanzania, the abundance of some rodent species has been shown to increase with food availability (Makundi *et al*., 2007; Mulungu *et al*., 2011).

Small mammals have been associated with plague in West Usambara Mountains, Tanzania (Kilonzo & Mhina, 1982; Mulungu *et al*., 2010). It is known that irregular epizootics are a common feature of sylvatic plague (Gage & Kosoy, 2005) and such dynamics in the wildlife host populations in the Usambara Mountains provide the most likely explanation for the high degree of temporal variation in human plague cases. That is, years in which there are outbreaks of human plague are those that plague epizootics occur in the wildlife and peridomestic rodent communities (Davis *et al*., 2006). Therefore, increasing densities of rodents in the West Usambara

[*] Correspondence: Proches Hieronimo; E-mail: phmusigula@gmail.com

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Mountains is likely to increase the risk of plague outbreaks in humans (Kilonzo *et al*., 2005; Makundi *et al*., 2007, 2008).

Various studies on the role of rodents in rodent-borne zoonoses transmission cycles have been conducted in the West Usambara Mountains and elsewhere in Tanzania (Kilonzo & Mhina, 1982; Kilozo *et al*., 2005; Makundi *et al*., 2003, 2008; Laudisoit *et al*., 2009a; Mulungu *et al*., 2010, 2011). These studies have demonstrated the role of shelter and food preferences of small mammals. However, the studies could not document the specific land use types and land management practices associated with small mammal distribution and abundance at a fine scale and within a wider geographic coverage which is important for delineation of potential risk areas (Eisen *et al*., 2012).

Since, some rodent species have been reported to play a dynamic role in the plague transmission cycle and the fact that these rodents are hosts of fleas (plague vectors) it is important to study their association with various land use types. This will contribute to an understanding of how to device ways and means to implement ecologically-based rodent management strategies focussing on specific land use types and land management practices which is currently lacking. The objective of this study was therefore to determine the relationship between land use types and practices and small mammal abundance and distribution in the West Usambara Mountains in Tanzania. Although, the role of individual species of small mammals and fleas in persistence and transmission of bubonic plague is not well known, gaining more insight in the relationship between land use and small mammals in general is certainly an important step towards an understanding of the plague system in a specific area.

Materials and Methods

Study area

The study was conducted in West Usambara Mountains, Lushoto District, Tanzania, in an area selected between Universal Transverse Mercator (UTM) coordinates 400000 m E and 430000 m E and between 9480000 m N and 9500000 m N, Zone 37M, covering about 34,000ha. The altitude ranges from 480 to 2 271 m above sea level (Figure1). The area has a bimodal rainfall pattern with an annual total ranging from 600 to 1,200mm. The study area is characterized by a mixed farming system. Rainfed agriculture is the most important land use followed by irrigated agriculture, livestock keeping and off farm activities including petty cash and carpentry (Msita *et al*., 2010). Other land uses include natural forestry, plantation forests and utility woodlots (Kaoneka & Solberg, 1994). Study sites were selected to reflect a geographic gradient in the frequency of plague incidence, based on results from previous research on rodents, fleas and plague casualties conducted in the area (Njunwa *et al*., 1989; Kilonzo *et al*., 1997; Davis *et al.,* 2006; Kamugisha *et al*., 2007; Laudisoit *et al*., 2007, 2009a,b; Neerinckx *et al*., 2010).

