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Small mammals distribution and diversity in a plague endemic area in West Usambara Mountains, Tanzania

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Abstract: Small mammals play a role in plague transmission as hosts in all plague endemic areas. Information on distribution and diversity of small mammals is therefore important for plague surveillance and control in such areas. The objective of this study was to investigate small mammals' diversity and their distribution in plague endemic area in the West Usambara Mountains in north-eastern Tanzania. Landsat images and field surveys were used to select trapping locations in different landscapes. Three landscapes with different habitats were selected for trapping of small mammals. Three types of trap were used in order to maximise the number of species captured. In total, 188 animals and thirteen species were captured in 4,905 trap nights. *Praomys delectorum* and *Mastomys natalensis* both reported as plague hosts comprised 50% of all the animals trapped. Trap success increased with altitude. Species diversity was higher in plantation forest followed by shrub, compared to other habitats, regardless of landscape type. It would therefore seem that chances of plague transmission from small mammals to humans are much higher under shrub, natural and plantation forest habitats.

Keywords: Plague, small mammals, species diversity, distribution, Tanzania

Introduction

Information on the spatial distribution of small mammals at landscape scale in the West Usambara Mountains is lacking (Neerinckx *et al.,* 2008). This is a bottleneck in the surveillance and in policies concerning this dangerous disease as some of the small mammal species identified in the West Usambara Mountains are considered to be plague hosts (Kilonzo *et al.*, 2005).The Tanzanian Government spends over one million Euros per annum to combat plague outbreaks (Kilonzo *et al.,* 2005). From 1986 through 2003, there were 7800 plague cases and 700 deaths in the West Usambara Mountains, Tanzania (Kilonzo *et al.,* 2003).

It has become clear from a number of studies that environmental factors and their specific locations should be considered in an attempt to explain the outbreaks of plague. Neerinckx *et al*. (2008) demonstrated that there are significant relationships between plague occurrence and altitude in the West Usambara Mountains. It is reported that the spatial distribution of plague hosts is influenced by a combination of environmental factors, including vegetation habitat, which influence food availability and shelter for small mammals (Mulungu *et al.,* 2011).

The distribution of small mammals in a complex landscape with contrasts in landform, vegetation and land use is not well understood. The studies that have been undertaken so far do not allow the derivation of small mammals-landscape relationship (Laudisoit, 2009). This study therefore attempts to link the distribution of small mammals and indices of species diversity with

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landscape characteristics in plague endemic zones in the West Usambara Mountains in north-eastern, Tanzania.

Materials and Methods

Study area

The study was conducted in a rectangular section between 4°22'S, 38°05'E (northwest corner) and 5°08'S,38°38'E (southeast corner) in Lushoto District in north-eastern Tanzania from December 2009 to March 2010. The study area ranges in elevation from 300 to 2,250m. The annual precipitation varies from 600 mm in the plains up to 2000 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 1800m above sea level. By the time of the plague outbreak period (1980 to 2003) the population density in Lushoto District was 254 persons per km^2, making this district one of the most densely populated in Tanzania (NBS, 2003). From west to east the toposequence is characterised by a dry plain with stone rich shallow soils, across an abrupt rock escarpment, ending with an undulating plateau (Neerinckx *et al.*, 2008). Most of the soils are red to black Ferrasols, with a sandy-clay-loam texture, and low pH (Neerinckx, 2006; Laudisoit, 2009). Natural forest reserves (Magamba) and plantation forests (Shume-Nywelo) still cover at least 60% of the study area, although massive deforestation and conversion to agricultural land started around the 1960s in the study area.

Identification and mapping of habitats within landscapes

In total, 67 observations of vegetation categories were made within the study area with about 52 observations done in the plateau, eight in the escarpment and seven in the plain landscape (Figure 1).

