Terrestrial small mammal community composition in the Volcanoes National Park, Rwanda

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ACRONYMS AND ABBREVIATIONS

CCA: Canonical Correspondence Analysis

DFGFI: The Dian Fossey Gorilla Fund International

GIS: Geographic Information System.

HSD: Honestly Significant Differences

ITFC: Institute of Tropical Forest Conservation

IUCN: World Conservation Union

KRC: Karisoke Research Centre

MGNP: Mgahinga National Park

MVSP: Multi-Variate Statistical Package

PFIAO: Percy FitzPatrick Institute of African Ornithology

RDB: Rwanda Development Board

TBA: Tropical Biology Association

UCT: University of Cape Town

ViNP: Virunga National Park

VNP: Volcanoes National Park

WCS: Wildlife Conservation Society

ABSTRACT

We conducted a study on the terrestrial small mammal communities (< 1kg) in the Volcanoes National Park (VNP), Rwanda, to determine species diversity and altitudinal/habitat associations. Data on environmental variables (habitat cover, temperature, wind speed and rainfall) were incorporated into the analysis. Both Sherman live and snap traps were set in transects from 30 September to 8 November 2009 at eight habitats (ranging from 2380 m to 3710 m). Trapping over 4800 trap nights resulted in the capture of 305 individuals (including 4 recaptures), of which 247 were identified to species level. These represented eight species of rodents, three species of shrews and one mongoose. Total numbers of small mammals were high in brush ridge and herbaceous habitats, and low in alpine and bamboo habitats. The mid-altitude zone housed a high number of small mammals. Of the species captured, *Praomys degraaffi* is vulnerable and *Sylvisorex vulcanorum* is near threatened (IUCN 2009); six species (*Hylomyscus vulcanorum, Mus bufo, Praomys degraaffi, Sylvisorex vulcanorum, Lophuromys woosnami* and *Trachyoryctes ruandae*) are endemic to the Albertine rift; and four species are new to the Park list. Species richness varied significantly among the different habitat types. Species richness and diversity increased with elevation up to the middle altitudes (2860-3255 m) and then declined with increasing elevation. Endemic species were found mainly in low and middle attitude habitats, and thus, these habitat types are important for conservation of small mammals at VNP. The numbers of known small mammal endemics for VNP will probably be increased if trapping is done seasonally and a more diverse regime of trapping techniques is employed.

Key words: Rodentia, Soricidae, endemism, Volcanoes NP, species diversity.

INTRODUCTION

Terrestrial small mammals are important components of terrestrial ecosystems (Golley et al. 1975). In the context of this study, the term “small mammal” here refers to terrestrial mammals whose adult body mass ranges <1kg (Entwistle & Stephenson 2000). These animals are characterised by a high reproductive rate, low survival rate, and high density tolerance (French et al. 1975). Populations of terrestrial small mammals (here referring specifically to rodents and shrews) are found throughout most of the world (Jansa & Weksler 2004).

Small mammals are important contributors to biodiversity of ecosystems, by virtue of their species richness, role as regulators of energy/ nutrient transfers between producers, consumers and decomposers (Entwistle & Stephenson 2000), and their often dramatic effects on the structure and dynamics of plant communities (Golley et al. 1975). Their high fecundity and short generation times allow them to respond rapidly to fluctuating environments (Bourlière 1975). Despite this, they are not a prominent focus of any conservation agenda (Entwistle & Stephenson 2000). Approximately 70% of threatened and 78% of critically endangered mammals are small, reflecting the size distribution of species (Entwistle & Stephenson 2000). For these reasons, small mammals are model candidates, as biotic indicators, when evaluating the importance of protected areas.

Ecology of terrestrial small mammal communities

Ecologically, small mammals are important functional components of terrestrial ecosystems, and play an important role in ecological process, though the magnitude of their impacts is habitat and density-dependent. They may mediate energy and nutrient cycling; destruct and alter soil and vegetation communities; impact on consumers, and influence the abundance and population dynamics of predator guilds. Small mammals also play an important role in the decomposition of organic materials so that essential nutrients can be released and used for primary reduction (Golley et al. 1975). For example, digging of burrows by small mammals may also enhance the movement, storage and drainage of water and nutrients in the soil, and thereby improve the growth conditions of plants (Golley et al. 1975). Many small mammals are granivorous and their foraging activities can influence the species composition, abundance, distribution, form and reproduction of plants as well as the number of progeny (Olff & Ritchie 1998; Vander Wall et al. 2005). Rodents may also influence the soil volume and density (Golley et al. 1975). In this role, rodents are ecosystem engineers (Alper 1998). Populations of small mammals play an important part in the destruction of harmful insects to humans as well as the eradication of weeds (Kingdon 1974; De Graaff 1981; Horner et al. 2007).