In selecting the study sites four criteria were used for detailed studies which include: (a) The incidence of plague as recorded for the period from 1986 to 2004, which in former studies allowed to subdivide the study area into three major landscapes of high (villages where plague incidence rates on average were 4.17–10.46 cases/1000 inhabitants), medium (1.91–4.17 cases/1000 inhabitants) and low (0.02–1.91 cases/1000 inhabitants) incidence; (b) Land use and human activity diversity; (c) Landform characteristics (plain, escarpment, plateau dissected at different levels and valleys); and (d) Climatic conditions. On the basis of these criteria, three landscapes were selected: (i) The Shume landscape (high plague incidence) - dissected upper part of the escarpment-edge of the plateau. The area is located in the cold dry zone (average temperature ranges between 15-19^{o} C, elevation 953-2040m and annual rainfall of 500-800 mm); the irregularly shaped 500 m deep escarpment has slopes up to 68 degrees and rock outcrops (Pfeiffer, 1990); (ii) The Lukozi landscape (medium plague incidence) - characterised by strongly dissected plateau, with broad ridge crest/summits and deep soils. The area is also situated in the cold dry zone. The average annual temperature ranges between 18-23^{o}C with an average annual

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rainfall of 1,000mm and elevation of 1,750-2,205m (Pfeiffer, 1990; Kaoneka & Solberg, 1997); (iii) The Mwangoi landscape (low plague incidence) is characterised by strongly dissected sunken part of the plateau. The climate in this area is hot and dry (average temperature 22°C), annual rainfall of 500–800 mm with an elevation of 1346-2002m (Pfeiffer, 1990)).

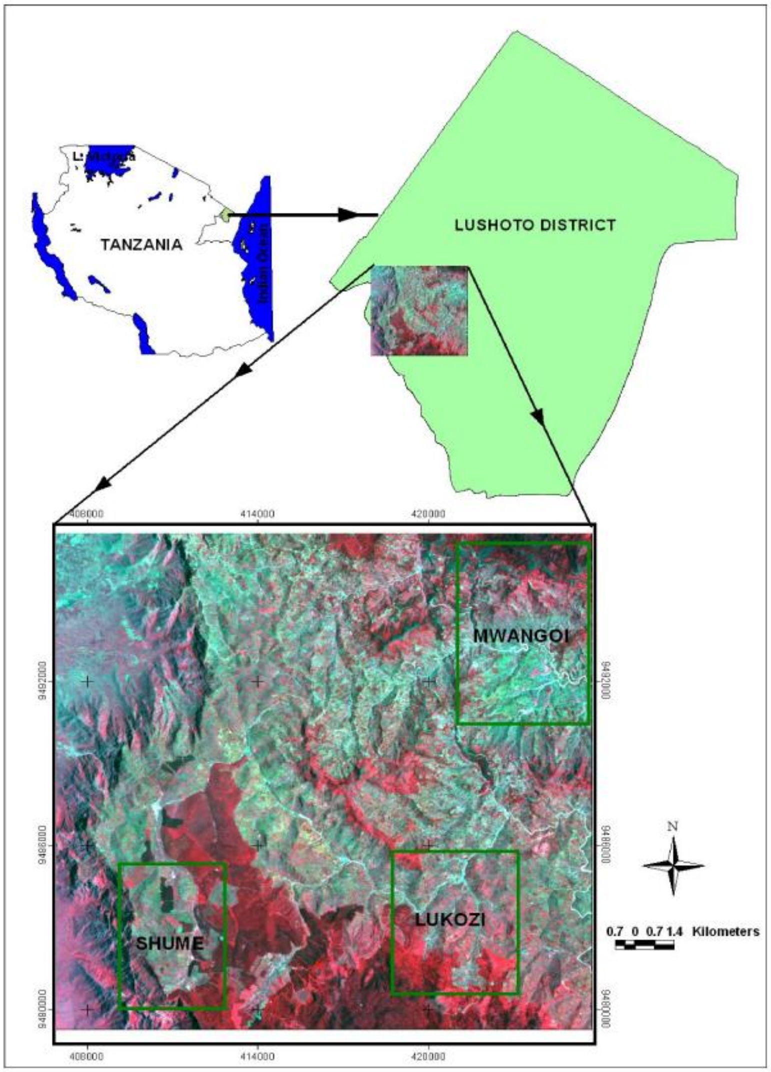

Figure 1: Location of study area: The Shume, Lukozi and Mwangoi landscapes

Sampling procedure
A total of 72 observation sites (quadrats) 100x100m were established. Twenty four quadrats were established per sample area (landscape). Stratified random sampling procedure based on broad land cover types and topography was used to locate the quadrats in each sample area. Decision on the number of observation sites considered representative sample size, time and human resources availability. At each observation site, data on land use including farm practices and management, small mammals and fleas combed out from small mammals were collected. Data collection was done in both wet (April-June 2012) and dry (August-October 2012) seasons.