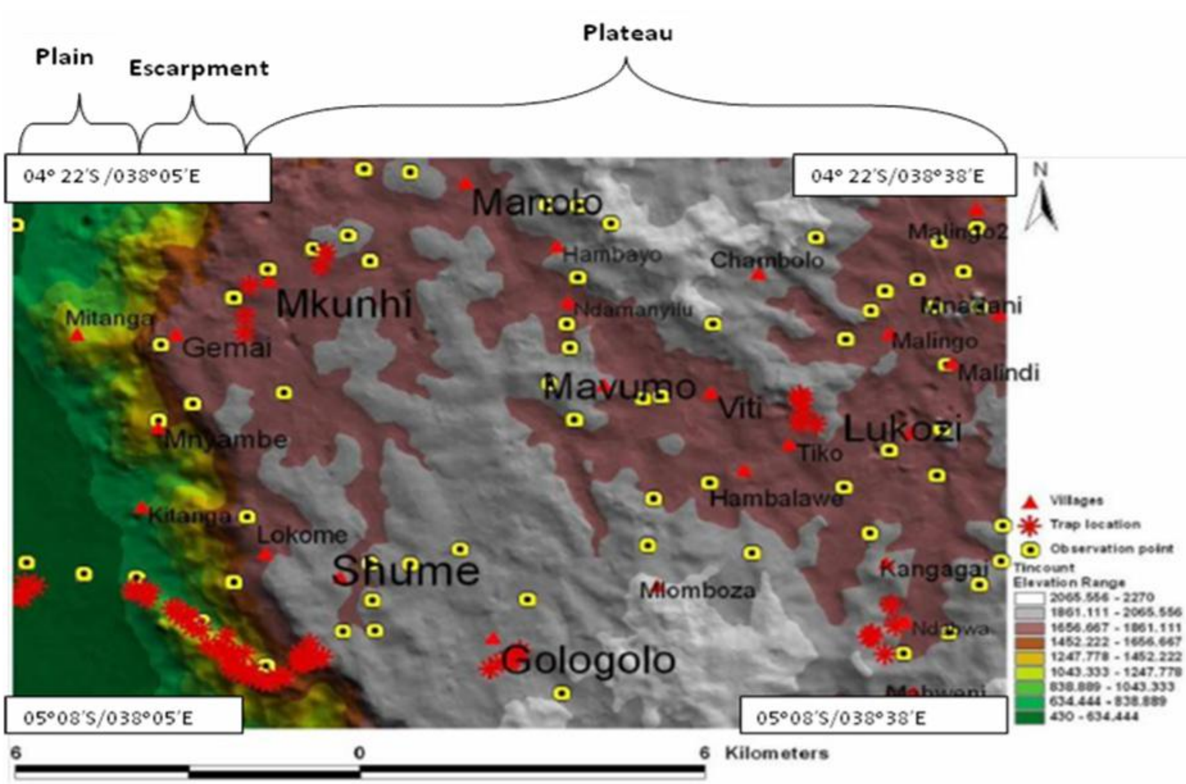

Figure 1: Selected sites for observation points and trapping locations in different landscapes

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Nine habitat types, namely natural-forest, plantation-forest, horticulture, shrub, herbaceous, cultivation (mixed-crops), rockiness, bare-ground (<10% cover) and human settlement were mapped as top level of differentiation, according to FAO rules (di Gregorio, 2005). The second level involved description of sub-habitats in terms of openness and height of the first dominant layer (strata) of the vegetation (di Gregorio & Jansen, 1998). Fourteen sub-habitats were identified and these included closed-forest (CT3), open-forest (OT3), closed-shrub (CSh), edge-of-forest (Edg Csh), open-shrub (Osh), sparse-shrub (SSh), closed-herbaceous (CHe), closed-plantation forest (CT3p), mixed-contour-cultivation (mCMz), '*miraba*-cultivation (an indigenous land management practice with grass strips surrounding crop fields) (McMz), fallow-cultivation (ScFal), cultivation-without-contour (ScMz), settlements and rocky-habitat.

Small mammals trapping

Trapping small mammals was executed twice in December 2009 and in March 2010. Three different types of traps (Figure 2a, b and c) were employed in order to trap a variety of small mammal species and reduce bias associated with some traps (Laudisoit, 2009). Traps used included 49 Sherman traps, 20 wire cages and 30 buckets for pitfall traps per habitat. The bait used was a mixture of peanut butter and maize bran for Sherman traps. Roasted maize grains and roasted sardines '*dagaa*' were used for wire cage traps. The Sherman traps (23 x 9.5 x 8 mm) were placed 5 m apart and pitfall traps made of 10-litre water buckets were set 10 m apart along a pitfall line. Two trap nights were organised per habitat type. Each trap site was georeferenced by GPS and inspected every morning. Traps having animals were replaced by empty traps.