Small mammals may alter plant species composition and plant communities through foliage feeding and seedling predation (French et al. 1976; Vander Wall et al. 2005). They may significantly reduce forest regeneration through direct destruction of the seed crop, but may also enhance forest regeneration through the spread of ectomycorrhizal fungal spores. Because of their high nutritional value, seedlings are often preferred to older plants. Mice can consume a large quantity of seeds (Golley et al. 1975, Vander Wall et al. 2005).

Like other organisms, small mammal are vulnerable to anthropogenic disturbances, such as habitat loss, pollution, effects of introduced species, hunting and persecution (Entwistle & Stephenson 2000). Small mammals have been hunted as bush meat (including rodents and shrews) and are often persecuted as agricultural pests and carriers of disease. A number of small mammal species (i.e. *Xeromys* *myoides)* are considered at risk from commercial trade (Entwistle & Stephenson 2000).

Ecological correlates of community structure

Numerous habitat features influence the dispersal and local occurrence of small mammals. Of these, vegetation structure is the most important (Vermaak 2000). Most small mammals are dependent on cover for protection from predators and climatic extremes (Mulungu et al. 2008). Habitat cover may also influence the micro and macro-climates of small mammals, which in turn may determine species distribution and population sizes (Vermaak 2000). An increase in food supply may result in extension of breeding season, increase in reproductive intensity and an increase in the growth rate and body weight of small mammal species (Golley et al. 1975). Fluctuations in small mammal numbers may also reflect seasonal movements of small mammals, which temporarily gather in refugia until conditions in surrounding habits are suitable for re-colonization and/or reproduction (Barrière et al. 2005). In strongly seasonal environments (both temperate and tropical), many small mammals can survive only by periodically entering a state of reduced metabolism (hibernation and estimation), by eating concentrated food (seeds, nectar) during the favourable season, and by storing energy in their body fat depots when food is abundant (French et al. 1976).

Small size has ecological advantages: Small size is generally correlated with high reproductive potential, rapid population turnover rates and faster evolutionary time scales. Small size also allows easy access to a number of food resources that are sparsely exploited by other animals and thereby enables small animals to take full advantage of certain microhabitats (Bourlière 1975). Being small enables populations to split into a number of local demes, each well adapted to particular local conditions (Bourlière 1975), which over time may lead to rapid speciation.

Small size, however, also has disadvantages. Owing to the relationship between body size, volume and surface area, many small mammals have a high mass-specific metabolic rate, and thus high energy requirements (Bourlière 1975). Another handicap of small size is the high energetic cost of their locomotion. The high energy expenditure requires a high daily intake, which in return requires moving around more often and over long distances (Bourlière 1975).

Small mammal communities of the Albertine Rift

The Albertine Rift region is located in the eastern portion of the Africa continent. It stretches from the northern end of Lake Albert to the southern end of Lake Tanganyika (Fig. 1) and covers countries that border the western part of the Great Rift Valley, namely, Burundi, Democratic Republic of Congo (DRC), Rwanda, Tanzania and Uganda. It contains the Rift Valley lakes such as Tanganyika, Kivu, Edward, and Albert (IRA & PASS 2007). The rift system is well known for its richness in biodiversity, including many species of fauna and flora that thrive in these habitats. Collectively, its recent geological history location within Africa juxtaposition of habitats, and distinctive altitudinal zonation, makes the Albertine Rift globally noteworthy for its high species diversity and large numbers of endemics (Pickford 1990; Plumptre et al. 2003).

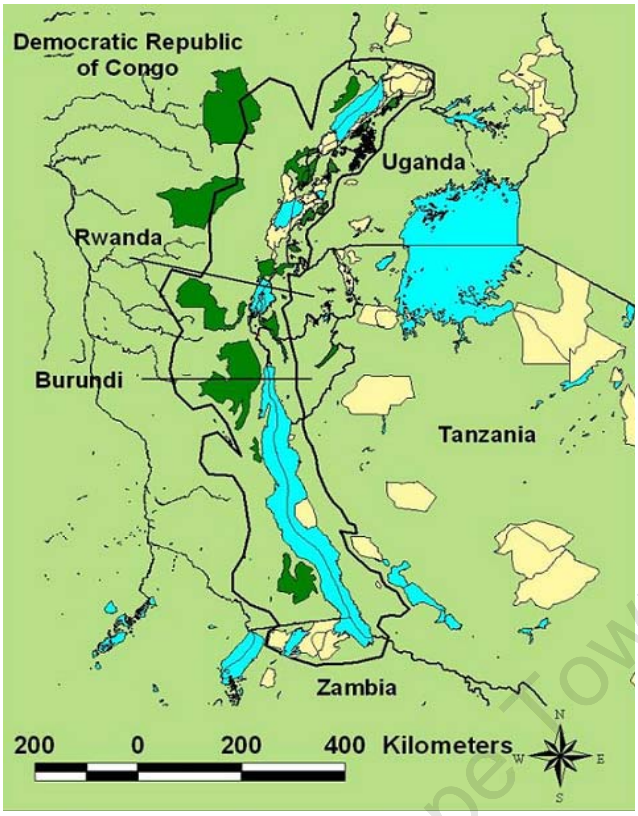

Figure 1. Map of the Albertine Rift showing existing protected areas or regions referred to in this study and the approximate boundary of the Albertine Rift (strong darkline). Green shaded areas are forested and lighter areas are savannah grassland or woodland. Light dark lines are rivers (from Plumptre et al. 2003).

