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Vegetation habitats and small mammals in a plague endemic area in Western Usambara Mountains, Tanzania

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Abstract: Human plague still exists in different parts of the world, including some landscapes in north-eastern Tanzania. Wherever the hotspot of plague, small mammals seem to play a key role as host. The objective of this study was to investigate the relationship between vegetation habitats types and small mammals in a plague endemic area of Lushoto District in Tanzania. A combination of field survey and Landsat images was used to identify the vegetation habitats. Small mammals were trapped in the mapped vegetation units, and identified. In total, six main types of vegetation habitats were investigated. A total of 13 small mammal species, potentially related to plague were trapped. Results show that annual cultivated crops habitat accounted for 80% of *Mastomys natalensis* while natural forest accounted for 60% of *Praomys delectorum*. These findings have shed new light on the diversity of rodents in different habitats of natural and semi-natural vegetations, and agricultural crops in the study area, which is an important intermediate step in unravelling the complex human plague system.

Keywords: plague, vegetation, habitats, rodents distribution, Tanzania

Introduction

Small mammals are an integral part of biodiversity and ecosystems of sub-Saharan Africa (Stanley *et al.,* 1998; Mulungu *et al*., 2008). Certain species of small mammals are seen as pests for crops and livestock as well as transmitters and/or reservoirs of different zoonotic diseases such as plague (Kilonzo *et al*., 2005). Rodents exist in a wide diversity of species all over the world except Antarctica, and their overall ecological range is extremely broad and complex (Mulungu *et al*., 2008). Each rodent species has a specific adaptation capability to various environments in its feeding and living habits (USAID/Tchad, 1997). The spatial distribution of small mammal species is influenced by interaction of various factors including food availability, water and predators (Poulin *et al*., 2002; Pinzon *et al,*. 2005; Elmhagen & Rushton, 2007; Oosthuizen & Bennett, 2009; Bateman *et al*., 2010). Small mammal species considered individually, however, clearly exhibit habitat preference (Hackley *et al*., 2010; Mulungu *et al*., 2012).

The domestic rodents (*Rattus* spp. and other murids) which may also be plague hosts have been found in a variety of habitats such as cultivation area (Claveria *et al.*, 2005), forest and shrubland (Harper *et al.*, 2005) in many countries including Tanzania (Laudisoit *et al.*, 2006; Mulungu *et al*., 2013). The black rat, *R. rattus*, and *Mus musculus* often live in complex habitats of farmland and farm buildings (Bennett, 1990). *Mastomys natalensis* is known to be a pioneer small mammal species in the colonisation of heavily overgrazed areas (Meester *et al.*, 1979). The white-footed mouse (*Peromyscus leucopus*) is a habitat generalist and a permanent resident of shrubland, forest and grassland (Adler & Wilson, 1987). Observations show that it is found generally at higher densities in hardwood forests with a large volume of stumps and logs (> 5 cm diameter), and dense ground cover (Brannon, 2002). In the New York Metropolitan region, meadow voles (*Microtus pennsylvanicus*) tend to be restricted to grassland, while short-tailed shrews (*Blarina brevicauda*) and masked shrews (*Sorex cinereus*) favour moist herbaceous and woody habitats (Howell, 1984).

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Man has created transitional habitats which attract different kinds of small mammals including those considered as disease hosts (Kilonzo *et al*., 2005). In such habitats, the transfer of disease from one animal to another may take place (Anderson & Wait, 2008). Therefore, fine-tuned studies on vegetation are an essential part of the efforts to explain and predict zoonotic diseases (Eisen *et al*., 2007), and for the development of pest management strategies (Mulungu *et al.,* 2012).

The main objective of this study was to find out whether and in what degree vegetation-defined habitats can be labelled as habitats of small mammals that are suspected of transferring plague from its natural hosts to humans. The results of this study envisaged to be useful in designing management strategies to minimize the risks of further outbreaks of the plague in the West Usambara Mountains in Tanzania.