Figure 2: (a) Sherman live trap, (b) live wire cage or spring door trap and (c) bucket used for pitfall trap

Trapped animals were collected early morning and identified to genus level following the established taxonomic nomenclature (Kingdon, 1974; Wilson & Reeder, 2005), weighed (to nearest gramme), and the state of the vagina (closed or perforated) or position of the testes (scrotal or abdominal) was noted. In addition the following measurements were taken: head and body length, tail, hind foot and ear length (to nearest millimetre) (Nagorsen & Peterson, 1980). All collected specimens were prepared as scientific voucher specimens in the form of fluid preserved specimen. Initially, the specimens were preserved in 10% formalin with transfer later to 70% ethanol. Specimens collected from the study area are currently deposited at Sokoine University of Agriculture, Pest Management Centre, Morogoro, Tanzania.

Data analysis

The percentage trapped individuals was expressed according to Telford (1989) (Equation 1)

$$\text{Trap success} = \frac{N}{Nt \times Nn} \times 100 \qquad (1)$$

where: N is number of animals trapped; Nt is number of traps used; Nn= duration in terms of nights during which the trap was set. Species diversity was estimated using the standard Shannon Wiener index (Equation 2) in order to characterise species diversity and assess for both abundance and evenness of the species in the habitat as:

$$H = -\sum_{i=1}^{s} (P_i \ln P_i) \qquad (2)$$

Where: P_i is the relative proportion of species *i* in habitat and ln is the natural logarithm.

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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

Trap success

The trap success ranged from 0.3 to 66.7% for 4,905 trap nights (Table 1). Trap success was significantly different ($F_{5,80}$=52.2; p=0.001) among habitats along the landscapes. Mixed contour cultivation on the plateau had more small mammals than other types of contour cultivation. Results show further that '*miraba*' cultivation in the plateau above 1,600 m had a trap success of 11%, which is much higher than the same habitat at lower altitudes (<1,000m) with a trap success of <4%.

Table 1: Trap success of small mammals in various habitats and different altitudes

Main habitat	Altitude	Sub-habitat	No. of trapped animals	Trap nights	Trap success
Natural forest	700-1000	CT3	2	224	0.9
	1000-1600	CT3	1	298	0.3
	1600-1900	CT3	7	72	9.7
	1900-2200	CT3	5	29	17.2
	Total	CT3	15	623	2.4
	700-1000	OT3	2	147	1.4
	1900-2200	OT3	5	52	9.6
	Total	OT3	7	299	2.3
Shrub	400-700	CSh	6	425	1.4
	700-1000	CSh	2	408	0.5
	1000-1600	CSh	1	134	0.8
	1900-2200	CSh	19	238	8.0
	Total	CSh	28	1205	2.3
	1000-1600	Edge CSh	2	3	66.7
	1900-2200	Edge CSh	13	203	6.4
	Total	Edge CSh	15	206	7.3
	400-700	Osh	7	494	1.4
	1000-1600	Osh	3	134	2.2
	1600-1900	Osh	16	156	10.3
	1900-2200	Osh	23	98	23.5
	Total	Osh	49	953	5.1
	1000-1600	SSh	4	100	4.0
	Total	SSh	4	100	4.0
	1000-1600	Che	2	200	1.0
	1600-1900	Che	1	10	10.0
	Total	Che	3	310	1.0
Plantation forest	1900-2200	CT3p	20	266	7.5
	Total	CT3p	20	266	7.5
Settlement	1900-2200	Sset	1	10	10.0
	Total	Sset	1	10	10.0
Cultivation	1600-1900	mCMz	13	64	20.3
	Total	mCMz	13	64	20.3
	1600-1900	McMz	16	400	4.0
	1900-2200	McMz	7	62	11.3
	Total	McMz	23	462	5.0
	1000-1600	ScFal	1	40	2.5
	Total	ScFal	1	106	0.9
	1600-1900	ScMz	9	180	5.0
	Total	ScMz	9	180	5.0

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

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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