The Albertine Rift has been identified as a region of great importance for conservation by several priority-setting studies (IRA & PASS 2007). It is a “biodiversity hotspot” (Myers et al. 2000; Plumptre et al. 2003) and central refuge for vertebrates (Hutterer et al. 1987). The Albertine Rift contains 34 species of endemic mammals, predominantly small mammals: 10 of these species are shrews and 12 species rodents. One of only three species of the family Tenrecidae (Afrotherian) found on mainland Africa, the endangered Ruwenzori otter shrew (*Micropotamogale ruwenzorii*) is also strictly endemic to these mountains (Saundry 2009). No endemic families occur in the Albertine Rift but two endemic genera occur, *Rwenzorisorex*, and *Delanymys* (Plumptre et al. 2007). Hutterer et al. (1987) found that the Albertine Rift houses an important representation of the African shrews, and suggests that this region acted as refuge for them during Pleistocene period.

Studies in the ecology and community characteristics of small mammals in the Albertine Rift have increased in recent years (Kerbis Peterhans et al. 1998; Kasangaki et al. 2003), but these targeted the northern forests rather than those in the southern part. Small mammals in Albertine Rift forests exhibit different habitat preferences in the different areas studied. Kerbis Peterhans et al. (1998) found breeding seasonality and different habitat patterns in small mammal species, and species diversity decreased with altitude while Albertine Rift endemics increased with increasing altitude in Ruwenzori Mountains (Uganda). Kaleme et al. (2007) conducted a study on diversity and habitat requirements of small mammals in the western part of the Albertine Rift (eastern Democratic Republic of Congo), he found that small mammals exhibit habitat preferences in Kahuzi-Biega, all shrews were recorded in wet and undisturbed habitats, except *Crocidura lanosa,* and habitats with poor vegetation diversity housed relatively few species. Kasangaki et al. (2003) discussed the small mammal species diversity in the major vegetation zones of Bwindi Impenetrable National Park in relation to altitude, he found that the main factors accounting for the observed diversity was the wide altitudinal variation and a complex array of vegetation types. Kerbis Peterhans and Austin (1996) found many small mammal species at the edge rather than the inside of the park at Mgahinga Gorilla National Park (Uganda), Kerbis Peterhans (1998) has found the same pattern in Bwindi Impenetrable forest and Echuya forest (Uganda). Isabirye-Basuta and Kasenene (1987) concentrated on the small rodent population in selectively felled and mature forest of Kibale forest in Uganda, he found many rodents were associated with forest edges, and both rodent species richness and diversity were higher in plots located in selectively felled than in mature forest. These findings show that small mammal diversity of Albertine Rift show a positive correlation with environmental variables such as habitats cover, and their distribution are related to habitat types. Vegetation cover appears to be the main driver of community structure and composition of small mammal in the Albertine Rift.

A review of some species (e.g. *Hylomyscus denniae*) and description of new species to science, including *Suncus hututsi, Praomys degraaffi and Hylomyscus vulcanorum* have been published (Carleton et al. 2006; Kerbis Peterhans & Hutterer 2009; Thorn & Kerbis Peterhans 2009; Van der Straeten & Kerbis Peterhans 1999). *Suncus hututsi* was first recognized in collections from Kibira National Park (Burundi), subsequently in Bwindi Impenetrable National Park and mid-elevational forests (Uganda) and in Itombwe forest (DRC), and possibly in Nyungwe National Park (Rwanda) (Kerbis Peterhans & Hutterer 2009); the mouse *Praomys degraaffi,* was recently described with a similar distribution, and was also found at VNP (Rwanda) (Van der Straeten & Kerbis Peterhans 1999) and in Kahuzi-Biega forest (DRC) (Kaleme et al. 2007). Specimens traditionally referred to *Hylomyscus denniae* collected in Albertine Rift forests differ from other museum material collected in southern Africa and Eastern Rift Valley (Kenya), and have now been renamed as *Hylomyscus vulcanorum* (Carleton et al. 2006). This species is an Albertine Rift endemic.

Since many of the mammal species endemic to the Albertine Rift include rodents and shrews, future surveys on small mammals would be of considerable conservation value (Plumptre et al. 2003; Burgess et al. 2004). Given that small mammals have been poorly surveyed throughout much of the Rift, particularly towards the southern end, and it is very likely more species will be added with further effort (Plumptre et al. 2007). To address this paucity of information on this group, this study was based in southern region of the Albertine Rift, comprising the Virunga volcanoes or Virunga massif. The massif contains a very high proportion of endemic plants and animals. Several surveys have gathered information on some 86 species of mammal, of which 34 are large mammals (Owiunji et al. 2005). Other surveyed taxa are birds, plants, reptiles and amphibians (Table 1). However, the terrestrial small mammal fauna of the Virunga massif forests remains little known, largely because the area has not been thoroughly surveyed.