Materials and Methods

Study area

The study was conducted from December 2009 to March 2010 in the West Usambara Mountains in Lushoto District in north-eastern Tanzania. The area is within a rectangular section between 4°22'S, 38°05'E (northwest corner) and 5°08'S, 38°38'E (southeast corner). The study area ranges in elevation from 300 to 2,250 m above mean sea level. The annual precipitation varies from 600 mm in the plains up to 2,000 mm in the escarpment and on the plateau. The average annual temperature ranges from 27°C down to 17°C in a toposequence from 800 to 1,800 m above mean sea level. With population density of 254 persons per km^2, Lushoto District is among the most densely populated districts in Tanzania~~,~~ compared to the national average of 39 persons per km^2 (NBS, 2013). The toposequence is characterised from west to east by a dry plain with stone rich shallow soils, over an abrupt rock escarpment, and an undulating plateau (Neerinckx *et al.*, 2008). Most of the soils are red to black Ferrasols, with sandy-clay-loam texture, and a low pH (Neerinckx, 2006; Laudisoit, 2009). Natural forest reserves (Magamba) and plantation forests (Shume-Nywelo) dominate the study area. Major deforestation and conversion to agricultural land started around the 1960s in the study area.

Vegetation habitats mapping

Vegetation habitats and associated characteristics were determined and mapped using a combination of field survey, remote sensing and Geographic Information System (GIS). Positions were recorded using Global Position System (GPS). The identification of vegetation types was according to the FAO guidelines (Di Gregorio, 2005) based on the definition of General Habitat Categories (GHC), in a grid of 20x20 m resolution. These systems are based in the first place on growth forms according to the principles of Raunkiaer (1934), rather than on species composition. At the upper level of the FAO the GHCs present in this area are natural forest, plantation forest, horticulture, shrub, herbaceous vegetation, and cultivation (with annual crops like maize, cassava and sweet potatoes). In the cultivated area, distinction was made between the *miraba* cultivation type (a system of small rectangular fields surrounded by grass strips, not strictly oriented according to the contour lines, and cultivation without such characteristics. The habitats map was produced with a legend and a table showing vegetation species and other habitat characteristics. The vegetation habitat map and associated characteristics were used to establish relationships with small mammals' distribution.

Trapping procedure

The mapped vegetation habitats were used as a basis to define the trapping sites for small mammals. A total of 41 vegetation habitat units were selected for trapping and 100 traps were used for each selected habitat type. Three different types of traps (i.e. Sherman live traps, local

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wire cages and pitfall traps) were used to assure a sufficient number of species to be captured. In Sherman and local wire cage traps, the bait consisted of a mixture of peanut butter, maize bran and sardines. The traps were placed five meters apart and left open during an average of two consecutive days. The trapped animals were counted, measured and identified to species level following the established taxonomic nomenclature according to the Kingdon (1997) book. The carcasses were initially preserved in 10% formalin and later transferred to 70% ethanol. All preserved carcasses were stored at Sokoine University of Agriculture, Pest Management Centre, for further studies.

Trap success

Trap success was determined to establish an index for assessing small mammal abundance in various vegetation habitats. Trap success refers to the mean number of small mammals without considering their species within one or different vegetation habitats during a certain period of time (Saunders, 2007). This can help to reveal the possible occurrence of the animals within a particular habitat. Trap success was expressed as:

$$\text{Trap success} = \frac{N}{Nt \times Nn} X\ 100$$

N= number of small mammals trapped, Nt= number of traps used, Nn= duration in terms of nights during which the trap was set.

Data analysis

Costat 6.4 package was used to determine the effect of vegetation habitats (treatments arranged in a complete randomised block design) combined with landscape characteristics and slope azimuth (blocks) on small mammal distribution. Qualitative assessment and predictive statistical analysis were employed in the exploratory analysis of small mammal abundance and the vegetation characteristics. This included the estimation of average and percentage cover of vegetation types. Wherever it was applicable the degree of association between variables was measured by linear regression, scatter plot analysis and the Pearson correlation coefficient (R) at $p \leq 0.05$.

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

Vegetation habitat types

The vegetation habitat map at a scale of 1:20,000 obtained in this study portrayed nine general vegetation habitats (Figure 1). Cultivation (annual crops: maize, beans and Irish potatoes) occupied 24% of the total study area followed by plantation forest (19%), shrub (18%), natural forest (17%), settlements (12%), and the rest included herbaceous vegetation, rocky surfaces, and horticulture (10%). Natural forest and other vegetation habitats including cultivation (annual crops), horticulture, and plantation forest occupied the plateau landscape. The plantation forest was dominated by agrocarpus (*Agrocarpus* spp.), cedar (*Cedrela odorata*), cypress (*Cupressus sp.*), eucalyptus (*Eucalyptus camadulensis*), grevillea (*Grevillea robusta*), pine (*Pinus patula*), and wattle (*Acacia mearnsii*). Shrubs occupied the major part of the escarpment and the plain landscapes. However, shrubs were also found in different parts of the plateau including forest edges and hill summits.