Doi: http://dx.doi.org/10.4314/thrb.v16i3.8

Land use data

At each of the observation sites various visible indicators of land use were georeferenced and mapped. Two major categories namely, land management practices and crop types were classified. The land management practices were identified by characteristic land cover patterns as seen in the field. For example a rectangular *Guatemala*/elephant grass strips cover was identified as *miraba* (an indigenous land management practice with grass strips surrounding crop fields). Thus in this category five land use management types were mapped which include *miraba*, terraces, other hedge-like structures, tree stumps (dead and live) and fallow. "Other hedge-like structures" included crop fields demarcating grass/shrub strips, and hedges along footpath/roads and around houses. Fallow was composed of such land cover type as bushed grassland, bushes, shrubs, unattended banana bushes, and inter-seasonal weedy/shrub fallow, or a mixture of these.

Crop types and other elements were also identified by characteristic land cover patterns as seen in the field. For a field with a mixture of crops, each crop type was differentiated from other crop or physical features. In this group a total of 15 categories were mapped: maize, cassava, beans, potato, sugarcane, vegetables, settlement, *Guatemala* grass fields, tilled land, woodlot, rock outcrop, natural forest, plantation forest (monocrop), plantation forest (with annual crop farming going on or recently stopped) and other land uses. The "vegetables" category had a mixture of vegetables commonly grown in Lushoto (Kaoneka & Solberg, 1997). "Other land uses" category had a mixture of crops which were scant within quadrats (not one of the above listed crops). "Woodlots" had one or mixture of such land cover types as eucalyptus, grevillea, black wattle and pine woodlots. Each of the categories natural forest, plantation forest monocrop and plantation forest with farming activities were treated as single use in their respective observation sites.

Data on small mammals

Small mammals were captured mainly using Sherman LFA live traps (7.5 x 9.0 x 23 cm; HB Sherman Traps, Tallahassee, USA) baited with peanut butter and maize flour. A total of 49 Sherman live traps spaced 10 m apart were set in grids per trapping (observation) site for each trapping session. For the sites in natural forests, additionally two wire cages were used to capture somewhat bigger mammals like squirrels. Each trapping session lasted 3 nights. Each trap was inspected every morning and traps with captured animals were replaced by empty traps. Each captured animal was weighed; its sex identified and morphological measurements (length of body, tail, ear and hind foot) recorded and identified. For small mammals species that could not be identified to species level due to lack of morphological differences that were detectable in the field, individuals were identified to genus level (Eisen *et al*., 2012).

Data analysis

Data collected in the dry and wet seasons were compiled and descriptive statistical analysis and one-way analysis of variance (ANOVA) were carried out. Data included: Land use variables for Shume, Lukozi and Mwangoi landscapes; small mammals (genus/species name), trap success and overall fleas index per landscape. The trap success was calculated as number of animals trapped times 100 divided by the product of number of traps used and duration in terms of nights during which the trap was set (Laudisoit *et al*., 2009a). Overall flea index was calculated as the total number of fleas collected in a landscape per total number of captured small mammals in that landscape (Laudisoit *et al*., 2009a).