Table 1. The species richness, number of Albertine rift endemic and IUCN threatened species (IUCN 2009) for five well studied taxa of Virunga massif.

Taxa	Species richness	Endemic	Threatened
Mammals	86	18	6
Birds	294	20	4
Reptiles	43	7	0
Amphibians	47	16	9
Plants	1244	124	4

The Study area: Volcanoes National Park

The Volcanoes National Park (VNP; borders 1°21'-1°35'S, 29°22'-29°44'E) is located in the southern part of Albertine Rift (Fig.2). It lies in north-western Rwanda and borders Virunga National Park (ViNP) in the Democratic Republic of the Congo (DRC) and Mgahinga National Park (MGNP) in Uganda. The Volcanoes National Park, ViNP and MGNP form Virunga volcanoes protected area (Virunga massif) (Fig. 3). The Volcanoes National Park is located on the eastern edge of the Albertine Rift, and situated on volcanic peaks, of Pleistocene age, belonging to the chain which forms part of the watershed between the Nile and Congo River systems (Fossey & Harcourt 1977; Weber 1987; IUCN 1992). As a result of conversion activities for agriculture, the total area of the VNP has been reduced by 54% from 328 km^2 to a remnant 150 km^2 (Weber 1987). The altitudinal variation (2370-4507m above sea level), high rainfall and cool temperatures at VNP have resulted in a broad range of habitat zones, with a rich biodiversity (Weber 1987; Gray et al. 2005; Owiunji et al. 2005).

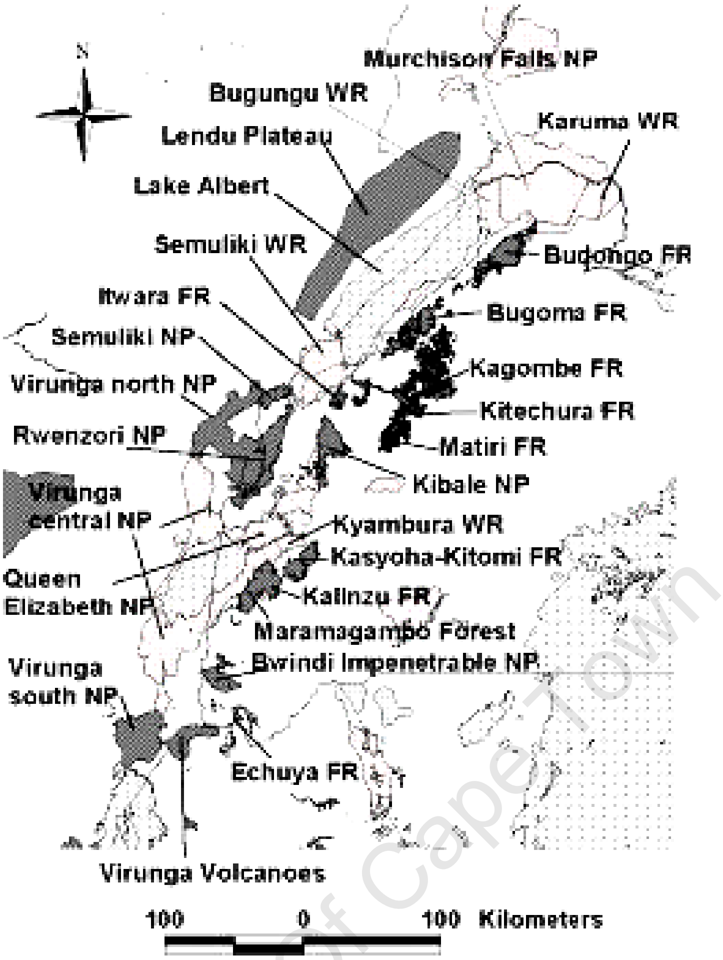

Figure 2 . Northern part of the Albertine Rift showing the locations of the various protected areas. The Virunga Volcanoes (Virunga massif) is located in the southern region (from Plumptre et al. 2003)