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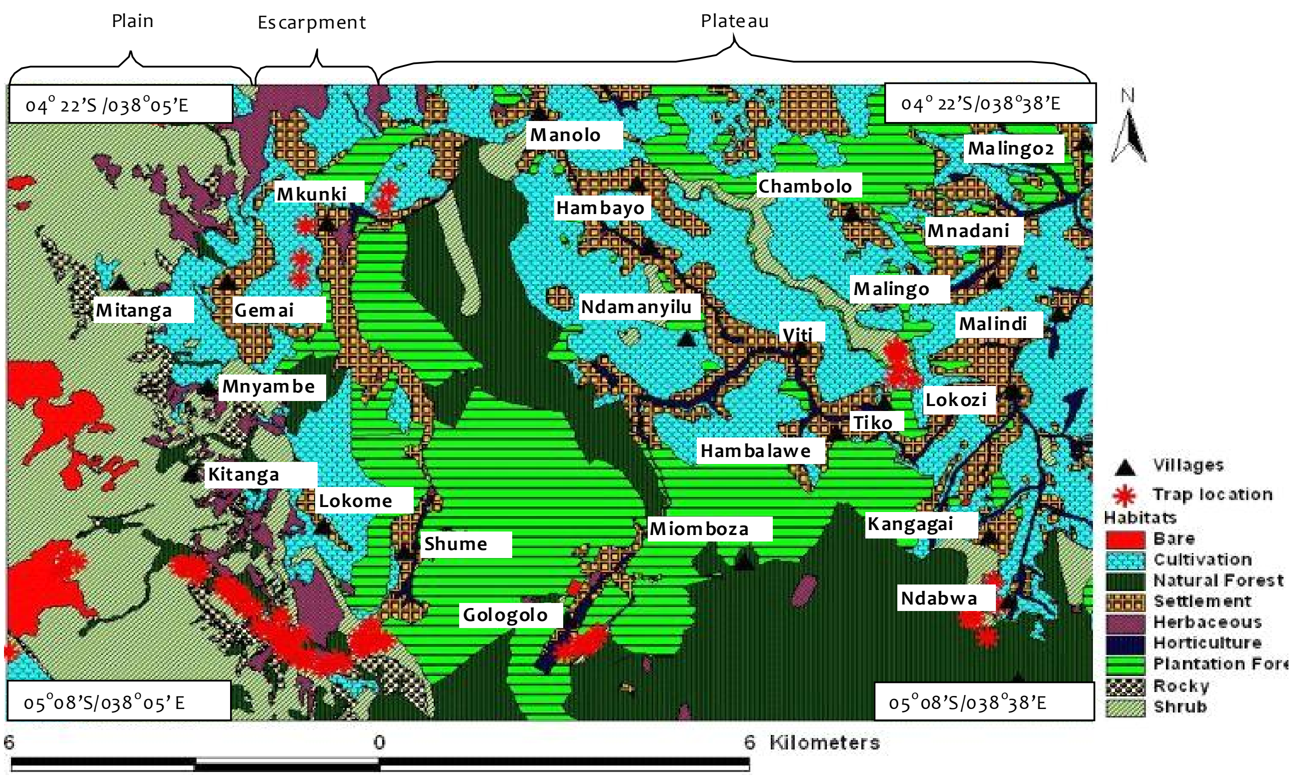

Figure 1: Spatial distribution of vegetation habitats on different landscapes in the study area

Relationship between vegetation habitats and their characteristics

The results show significant difference (p≤0.05) between vegetation and its associated characteristics (Table 1). Plantation forest, natural forest and horticulture comprised the highest cover (>55%) among the dominant vegetation species (Table 1).