Prior to ANOVA, data was checked for normality and homogeneity (Zuur *et al*., 2010). Whenever normality was not fulfilled, data were $\log_{10}(x+3/8)$ transformed to achieve normal distributions (Axelsson *et al*., 2011; SAS Resource on the web, 2012). All statistical analyses were done using MS Excel and Minitab 14 software at the 95% confidence level. A one-way ANOVA of trap success among land use types was carried out on aggregated land uses data. For example

 Doi: http://dx.doi.org/10.4314/thrb.v16i3.8

wherever the observation site was dominated by both annual and perennial crops, the aggregated land use type for that particular observation site was classified as 'Mixed annual perennial crops' and wherever the observation site was composed of natural forest only the aggregated land use type became 'Natural forest'. A total of seven groups of aggregated land use (Plantation forest with farming, Natural forest, Fallow, Mixed annual crops, Mixed annual perennial crops, Plantation forest monocrop, Woodlot) were classified. Trap success was treated as dependent variable and aggregated land use was treated as independent variable.

Boosted Regression Trees (BRT) modelling technique was used to establish the relationships between small mammals' abundance (trap success) and individual land use variables. The individual land use variables used in BRT model are the originally sampled variables before aggregation. Boosted Regression Trees were constructed in R statistical program version 2.6.2 (R Development Core Team, 2006) using custom code (Elith *et al*., 2008). Analyses were based on a Gaussian distribution. The 10-fold cross-validation (CV) was used for model development and validation, with the benefit of still using the full data set to fit the final model. Models were fitted using the gbm.step function (aimed at minimising squared error), with most effective settings for learning rate (0.01–0.000001) and bag fraction (0.5–0.75) as found by repeated trial-and-error.

Tree complexity, i.e. the number of nodes in a tree, was set to 3, according to recommendations by Elith *et al*. (2008) for small datasets. The measure of model performance was cv deviance and standard error (Elith *et al*., 2008; Williams *et al*., 2010). The combination of learning rate and bag fraction settings with the lowest cv deviance and standard error was the one selected to produce the final BRT model (Williams *et al*., 2010). Also during data exploration all predictor variables were tested for ecologically acceptable level of collinearity (i.e. individual variance inflation factor (VIF) of <5) between predictor variables (Zuur *et al*., 2010; Aertsen *et al*., 2012). Partial dependency plots were used for interpretation and to quantify the relationship between each predictor variable and the trap success (Elith *et al*., 2008). The unit of measurement for *Miraba*, Other hedge-like structures and Terraces predictor variables was length (m) whereas Tree stumps were counted (number). The rest of land uses variables were measured as proportions of coverage (%) of each land use within sampled 100 x 100 m quadrat area.

Ethical considerations
This study received approval from Directorate of Research and Post-Graduate Studies of Sokoine University of Agriculture, Tanzania and Flemish Inter-University Council (VLIR-UOS) of Belgium.

Results

Influence of aggregated land use types on small mammal abundance
The trap success among aggregated land use types indicated significant variation at $p \leq 0.05$. The highest trap success was found in Plantation forest with farming followed by Natural forest and Fallow whereas the lowest was recorded in Woodlot (Table 1).

Table 1: Influence of aggregated land use types on small mammal abundance

Season	Land use	Mean Trap success (%)
Dry season	Plantation forest with farming	10.33
	Natural forest	8.16
	Fallow	6.43
	Mixed annual crop	4.46
	Mixed annual perennial crop	3.63
	Plantation forest monocrop	1.27
	Woodlot	1.99
Wet season	Natural forest	8.33
	Plantation forest with farming	8.18

Fallow	4.45
Mixed annual crops	4.11
Mixed annual perennial crops	2.69
Plantation forest monocrop	1.57
Woodlot	0.58

Influence of individual land use variables on small mammal abundance as demonstrated by BRT model

Seven land use variables (predictor variables) were selected by the BRT model to have influence (to be important) on the observed spatial pattern of trap success (small mammal abundance) during the dry season (Figure 2). All seven predictor variables had the ecologically acceptable level of individual variance inflation factor (VIF<5). *Miraba* was the most important predictor with contribution of more than a third of the total (40.5%) and a strong positive effect. The presence of at least 25m of *miraba* was enough for trap success increase. Fallow was the second important predictor with contribution of 22.9% and a strong positive effect. A threshold value of 20% fallow appeared to be an important condition for an increase of trap success. The third important predictor was other hedge-like structures (13.1% contribution) with immediate strong negative effect followed by weak positive effect with the higher and lower values respectively lying around zero. Tillage had contribution of only 8% and a weak then strong negative effect. The presence of at least 5% of tilled land appeared to be an important condition for a decrease of trap success. Other predictors had relatively weak influence and small contributions.