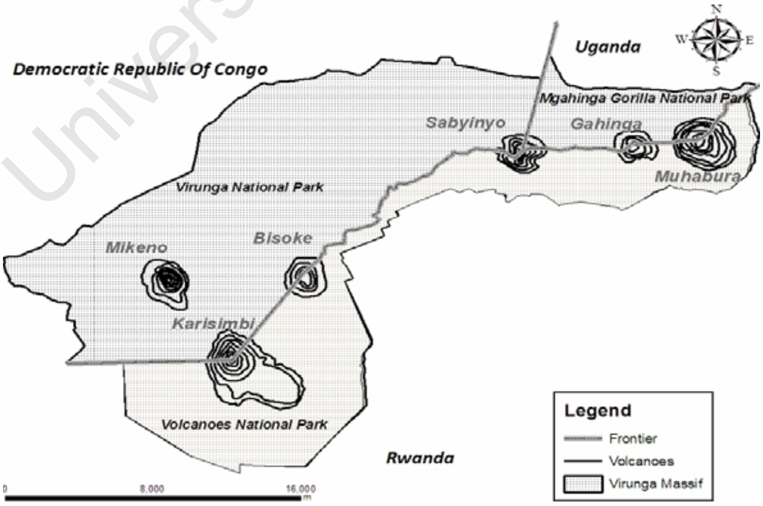

Figure 3. The Virunga Volcanoes (Virunga massif), showing the location Volcanoes National Park (Rwanda), Mgahinga National Park (Uganda), and Virunga National Park (DRC). Contour lines are volcanoes.

Vegetation varies considerably due to the large altitudinal range within the park. Generally, VNP contains the upper stages of the afromontane vegetation sequence of bamboo, *Hagenia-Hypericum* zone, sub-alpine and alpine associations (Plumptre 1991). There is some lower montane forest (now lost to mainly agriculture). Between 2400-2500m, *Neoboutonia* forest is the main vegetation type. From 2500-3200m *Yushania alpina* (bamboo) forest occurs, covering about 30% of the park area. From 2600-3600m, mainly on the more humid slopes in the south and west, is *Hagenia-Hypericum* forest, which covers about 30% of the park. This is one of the largest forests in Africa with *Hagenia abyssinica*. The vegetation from 3500-4200m is characterized by *Lobelia wollastonii*, *L. stuhlmannii*, and *Dendrosenecio erici-rosenii* and covers about 25% of the park (Plumptre 1991; Fischer & Hinkel 1992; IUCN 1992; Owiunji et al. 2005).

The park is home to a rich variety of mammals, birds, reptiles, amphibians and insects. The large mammals include the mountain gorilla (*Gorilla beringei beringei*), star of Rwanda’s tourism and endemic to the volcanoes range, and the golden monkey (the guenon, *Cercopithecus kandti*) (Grubb et al. 2003), endangered and endemic to the Albertine Rift (Groves 2001; Gray et al. 2005). Large mammals that remain in the park are elephant *Loxodonta africana,* buffalo *Syncerus caffer*, bushbuck *Tragelaphus scriptus*, and black fronted duiker *Cephalophus nigrifrons* (Owiunji et al. 2005). Carnivores include jackals *Canis adustus*, civets *Civettictis civetta*, genets *Genetta johnstoni*, serval cats *Leptailurus serval*, and golden cats *Profelis aurata (*Weber 1987, Owiunji et al. 2005). Based on limited surveys, a small number of rodents *(Lophuromys aquilus, Lophuromys woosnami, Hylomyscus vulcanorum, Mus triton, Oenomys hypoxanthus, Thamnomys venustus* and *Dendromus mesomelas)* (Kajonjoli

1993), and shrews (*Sylvisorex vulcanorum and Crocidura olivieri)* (Hutterer et al. 1987) occur at Volcanoes National Park.

Context of this research

While a considerable amount of work has been carried out on the vegetation, birds and large mammals of VNP (Plumptre 1991; Fischer & Hinkel 1992; Owiunji et al. 2005), small mammal communities in the park remain little studied. A previous unpublished study (Kajonjoli 1993), rendered incomplete by civil war, reported on some ubiquitous species from the region, and suggested that at least 10 small mammal species occur in VNP, but no detailed examination of patterns of small mammal diversity and distribution in the park has been undertaken (Owiunji et al. 2005). Given that the majority of Albertine Rift endemic mammals are small mammals (Plumptre et al. 2003), determining the distributions and diversity of small mammals at VNP is of high conservation importance.

Extensive biodiversity surveys of the entire Virunga massif, conducted in 2004 (Owiunji et al. 2005), ranked VNP amongst the highest areas for species richness, and identified VNP as a priority for the conservation of Albertine Rift biodiversity. By studying the small mammal community in VNP and by examining the relationship between species richness and a number of factors (namely environmental variables such as altitude, habitat type, wind speed, rainfall and temperature), we aimed to enhance current knowledge of the biodiversity in this hotspot.

A number of factors are known to determine species richness of a community. Eco-geographic factors, notably latitude and altitude (Townsend et al. 2008), are often correlated with species richness. These patterns, and their determinants, extend from global, through regional to more local. It is equally important to distinguish historical factors (notably evolutionary factors) from proximate ecological factors that structure ecological assemblages (Morrone 2009). The most widely recognized global pattern in species diversity is its increase from the poles to the tropics (Begon et al. 1990). At the regional scale, habitat types are distributed along altitudinal and latitudinal ranges (Morrone 2009).