Table 1: Vegetation habitats in relation to their associated characteristics

Small mammal habitat	Total number of fragments (patches)	Total area (km^2)	Average area per fragment (km^2)	Mean vegetation height (m)	Mean number of dominant vegetation species	Cover of dominant vegetation species (%)	Total habitat cover (%)
Bare*	12	314	26abc	1.71ef	1.75e	3.25d	7.50h
Cultivation	313	4738	15c	4.02d	1.93d	16.18c	20.33g
Natural forest	72	3384	47a	10.14a	3.26b	61.87a	75.56a
Settlement	233	2483	10c	5.39c	1.61e	12.53d	29.77f
Herbaceous	119	749	6c	1.40f	2.47c	44.49b	69.65bc
Horticulture	21	387	18bc	0.35f	3.95a	59.05a	59.52de
Plantation forest	131	3823	29ab	7.04b	1.18e	64.47a	73.01ab
Rock*	49	336	6c	1.64ef	2.31cd	8.18d	58.94e
Shrub	301	3662	12c	2.318e	3.47ab	47.35b	67.56cd
Mean			15	4.11	2.34	33.66	48.89
F-test (0.05)			***	***	***	***	***
CV (%)			0.3	60.37	49.71	56.52	39.56

The same letter on the same column indicates no significant difference at p ≤ 0.05. ***= highly significantly different (p ≤ 0.001). Rocky and bare habitats have vegetation cover less than 10%; CV = Coefficient of Variation

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Results show that horticulture, shrubs and natural forest had the highest number of dominant vegetation species. In terms of coverage area per fragment, natural forest had the largest patches (47 km^2) followed by plantation forest (29 km^2). Other habitats comprised of cultivation, shrub and herbaceous plants were the smallest (less than 15 km^2). The natural forest had the tallest vegetation with an average height of 10m followed by plantation forest (7m). The vegetation height in the settlement habitat was about 5m while those in shrub habitat had an average height of 2m (Table 1).

Table 2 (a): Vegetation species identified in different vegetation habitats in the plain landscape

Habitat	Tree	Shrub	Herbaceous
Bare		*'Mpingo' (Salvadora persica), 'Mponda' (Commiphora africana)*	
Cultivation		Sisal *(Agave sisalana)***	
Forest	*Acacia* spp.*, *Albizia* spp.*	*'Kikwata', 'Mijwa', 'Mkole', 'Mponda', 'Msaji'*	
Rocky		Euphorbia, *'Mijwati', 'Mjavikai', 'Mkole', 'Mpingo' (S. persica), 'Mponda'*	Grass
Settlement	*'Mkui'*	*'Mkole'*	
Herbaceous		*'Mkonge', 'Mponda'*	Grass
Shrub	*'Mvumo'*	*'Kikwata'**, Mexican Euphorbia * (*E. bussei var. kibwezensis*), *'Mijwati'**, *'Mjavikai'**, *'Mkayo', 'Mkole'**, *'Mkonge', 'Mleza', 'Mpingo mchanga' (Salvadora persica)**,	

*= dominant vegetation species. Scientific names are italicised in bracket while vernacular names are italicised between quotation marks

Shrubs were the dominants vegetation species all the habitats. Trees were absent in the cultivation, Rocky and Herbaceous habitats. Acacia, and Albizia were the only tree species in the forest habitat. In the cultivation habitat, sisal was the dominant vegetation (Table 2a).

Table 2 (b): Vegetation species identified in different vegetation habitats in the escarpment landscape