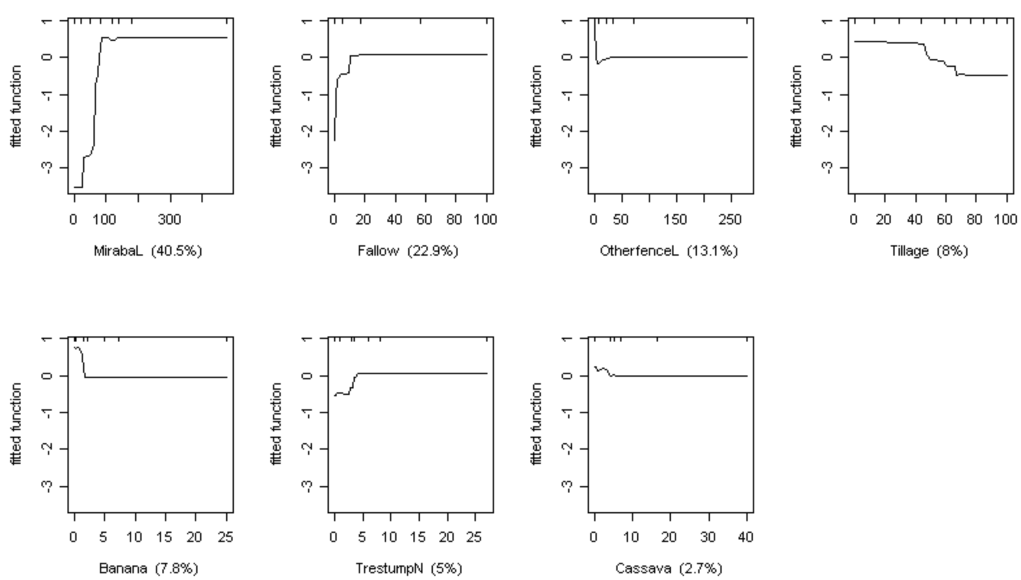

Figure 2: Partial dependence plots showing the effect of land use on spatial pattern of trap success during dry season. The relative contribution of each predictor is reported between brackets. CV deviance=21.6, standard error=5.943, number of trees=3250.

Key: TrestumpN= Tree stump, MirabaL=Miraba, OtherfenceL= Other hedge-like structures, CV = cross validation

Five land use variables (predictor variables) were selected by the BRT model to have influence (to be important) on the observed spatial pattern of small mammals in the wet season (Figure 3). All five predictor variables had the ecologically acceptable level of individual variance inflation factor (VIF<5). Potato was the most important predictor with contribution of half of the total (51.8%) and immediately showed a strong positive effect; the lower limit of the proportion of potatoes

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being only slightly greater than 0%. This implies that having just few potatoes in a field was enough to trigger off increased abundance of small mammals. *Miraba* and maize with contributions of 14% and 7.8%, respectively had weak positive influence. Other hedge-like structures (10.8% contribution) had immediate strong negative influence between 0 and 20m length. Tree stumps had a contribution of 15.5% but with a weak effect.