Begon et al. (1990) stated that the light, temperature and water regimes of tropics lead to the high plant and animal biomasses and high species richness. High altitude communities almost invariably occupy smaller areas than lowlands at equivalent latitudes; and they will usually be more isolated from similar communities than lowland sites (Lomolino 2001; Brown 1971). These effects of area and isolation can be expected to contribute to the decrease in species richness with altitude. In an ecological context, the volcanoes comprise ‘islands’, isolating montane habitats from surrounding lowlands. On island, species have to adapt to changing conditions to survive (MacArthur & Wilson 1967).

Objectives and hypotheses

The purpose of this study was to document small mammal community characteristics at VNP, and specifically to: (1) compare small mammal abundances, diversity and distributions in seven habitats (bamboo, Hagenia, brush ridge, mixed forest, herbaceous, sub-alpine, alpine zones, and swamp); (2) assess levels of diversity in relation to altitude, environmental variables and habitat characteristics; and (3) to update the existing small mammal species list at VNP. During this study, we hypothesized that (1) small mammal diversity would change with habitats types. We also hypothesized that (2) there will be a relationship between environmental variables and small mammal diversity and richness, and (3) habitat-specific endemics will exist at VNP, particularly in the higher altitudinal zones.

METHODS

Site selection

This study was carried out in the Volcanoes National Park, Rwanda from 28 September to 8 November 2009 at three sites (Mts Bisoke, Sabyinyo and Gahinga) in VNP Eight habitat types were selected in the study area from those used in previous studies by Plumptre (1991) and Owiunji et al. (2005). These eight habitat types are as follows: (1) mixed forest; (2) bamboo; (3) Hagenia-Hypericum woodland; (4) Herbaceous, e.g. areas with no tree canopy and many tall herbs (5) Brush-ridge, e.g. Hypericum woodland on the slopes of Mt Bisoke; (6) Subalpine zone, i.e. an area dominated by *Dendrosenecio;* (7) Alpine: *Dendrosenecio erici-rosenii* interspersed with small meadows at the summit of Mt Bisoke; (8) Swamp, e.g. a wetland found in bamboo zone at Kabatwa on the flanks of Mt Sabyinyo. This last habitat was selected because it is sufficiently different from others, and had been a cultivated zone in 1980s and could have species typically found in disturbed habitats. A stratified random sampling procedure was followed to select five transect lines per habitat (Sutherland 2008), transects were spaced 200 m apart (Owiunji et al. 2005)

At each site a Global Positioning System (GPS) was used to obtain co-ordinates. The aspect was determined using a compass, and the altitude was recorded using an altimeter (Table 2).

Table 2. Trapping line coordinates in eight habitats types at VNP.

Transect number	Habitat type	Altitude (m)	Longitude	Latitude
1	Alpine	3640	29.488395	-1.462183
2	Alpine	3650	29.489246	-1.460266
3	Alpine	3680	29.488921	-1.459046
4	Alpine	3700	29.488597	-1.458658
5	Alpine	3710	29.486621	-1.457919
6	Bamboo	2540	29.561127	-1.410809
7	Bamboo	2560	29.561832	-1.406434
8	Bamboo	2580	29.562686	-1.407400
9	Bamboo	2620	29.560697	-1.403425
10	Bamboo	2660	29.562903	-1.400061
11	Brush ridge	3220	29.496220	-1.464832
12	Brush ridge	3225	29.495060	-1.463694
13	Brush ridge	3300	29.495060	-1.463694
14	Brush ridge	3345	29.493687	-1.463958
15	Brush ridge	3400	29.493290	-1.462828
16	Hagenia	2740	29.504769	-1.455340
17	Hagenia	2820	29.505634	-1.458476
18	Hagenia	2860	29.502954	-1.463269
19	Hagenia	2980	29.498892	-1.468959
20	Hagenia	3020	29.495913	-1.471548
21	Herbaceous	2900	29.502954	-1.463269
22	Herbaceous	3059	29.495914	-1.472361
23	Herbaceous	3095	29.498755	-1.466609
24	Herbaceous	3138	29.497297	-1.464071
25	Herbaceous	3183	29.497432	-1.464306
26	Mixed forest	2380	29.627390	-1.416925
27	Mixed forest	2440	29.619875	-1.409496
28	Mixed forest	2500	29.622486	-1.415883
29	Mixed forest	2525	29.619486	-1.407282
30	Mixed forest	2580	29.635852	-1.411692
31	Subalpine	3420	29.492698	-1.463299
32	Subalpine	3460	29.492213	-1.463290
33	Subalpine	3510	29.491810	-1.463090
34	Subalpine	3550	29.491135	-1.462840
35	Subalpine	3600	29.489579	-1.461341
36	Swamp	2540	29.559933	-1.410431
37	Swamp	2540	29.559960	-1.411045
38	Swamp	2540	29.560111	-1.409671
39	Swamp	2540	29.560929	-1.410140
40	Swamp	2540	29.620994	-1.415044