Habitat	Tree	Shrub	Herbaceous
Bare			Grass*
Cultivation	*Albizia* spp., Cider *(Cedrela odorata)*, Cypress *(Cupressus spp.)*,	*'Kikwata', 'Maharasha', 'Mdaa', 'Mdala', 'Mgaha', 'Mhongo','Mijwati', 'Mjavikai', 'Mkole', 'Mponda' (Commiphora Africana),' Msusuambuzi', 'Mtanga', 'Tende' (Aloe bainesii)*	Banana *(Musa* spp.), Fen *(Bovista* spp.) Grass, *'Sopolowa', 'Nywa',)*
Forest	*Acacia* spp.**, *Agrocarpus* spp., *Albizia* spp.**,	*'Huiu', 'Kibara', 'Kikwata', 'Mdaga', 'Mgaha', 'Mihongo', 'Mijwa', 'Mjavikai', 'Mkole', 'Mkui', 'Mponda' (C. Africana)*	*Five*, Grass, *'Nywa', 'Sopolowa'*
Herbaceous	*Albizia* spp., Gravellia *(Grevillea robusta),)*	Banana, *'Kibaranga', 'Kwemsoso', 'Maharasha', 'Mdaa', 'Mdagha', 'Mihongo', 'Mjavikai', 'Mkayo', 'Mkole', 'Mpingo'* or *'Mswaki' (S. persica), 'Mponda'*	Fen *(Bovista* spp.), *Five*, Grass*, '
Plantation Forest	Cypress *(Cupressus* spp.)*, wattle *(A. decurrens)**	*'Maharasha', 'Mtanga'*	*'Swizo'*
Rocky	*Albizia* spp.	*'Kikwata', 'Mdagha', 'Mijwati', 'Mjavikai', 'Mkole', 'Mponda' (C. Africana), 'Tende' (A.bainesii)*, Wild banana (*E. ventricosum*)	*'Sopolowa'**, Grass*
Shrub	*Acacia* spp., *Albizia* spp., '	*'Kibara', 'Kikwata'**, *'Mdaga', 'Mhongo mkubwa', 'Mijwati', 'Mjavikai', 'Mkole'**	Fen *(Bovista* spp.), , *'Sopolowa'*
Settlement	*'Mkui'*	*Wild banana (E. ventricosum)*	Fen *(Bovista* spp.)*, Grass*

*= dominant vegetation species; Scientific names are italicised in bracket while vernacular names are italicised between quotation marks

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Vegetation species distribution in different landscapes

The plain landscape was dominated by different shrub species such as '*Mtiwamiba*' or '*Mbambara*' (Kiswahili) or *Commiphora africana*, '*Mpingo mchanga*' (Kisambaa), '*Mswaki*' (Kiswahili) or *Salvadora persica*, and Mexican Euphorbia (*Euphorbia bussei var. Kibwezensis*) (Table 2a). In the escarpment landscape, other shrub species including 'Kikwata' (Kisambaa), '*Mjavikai*' (Kisambaa), and '*Tende*' (Kisambaa) or '*Endukushi*' (Kimasai) or *Aloe bainesii*, and some herbaceous species such as '*Sopolowa*' wre common (Table 2b). In the plateau landscape (Table 2c), some exotic trees including agrocarpus (*Agrocarpus* spp.), cedar (*Cedrela odorata*), cypress (*Cupressus* spp.), eucalyptus (*Eucalyptus* spp.), grevillea (*Grevillea robusta*), pine (*Pinus* spp.), and wattle (*Acacia decurrens*) combined with indigenous trees such as Camphor *(Ocotea usambarensis)* and 'podo' *(Podocarpus usambarensis and Podocarpus pensiculy)* were dominant. Tomatoes (*Solanum lycopersicum*), carrot (*Daucus carota sativus*), cabbage (*Brassica oleracea*), maize (*Zea mais L.*), and Irish potatoes (*Solanum tuberosum*) were also found in the plateau landscape, particularly in the valley bottoms (Table 2c).

Table 2 (c): Vegetation species identified in different vegetation habitats in the plateau landscape