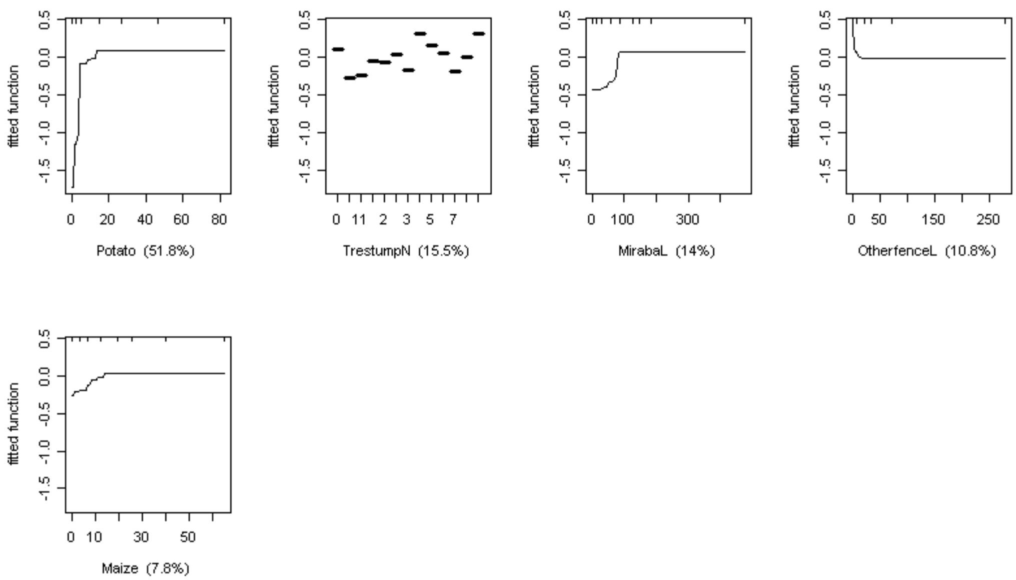

Figure 3: Partial dependence plots showing the effect of land use on spatial pattern of trap success during wet season. The relative contribution of each predictor is reported between brackets. CV deviance=12.911, standard error=2.633, number of trees=1200.
Key: TrestumpN= Tree stump, MirabaL=Miraba, OtherfenceL= Other hedge-like structures, CV = cross validation

Table 2: Distribution of small mammals and fleas by season collected in the three landscapes

Season	Dry season			Wet season		
Landscape	**Shume**	**Lukozi**	**Mwangoi**	**Shume**	**Lukozi**	**Mwangoi**
Small mammal (Genus/Species)						
Mastomys natalensis	166 (62.6%)	140 (60.3%)	26 (32.9%)	111 (47.4%)	73 (37.8%)	34 (36.6%)
Lophuromys sp.	30 (11.3%)	19 (8.2%)	5 (6.3%)	51 (21.8%)	24 (12.4%)	6 (6.5%)
Praomys sp.	9 (3.4%)	36 (15.5%)	14 (17.7%)	11 (4.7%)	54 (28.0%)	33 (35.5%)
Arvicanthis sp.	14 (5.3%)	4 (1.7%)	3 (3.8%)	9 (3.8%)	5 (2.6%)	0 (0.0%)
Crocidura sp.	9 (3.4%)	0 (0.0%)	1 (1.3%)	12 (5.1%)	14 (7.3%)	5 (5.4%)
Mus sp.	13 (4.9%)	19 (8.2%)	10 (12.7%)	10 (4.3%)	10 (5.2%)	1 (1.1%)
Grammomys sp.	13 (4.9%)	11 (4.7%)	8 (10.1%)	16 (6.8%)	9 (4.7%)	12 (12.9%)
Aethomys sp.	6 (2.3%)	0 (0.0%)	9 (11.4%)	10 (4.3%)	0 (0.0%)	0 (0.0%)
Lemniscomys sp.	3 (1.1%)	1 (0.4%)	1 (1.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Otomys sp.	2 (0.8%)	1 (0.4%)	0 (0.0%)	1 (0.4%)	2 1.0%)	1 (1.1%)
C.gambianus	0 (0.0%)	1 (0.4%)	0 (0.0%)	0 (0.0%)	2 (1.0%)	0 (0.0%)
Beamys sp.	0 (0.0%)	0 (0.0%)	1 (1.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Rattus rattus	0 (0.0%)	0 (0.0%)	0 (0.0%)	3 (1.3%)	0 (0.0%)	0 (0.0%)
Paraxerus sp.	0 (0.0%)	0 (0.0%)	1 (1.3%)	0 (0.0%)	0 (0.0%)	1 (1.1%)
Total small mammals	265	232	79	234	193	93
Total fleas	358	180	137	179	124	67
Flea index	1.4	0.8	1.7	0.8	0.6	0.7