Trapping procedures

Most studies on small mammal community characteristics rely on trapping regimes (Nicolas & Colyn 2006), an assortment of traps should ideally be employed in studies of small mammal communities in African rainforest to obtain a wide range of taxa, and thus a better representation of the community (Nicolas & Colyn 2006). Trapping at VNP started on the 30th of September and ended on the 8th of November 2009. The traps used were standard Sherman (H.B. Sherman, USA) with large Sherman folding traps (23x8x9), and small non-folding perforated traps (12x5x6).These two types of traps (Sherman) were laid out in lines, 10 m apart (Tews et al. 2004), with five lines (50 trap stations) located randomly in each habitat at least 100 m away from human paths (White & Edwards 2000; Davies 2002; Sutherland 2008). At each trapping station, one trap was placed on the ground whilst another was placed at 2 m above ground in the branches of a tree, or as close to a height of 2 m as habitat permitted (Shanker 2000). Traps were set for three days and nights per trapping session, with 2 trapping sessions per habitat giving 600 trap-nights in each of the eight habitat types.

Pitfall traps are especially effective for sampling shrews and small rodents, and have been demonstrated to capture a greater array of species than standard live traps alone (Nicolas & Colyn 2006). Drift fencing was also erected in an attempt to increase capture rates in pitfalls. Four pitfall lines with drift fences (4 m long) comprising 5-litre buckets (30 cm deep, 20 cm top internal diameter and 17 cm bottom internal diameter, four buckets at 100m of line) were located at three transects per habitat. However, no small mammals were captured in any pitfall traps, perhaps because of heavy rains which filled buckets with water. As pitfall traps were not successful during the first trapping sessions, we used local-made snap traps to increase captures of small shrews during the second trapping sessions. All snap traps were placed at the same points of live traps, 100 per habitat and 20 per transect line.

Traps were baited with crushed ground-nuts, meat and fish, bananas, and pieces of potatoes (in an attempt to attract squirrels). They were checked daily between 07H00 and 10H00 and again between 14H00 and 16H00 (Tews et al. 2004).

At each station, any trapped animals were collected, processed and/or released, traps were then scraped clean of any old food or faeces (old bait was removed from the area), and new bait was added and the traps were repositioned (Nicolas & Colyn 2006). Care was taken to check the trap mechanisms and maintain a relatively constant degree of tripping sensitivity for all traps. Every trap was washed in between being used at different sites. This is because as previous studies have reported that the smell of certain species on a trap may deter other individuals or other species from entering. When set, all traps were placed under cover to increase capture probabilities.

Captured live animals were placed in a zip-lock plastic bag and weighed using either 100g or 500g Pesola spring balances. Upon capture the following data were recorded for each individual: species (based on body dimensions and overall appearance) following Kingdon (1974, 2004) and species profiles on the Animal Diversity Website (Myers et al. 2006); sex (male or female); weight in grams; head-body length (in mm); tail length (in mm; damaged tails with missing ends were recorded but not measured); ear length (in mm; damaged ears were recorded but not measured) and hind foot length (excluding claws); the trap line; date and time period within which it was caught. Each newly captured animal to be released was marked by fur-clipping to ensure it could be recognized if subsequently recaptured.

Individuals selected as voucher specimens were euthanized in accordance with criteria approved by the UCT Science Faculty Animal Experimentation Committee (Clearance number 2009/V15/DT), and then preserved by either: fixation in 10% formalin; skinning; or fixation of tissues in 96% ethanol. As far as possible the deliberate collection of specimens was avoided by using individuals that had died accidentally. Nevertheless, the collection of voucher specimens is critical in biodiversity surveys to provide authentic scientific evidence against which historical and future collections can be compared (Tews et al. 2004). Two hundred and thirty-five voucher specimens were sent to the Field Museum of Natural History (Chicago, USA) for verification of identifications by Dr Julian Kerbis, and 35 were sent to the Durban Natural Science Museum (South Africa). These specimens are preserved in these collections as the vouchers of this inventory of VNP.

Environmental variables

Cover is a measure of the area covered by the above-ground parts of plants of a species when viewed from directly above, i.e. it is the proportion of the ground occupied by the vertical projection onto it of the parts of all individuals of a species (Sutherland 2008). Because the vegetation may be layered the cover of all species often sums to >100%. Vegetation cover can be measured by estimating visually the proportion of the quadrat occupied by each species (e.g. the vertical projection of each plant). Various measures can be used. One visually can estimate cover to the nearest per cent (or less), but this is often difficult and prone to errors, and thus inaccurate. It is useful to divide the vegetation into layers, e.g. canopy (>2m), shrub (1-2m), herbaceous (<1m), and make cover estimates separately for each layer (Sutherland 2008). We did not consider plant individuals with non-measurable cover (< 1% cover) as it is recommended by Sutherland (2008). In order to assess relationships between plant cover and small mammal relative abundances, herbaceous, shrub and canopy covers were recorded separately.