Habitat	**Tree**	**Shrub**	**Herbaceous**
Cultivation	*Agrocarpus* spp., Grevellia (*Grevillea robusta*), Pine (*Pinus* spp.)	'*Kwemisoso*', '*Maharasha*', '*Mdala*', '*Mhongo*', '*Mshiay*', '*Msusuambuzi*', '*Mtanga*', '*Mzilageme*'	Bean (*Phaseolus vulgaris*)*, Cabbage (*Brassica oleracea*)*, Carrot (*Daucus carota sativus*)*, Guatemala grass (*Tripsocum andersoni*)*
Forest	*Ocotea usambaraiensis, Podoptera usambaraiensis,*	'*Kwemisoso*'	
Herbaceous	*Albizia* spp., Wattle (*A. decurrens*)	'*Mjavikai*', '*Tende*' (*A. bainesii*)	Fen (*Bovista* spp.)*, *Nywa** Grass*
Horticulture		Prune (*Prunus domestica*), Peach (*Prunus persica*), Apple (*Malus domestica*)	Bean (*P. vulgaris*)*, Cabbage (*B. oleracea*)*, Carrot (*D. carota sativus*)*, Guatemala grass (*T. andersoni*)*, Elephant grass (*P. purpureum*)*,
Plantation Forest	*Agrocarpus* spp.*, Cider (*C. odorata*)*, Cypress (*C. spp.*), *Eucalyptus* spp.*, Grevellia (*G. robusta*)*	'*Maharasha*','*Mtanga*', '*Swizo*'	Bean (*Phaseolus vulgarus*), Maize (*Zea mais L.*), Potatoes (*Solanum tuberosum*)
Settlement	*Agrocarpus* spp., Cider (*C. odorata*), Cypress (*C. spp.*), *Eucalyptus* spp., Grevellia (*G. robusta*)*	Banana* (*Musa* spp.), '*Kwemisoso*', '*Mdala*', '*Mkindoly*', '*Mlagena*', '*Mshiay*', '*Mzilangwa*', Sugar cane (*Saccharum officinarum*)	Grass, '*Nywa*'
Shrub	Cider (*C. odorata*), '*Kigwandi*', '*Mvumo*'	'*Boho*', '*Gwanguzo*', '*Hoko*', '*Kihagio*', '*Kihongo*'*, '*Kovo*', '*Marashia*'*, '*Mbaanga*', '*Mdala*'*, '*Mdogoniezi*'*,	'*Donado*', Fen, '*Isale*' (*Kiniywanya*),

*= dominant vegetation species, scientific names are italicised in bracket while vernacular names are italicised between quotation marks

Distribution of small mammals in different vegetation habitats

A total of 188 small mammals comprising 13 species, not only rodents, were trapped over a period of 4,905 trap nights. *Praomys delectorum* and *M. natalensis* were the most common small mammals trapped, accounting for about 50% (Table 3). *Lophuromys kilonzoi* and *Gramomys dolichurus* comprised 30% of the total number of small mammals trapped. Some species like *Otomys angoniensis*, *Mus minutoides*, dwarf mongoose (*Helogale parvula*), striped ground squirrels (*Xerus erthropus*), genet (*Genetta genetta*), *Crocidura hirta, Aethomys chrysophilus* and *Rattus rattus* were trapped only once. In the plain and on the escarpment, a total of 30 small mammals (9 species) were trapped while in the plateau landscape, 157 small mammals (9 species) accounting for 80% of the total small mammals were captured.

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Table 3: Distribution of small mammal species according to vegetation habitats

Species	Cultivation		Natural forest	Plantation forest	Settlement	Herbaceous		Shrub				Total*
	Mc	Sc	CT3	OT3	CT3p	Sset	CHe	CSh	EdgCSh	OSh	SSh	
H. parvula										X		1(1)
G. genetta								X				1(1)
O. angoniensis		X										1(1)
R. rattus						X				X		2(2)
M. minutoides	X				X			X				3(4)
X. erthropus				X				X				2(4)
C. hirta.			X		X			X				3(5)
A. wilsoni								X		X		2(9)
A. chrysophilus			X				X	X		X	X	5(11)
G. dolichurus	X			X	X		X	X	X	X	X	8(25)
L. kilonzoi	X		X		X				X	X	X	6(29)
M. natalensis	X	X			X					X		4(42)
P. delectorum			X	X	X			X	X	X		6(54)
Total	4	2	4	3	6	1	2	8	3	8	3	44(188)

Where: CT3= closed forest, OT3= disturbed forest, CSh= Closed shrub, Osh= open shrub, SSh= sparse shrub, CHe= closed herbaceous, CT3p= closed plantation forest, ESet= very scattered (emergent) settlement, SSet= sparse settlement, Mc= Contour cultivation, Sc= cultivation without contour. * Figures in the brackets indicate total number of animals trapped

The number of individual mammals captured varied with the type of vegetation habitats. More individual mammals were captured in shrubs (96) as compared to cultivation (46), natural forest (22), forest plantations (20), herbaceous vegetation (3) and settlement compounds (1) (Table 3).