Species distribution in different landscapes and habitats

Praomys delectorum was found in almost all landscapes, but mostly in the natural forest, plantation forest and shrub habitats. *Xerus erthropus* was strictly limited to plain landscapes. *Acomys wilson* was limited to the plain and the escarpment (Table 2). *Xerus erthropus*, *A. wilson*, *Helogale parvula* and *Genetta genetta* were only found in the plain landscape while *Otomys angoniensis* and *Aethomys chrysophilus* were found mainly on the escarpment. Similarly, *Grammomys dolichurus*, *Luphoromys kilonzoi*, *Rattus rattus*, *Mastomys natalensis*, *Mus munitoides* and *Crocidura hirta* were found on the plateau (Table 2).

Table 2: Distribution of different species of small mammals according to landscapes

Species	**Plain**		**Escarpment**				**Plateau**					
	NF	SH	CU	NF	HB	SH	CU	NF	PF	ST	HB	SH
Praomys delectorum	x			X				x	x			x
Xerus erthropus	x	x										
Acomys wilson		x				x						
Helogale parvula		x										
Genetta genetta		x										
Otomys angoniensis			x									
Aethomys chrysophilus				X	x	x						x
Grammomys dolichurus						x	x	x	x		x	x
Luphoromys kilonzoi						x	x	x	x			x
Rattus rattus										X		x
Mastomys natalensis						x	x		x			x
Mus munitoides							x		x			
Crocidura hirta								x	x			x

Key: NF= natural forest; SH=shrubs; CU= cultivation; HB=herbaceous; PF=plantation forest; ST=settlement, x = presence of species per habitat

Table 3: Species diversity within main habitats under Plain and Escarpment landforms

Landform	**Main habitat**	**Species**	**No. of animal trapped**	**Diversity index**
Plain	Natural Forest	*P. delectorum*	1	
		X. erthropus	1	
		Sub-total	2	0.3
	Shrub	*A. wilsoni*	8	
		H. parvula	1	
		G. genetta	1	
		X. erthropus	3	
		Sub-total	13	0.4
Escarpment	Cultivation	*O. angoniensis*	1	0.0
		Sub-total	1	
	Natural Forest	*A. chrysophilus*	2	
		P. delectorum	1	
		Sub-total	3	0.3
	Herbaceous	*A. chrysophilus*	2	
		Sub-total	2	0.0
	Shrub	*A. wilsoni*	1	
		A. chrysophilus	6	
		G. dolichurus	1	
		L. kilonzoi	1	
		M. natalensis	1	
		Sub-total	10	0.5

Small mammal species diversity

Species richness varied with landscape and habitat type. In the plateau, the highest number of species was found in the shrubs followed by plantation forest whereas the lowest number was

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found in herbaceous cover with *G. dolichurus* or *A. chrysophilus* as characteristic species (Table 3). The plain had two types of habitat with diversity indices of 0.3 and 0.45 for natural forest and shrub respectively. Dominant small mammal species in the natural forest habitat were *P. delectorum* and *X. erthropus* while shrub habitat hosted *A. wilsoni, H. parvula, G. genetta* and *Squirrel* spp. The *A. wilsoni* and two species of Squirrel were dominant species in the plain comprising 85% of the trapped species.

On the escarpment, results show that shrub habitat had higher species diversity than other habitats with *A. chrysophlilus* and *P. delectorum* comprising 60% of trapped small mammals. Rodent species diversity in the plateau landscape is also presented in Table 3. Results show that plantation forest and shrub habitats had the highest species diversity index of >0.5. The dominant species were *Grammomys* spp., *L. kilonzoi* and *P. delectorum.* Natural forest had species diversity index of 0.44, whereas cultivation had the least species diversity index (Table 4).