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Abundance and diversity of small mammals in different landscapes with historical plague incidence

Mastomys natalensis, *Lophuromys sp.* and *Praomys sp.* were the dominant species in both wet and dry seasons and make up a total of 842 animals which is 76.8 % of the total catch (Table 2). Shume landscape had many *M. natalensis* and *Lophuromys sp.* than the rest of the landscapes in both seasons. *Aethomys sp.* were captured only in Shume and Mwangoi landscapes. Other captured small mammals were *Rattus rattus* in Shume landscape only and *Paraxerus sp.* and *Beamys sp.* in Mwangoi landscape only. Figure 4 shows the mean trap success per trapping (observation) site. The results show that in both seasons, Shume landscape had more small mammals per observation site than Lukozi and Mwangoi. Seasonal difference is also clear whereby dry season had higher values compared to wet season for Shume and Lukozi whereas in Mwangoi it was the opposite. The overall flea indices for all three landscapes ranged from 0.6 to 1.7.

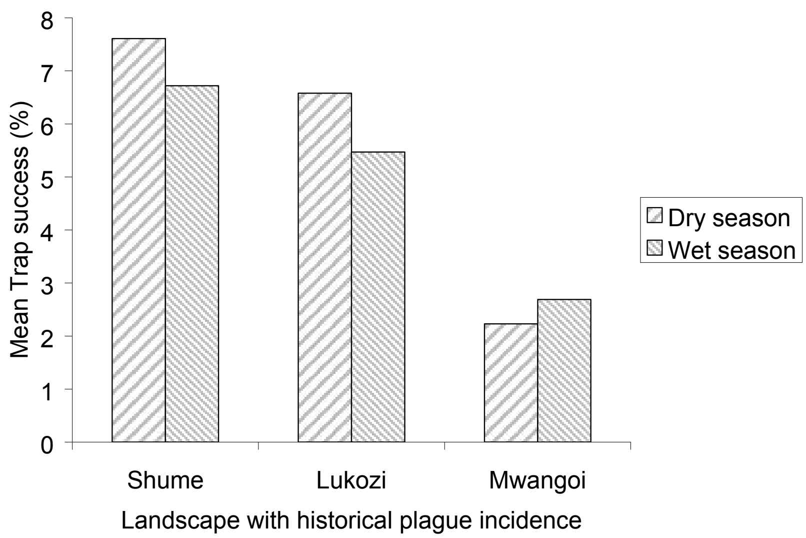

Figure 4: Mean trap success per sampling site in different landscapes in dry and wet seasons

Discussion

Variation in distribution of small mammals as influenced by land use types as observed in the current study is consistent with previous observations in the area (Laudisoit *et al*., 2009a). These variations may be attributed to the fact that, Plantation forest with crop farming provides both shelter and food resources (Tews *et al*., 2004). Fallow land is mainly surrounded by agricultural fields - a combination that provides shelter, breeding sites and supplementary food for rodents (Mwanjabe, 1993). Natural forest also provides food, water and shelter for small mammals. Generally, the results confirm findings from previous studies that small mammal abundance and distribution is critically associated with availability of food and shelter (Cooney *et al*., 1982). Results with the BRT model suggest *miraba* to be the most important predictor of small mammal abundance. *Miraba* is a unique indigenous soil erosion control practice in the Usambara Mountains (Msita *et al*., 2011). *Miraba* filter sediments from the runoff but the grasses grown in *miraba* construction may be used as animal fodder which is an added advantage. *Miraba* have many attributes as habitat for small mammals. They provide better locations for rodent burrows which do not easily get flooded with water during rainy season as well as shelter against predators (Kamugisha *et al*., 2007; Msita *et al*., 2011).