Table 4 (a): Trap success of small mammals with respect to natural forest habitat and altitude

Main habitat	Altitude	Sub-habitat	Trapped	Trap night	Trap success
	700-1000	CT3	2	224	0.89
	1000-1600	CT3	1	298	0.34
	1600-1900	CT3	7	72	9.72
	1900-2200	CT3	5	29	17.24
Natural forest	Total	CT3	15	623	2.41
	700-1000	OT3	2	147	1.36
	1000-1600	OT3	0	100	0.00
	1900-2200	OT3	5	52	9.62
	Total		7	299	2.34
	400-700	CSh	6	425	1.41
	700-1000	CSh	2	408	0.49
	1000-1600	CSh	1	134	0.75
	1900-2200	CSh	19	238	7.98
	Total		28	1205	2.32
	1000-1600	Edge CSh	2	3	66.67
Shrub	1900-2200	Edge CSh	13	203	6.40
	Total		15	206	7.28
	400-700	Osh	7	494	1.42
	700-1000	Osh	0	71	0.00
	1000-1600	Osh	3	134	2.24
	1600-1900	Osh	16	156	10.26
	1900-2200	Osh	23	98	23.47
	Total		49	953	5.14
	1000-1600	SSh	4	100	4.00
	Total		4	100	4.00

Where: CT3= closed forest, OT3= disturbed forest, CSh= Closed shrub, Osh= open shrub, SSh= sparse shrub,. Trap night= total number of day of traps times the total number of trap used

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Results show that trap success was significantly different ($F_{5, 80} = 52.17$, $p \leq 0.001$) among different habitats and in different landscapes ($F_{2, 80} = 2.58$, $p \leq 0.05$). Open shrub had more mammals than closed shrub while the edge of closed shrub had 7% trap success (Tables 4a). In the plateau the habitat category mixed contour cultivation (mCMz) had more small mammals than other types of contour cultivation, which was almost four times that of *miraba* and cultivation habitats without conservation structures. *Miraba* cultivation in the plateau at an altitude >1600m had higher trap success (11%) than in the lower altitudes (<1000m) which had trap success of 4%. Similarly, a higher percentage trap success of small mammals was observed on the plateau than in other landscapes (Tables 4a and 4b).

Discussion

Vegetation habitats and their associated characteristics are important indicators of the composition and abundance of small mammals (Mulungu *et al*., 2008) and fleas (Laudisoit, 2009) that play a role in plague transmission. Any change in vegetation through human activities could induce changes in the small mammal communities in an area. In the current study, different vegetation types were observed in the studied landscapes. It was observed that shrubs are dominant both in the plateau and escarpment. These upland shrubs seem to have developed after natural forests were cleared for cultivation (Makundi *et al*., 2007; Annaert, 2010) and later regenerated to secondary vegetation. To date, only 30% of the natural forest on the Usambara plateau remains (Burgess *et al*., 2007). Unprecedented deforestation in the mountains (Annaert, 2010) has adverse impact on fauna and rainfall distribution (Neerinckx *et al*., 2008). Therefore, disturbance of natural forest may lead to different responses on the flora (Brooks *et al*., 2002; Foley *et al*., 2010) and on the small mammal diversity (Mulungu *et al*., 2008). The conversion of land cover is thought to induce stress conditions in animals (Krebs, 1989), and pest re-emergence (Makundi *et al*., 2007).

Table 4 (b): Trap success of small mammals with respect to herbaceous, plantation forest, settlement and cultivation habitats and altitude

Herbaceous	400-700	Che	0	100	0
	1000-1600	Che	2	200	1
	1600-1900	Che	1	10	10
	Total		3	310	0.97
Plantation forest	1900-2200	CT3p	20	266	7.52
	Total		20	266	7.52
Settlement	700-1000	Eset	0	130	0
	Total		0	130	0
	1900-2200	Sset	1	1	100
	Total	Sset	1	1	100
Miraba cultivation	1600-1900	mCMz	13	64	20.31
	Total		13	64	20.31
	1600-1900	McMz	16	400	4
	1900-2200	McMz	7	62	11.29
	Total		23	462	4.98
Cultivation	700-1000	ScFal	0	66	0
	1000-1600	ScFal	1	40	2.5
	Total	ScFal	1	106	0.94
	1600-1900	ScMz	9	180	5
	Total		9	180	5