Table 4: Species diversity within main habitats under Plateau landforms

Plateau	Cultivation	*G. dolichurus*	4	
		L. kilonzoi	2	
		M. natalensis	37	
		M. minutoides	2	
		Sub-total	45	0.3
	Natural Forest	*C. hirta.*	1	
		G. dolichurus	2	
		L. kilonzoi	3	
		P. delectorum	11	
		Sub-total	17	0.4
	Plantation forest	*C. hirta*	2	
		G. dolichurus	3	
		L. kilonzoi	4	
		M. natalensis	3	
		M. minutoides	1	
		P. delectorum	7	
		Sub-total	20	0.7
	Settlement	*R. rattus*	1	
		Total	1	0.0
	Herbaceous	*G. dolichurus*	1	
		Sub-total	1	0.0
	Shrub	*A. chrysophilus*	1	
		C. hirta	2	
		G. dolichurus	14	
		L. kilonzoi	19	
		M. natalensis	1	
		M. minutoides	1	
		P. delectorum	34	
		R. rattus	1	
		Sub-total	73	0.6
		Total	188	

Discussion

Plague is a rare bacterial disease caused by *Yersinia pestis*. Plague has been endemic in Tanzania for more than a century (Kilonzo *et al.*, 2005). It has been reported that several rodent species and their associated flea complexes are maintenance (enzootic) hosts for plague and form the basis of epidemic foci in plague endemic areas. It has been reported that *M. natalensis* is the major reservoir of the disease and is responsible for maintaining and passing the infection to the *Rattus rattus*, and to humans (Makundi *et al.*, 2003) and *P. delectorum* (Haule *et al.*, 2013). Similarly, other rodent species such as *Arvicanthis nairobae, Lemniscomys striatus, Lophuromys spp., Pelomys fallax, Grammomys dolichurus*, *Otomys* spp., and *Rattus rattus,* have been

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mentioned for plague maintenance in the area (Kilonzo *et al.*, 2005). Findings from the current study are consistent with these reports. Results also indicate that the diversity of small mammals was higher in the plateau landscape, the most typical plague endemic area in the region (Neerinckx *et al.,* 2008).

These results imply that an increase in elevation is accompanied by concurrent increase in small mammals, both in number and diversity due to increased water and food availability (Hamilton, 1998). Bayessa (2010) indicated that modified habitats including plantation forest and cultivation influenced rodent distribution due to availability and quality of food, shelter and rainfall. Also, results show that the dominant species in the natural forest and in cultivation habitats were *M. natalensis* and *P. delectorum.* The presence of *M. natalensis* in the habitat is consistent with results by Makundi *et al.* (2008) who reported similar species in deforested habitats at higher elevations of the plateau in the West Usambara Mountains. *Praomys delectorum* was more common in the plantation forest. The dominant species in shrub habitats were *P. delectorum, L. kilonzoi* and *Grammomys* spp. comprising the majority of the trapped species. *Grammomys* were trapped at the interface of closed and open shrub. This is similar to the results by Matlack *et al.* (2008) who indicated that some rodent species prefer edge corridors. In contrast, a decrease of small mammals with elevation has been reported under Mediterranean climate. This was attributed to a decrease in food availability and increasing dryness and cool weather conditions (Corominas, 2004).

Results further show that different species of small mammals occurred independently in different habitats and landscapes. Similar observations have been reported by Linzey & Kesner (1997) in Kenya, South Africa, Angola, and Namibia. For example, the results from the current study show that small mammals found in both natural and plantation-forest include *A. chrysophilus*, *G. dolichurus*, *L. kilonzoi*, *P. delectorum*, *Crocidura hirta*, *M. minutoides* and *X. erthropus.* In the plateau landscape, *P. delectorum* comprises 60% of trapped small mammal's species. Similar results were reported by Stanley & Goodman (2000) for Gonja Forest Reserve in Tanzania.

It has been demonstrated in the current study that in both plateau and escarpment landscapes, shrubs support more small mammals species than other habitats, including *L. kilonzoi*, *P. delectorum, G. dolichurus*, *M. minutoides*, all of which have been reported as plague hosts (Kilonzo *et al.*, 2005; Laudisoit, 2009). This suggests that shrub, natural and plantation forest provide relatively "better" habitats for plague hosts. Therefore, the current results indicate the possibility for plague transmission from small mammals to humans in shrubs, natural and plantation habitats. It is likely therefore that both plateau and escarpment landscapes have potential hosts for plague transmission through interaction between plague hosts and humans (Duplantier *et al.,* 2005). Similarly, it was shown in this study that the escarpment acts like an interface between the plain and the plateau, a place where small mammal species from both landforms intermix. Further research on the relationship between vegetation types and small mammals particularly microclimate of habitats vis-à-vis plague hotspot areas is recommended.

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