Fallows which were identified and discriminated as being composed of such vegetation types as bushed grassland, bushes, shrubs, unattended banana bushes, and inter-seasonal weeds and shrub fallow had positive influence on small mammal abundance during the dry season.

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These vegetation types were previously found to be associated with rodents in the study area (Makundi *et al*., 2007; Laudisoit *et al*., 2009a). Indeed, these vegetation types not only provide nesting sites and diverse food sources, but also offer an effective shelter for ground dwelling small mammals from carnivores and avian predators (Tews *et al.,* 2004), and, hence, there is lower predation risk in these closed habitats (Laudisoit *et al*., 2009a). Fallow land matrices thus serve as refuges for rodents that infest crop fields (Makundi *et a*l., 2007; Mulungu *et al*., 2011). These findings shed light on the possible link between these two land management practices, i.e. *miraba* and fallow and plague infection risk during epizootic periods. This is because, previous studies in the Lushoto and Mbulu foci in Tanzania show that plague outbreak has been occurring after rodent increase (outbreak) followed by rodent mortality (Kilonzo *et al*., 2005; Makundi *et al*., 2008).

Land tillage, which takes place during the dry season, had a strong negative effect on trap success. Tillage of land could have resulted in the destruction of mounds, removal of vegetation and destruction of nest sites some of which comprise food sources and shelter for the rodents. It may also be associated with alteration of soil micro-environment including exposure of small mammals to predators. Similar findings have been reported by Massawe *et al*. (2006). These observations are of practical significance to the local communities with regard to keeping their surroundings clean and reducing the duration of fallow periods although the latter may be at variance with acceptable conservation practices. This could curtail rodent build-up and hence minimize risk of contracting plague.

During the wet season, both potato and maize crops appeared to have a direct and positive influence on small mammal abundance. This could be attributed to the fact that the most critical factors that have been found to influence rodent distribution are thought to be related to the availability of food and shelter (Cooney *et al*., 1982). Interviews with key informants revealed that maize and potato were among the crops reported to be highly preferred by rodents in the study area. Similar findings have been reported by Mulungu *et al*. (2011).

The three dominant species of small mammals (*Mastomys natalensis*, *Lophuromys sp.* and *Praomys sp.*) observed in this study have been previously reported to be involved in the plague transmission in the study area (Kilonzo & Mhina, 1982; Makundi *et al*., 2007, 2008). The overall flea index (0.6 - 1.7) which was associated with the captured small mammals in this study, further indicates the potential risk of transmitting the disease from small mammals to humans during epizootics (Kilonzo *et al*., 1992; Eisen *et al*., 2006; Laudisoit, 2009). The general trend of values of absolute number and mean trap success of small mammals was Shume>Lukozi>Mwangoi. This could be explained by land use pattern differences where Shume has more plantation forest with farming, fallow lands and rock outcrops which seem to attract more rodents (Laudisoit *et al*., 2009a; Mulungu *et al*., 2011). The other reasons might be related to topography which also varies in terms of providing food, water and shelter. In other words, Shume appears to be a natural habitat for small mammals.

The current study has demonstrated that small mammal abundance and distribution is strongly influenced by the specific land use types. These results suggest that land management practices including tillage of land and crop types and the associated human activities should be included in the general scheme of plague maintenance and transmission mechanisms. Future efforts to predict and map spatial and temporal human plague infection risk at farm scale should consider the role played by land use on small mammal abundance and distribution. These findings therefore, make a significant contribution towards efforts in the control of plague risk factors in space and time. Small mammal presence in different land use types can influence abundance of certain flea species. However, since rodent fleas are ectoparasites which tend to inhabit both rodents (hosts) and off-host environment, additional investigation on how land use practices affect microclimate conditions for fleas living on and momentarily off-host is vital.

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