Where: CHe= closed herbaceous, CT3p= closed plantation forest, ESet= very scattered (emergent) settlement, SSet= sparse settlement, mCMz= mix contour cultivation, McMz= 'Miraba' cultivation, ScMz= cultivation without contour, ScFal= cultivation without contour and in fallow. Trap night= total number of day of traps times the total number of trap used

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In the current study, variations in vegetation cover of dominant vegetation species were observed. Natural forest and horticulture habitats showed a consistency in both numbers of dominant species and cover. This was not the case for shrub habitats. The habitat patterns observed in this study are similar to those reported elsewhere (Lemen & Rosenzweig, 1978; Brooks & McDonald, 1983; Bateman *et al.,* 2010). The low number of dominant vegetation species in the other habitats can be attributed to human activities. Similar observations have been made that forest species diversity is negatively affected by human encroachment (Macdonald *et al.,* 2006) and that, vegetation clearance reduces mammal species diversity (Foley *et al.,* 2005)

The observed variability between different landscapes in terms of small mammal's habitat and vegetation species can probably be attributed to variability in terms of climate and slope aspect, which affect sunlight exposure, and to variability in soil characteristics as described previously (Huwe, 1988; Bounoua *et al.,* 2000; Taylor *et al.,* 2002). Results from the current study show that on the plateau, most tree species were exotic. These tree species were introduced by Soil Erosion Control and Agroforestry Project (SECAP) during natural resources conservation campaigns (Johansson, 2001). Other factors of variability in the spectrum of small mammals may be the degree of fragmentation of the habitats and the height of the vegetation. The patches of natural forest stand out by their size and by the average height of their trees. These observations are similar to those reported previously by other works (Debinski & Holt, 2000; Neerinckx *et al.,* 2008). The low vegetation heights observed in some habitats such as shrub and herbaceous vegetation could be explained by the nature of human activities including grazing, bush fires, fire wood collection and trespassing (Hubeau, 2010).

It is worth noting that *M. natalensis* was captured at high altitude (~2,000m) and this is in agreement with a report by Makundi *et al.* (2007) and Mulungu *et al*. (2008) who found that some small mammals including *M. natalensis* gained pest status by forest disturbance and cultivation while others preferred complex and heterogeneous habitats in different landscapes. It was observed that many small mammal individuals were captured in the plateau landscape compared with other landscapes. This implies that the likelihood of trapping small mammals in the higher altitudes is higher than in the lower altitudes and therefore, trap success in this study increased with altitude. This is consistent with other findings such as the study by Corominas (2004) in the forest habitat of the Natural Park and Reserve of Barcelona. However, this could have been due to habitat variability as observed by Mulungu *et al.* (2008) who reported more trap success within natural forest in the middle altitude of Mount Kilimanjaro compared to moorland in the high elevation and agricultural land in the lower altitude, which could be attributed to food availability and stability of the forest (Dueser & Shugart, 1978; Clausnitzer & Kityo, 2001; Makundi *et al.*, 2007). On the other hand Mena & Vazquez-Domınguez (2005), observed that the presence of small mammals was linearly correlated with altitude. In addition, Kelly & Caro (2003) reported that trap success is related with litter availability and also with moisture variability. Therefore, the high altitude ranges in this study indicate the likelihood of potential small mammals related to human plague.

It has been shown in this study that within thick forest and open forest, the highest trap success was realised in the high altitudes >1,900m. For shrub, the highest trap success was also within the same high altitude range. The highest trap success for thick herbaceous vegetation was similarly observed in altitudes above 1,600m. Within the scattered settlement in the lower altitude (<1,000m), there were no mammals trapped probably because the area was just recently built.

In conclusion, it is shown that the cultivation, natural and plantation forests, and horticultural habitats are localized in the plateau while the majority of deciduous vegetation and temporal herbaceous plants are located in the plain and escarpment landscapes. Similarly, findings from this study indicate that *P. delectorum* and *M. natalensis* formed the majority of the small mammals in the forest and cultivated habitats in the plateau, respectively. *Acomys wilsoni*

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and *squirrel* species dominated the shrub habitats in the plain. In the escarpment *Aethomys chrysophlilus* and *P. delectorum* were found within shrub and natural forest habitats. These observations demonstrate that natural forest, cultivated and shrub habitats were the most favoured by small mammals. Hence, during an outbreak of human plague, the disease could easily spread out due to the prevalence of these vegetation and small mammal interactions.

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