Within each of the habitat types, a stratified random sampling technique (Sutherland 2008) was used to sample the availability of plant species. In the majority of vegetation types a grid was used at each trapping station. Plants were collected from the grids as follows: 2m^2 plot: all plots located in herbaceous zone; 5m^2 plot: all plots located in shrub area; 10m^2 plot: all plot located in areas dominated by trees.

Plant species were identified from herbarium material at Karisoke Research Centre (KRC) and from the Flora of Rwanda (Troupin 1977-1988).

Rainfall data were collected from rain gauges located at the Karisoke field staff house, 2 km from the forest (specifically near Mt Bisoke), twice daily at 6:00 am and 6:00 pm by KRC staff. Equipment limitation made it impossible to measure temperatures at each trapping station the same day. No distinct seasonal changes in weather were experienced. Rainfall varied irregularly in both intensity and duration. Temperature and wind speed were collected daily at each transect site location as almost all transects ranged in altitude except in the swamp. Temperature (^{0}C) was measured using a thermometer (Cal-Temp Quick-Reading Calibratable Digital Thermometer), while wind speed was collected using Kestrel 2000 Pocket Wind Meter Plus (1mph = 1.61km/h). Both temperature and wind speed data were collected between 9:00-9:30am, allowing comparison between different sites.

Data analysis

Small mammal abundances, species richness and diversity were compared among the different habitat types, and in relation to altitude divided into three altitudinal classes, i.e. 2380-2820; 2860-3255; and 3300-3710 m above sea level. Statistica (Statsoft 2009), Biodiversity professional (BioDiversity Pro 1997, version 2) and Species Diversity and Richness (Species Diversity & Richness 2001, version 2.65) computers packages were used to perform analyses of results. To standardize data for all sites sampled so that species richness and diversity of the habitats could be compared, trap success (the number of animals caught per 100 trap nights) was calculated. The number of species trapped (per 100 trap nights) was also calculated for each site using the expression: [Species richness/Trap effort] x 100. Using daily trapping records, species accumulation rates were examined and were compared among habitat types.

The Shannon-Wiener index of diversity (Shannon 1948) was calculated for all sites sampled and evenness values were derived from it. The Shannon index increases with the number of species in a community, and in theory can reach very large values (Krebs 1989). Evenness values indicate how the numbers of individuals are distributed among species in a community. When the evenness is high, the mammal fauna is more diverse and the species are equally abundant (Magurran 2005). A high value of Shannon-Wiener index may indicate a large number of species with similar abundances; a low value indicates lower species richness or domination by a few species. The Shannon-Wiener index may be prone to errors related to non-random sampling and unequal samples sizes, whereas the Brillouin index (which generally has lower discriminatory power) is more robust to such sampling artefacts. As we used baits (i.e sampling was not random) and sample sizes for species, we also calculated the Brillouin index and compared it to Shannon diversity indices to select the best indices (Magurran 2005).

Species accumulation curves (McAleece et al. 1997) were plotted for samples from each of the habitat types and altitude classes. These curves were used to compare the trend in species encountered per unit sampling effort as measured by number of individual small mammals captured. Similarities of the small mammal communities in the different habitats were assessed using Bray-Curtis similarity indices and linked cluster analysis.

Parametric analysis of variance (ANOVA) was used to assess difference among habitats and altitudinal classes when data were normally distributed. Tukey's Honestly-Significant-Difference (Tukey HSD) tests were used for post-hoc comparisons when significant among-groups differences indicated. When data did not satisfy the criteria of normality, or significant deviations from homogeneity of variance were detected, non-parametric tests including Kruskal-Wallis and Friedman tests were used (Fowler & Cohen 1996; Zar 1999). Environmental variables including temperature and wind speed were averaged in the field using thermometer and wind speed measure, while rainfall was averaged between morning and evening samples (6:00 AM and 6:00PM). Temperature and wind speed were compared to species richness and species diversity while rainfall was compared to capture rates.

To provide further information on the relationship between small mammal species and environmental factors, a Canonical Correspondence Analysis (CCA) was used. This is an indirect gradient analysis technique used to study the distribution of species along easily measured, recognizable environmental variables (Gauch & Whittaker 1972). This technique displays the plot and species data along axes of multidimensional space, and is a product of both the environmental variables and the species data. The software package MVSP (Multi-Variate Statistical Package, version 3.13r) was used (Kovach Computer Services 2009). Log_2 transformed data with non species weighting were analysed using the Hill algorithm. Data for *Galerella sanguinea* and *Tachyoryctes ruandae* were excluded from the analysis as these species were captured co-incidentally, and are not typically associated with the habitats sampled. Rainfall was also excluded because it is not habitat specific.

Maps shown on figure 3 and 4 were produced using ArcMap 9.2., and GIS (Geographic Information System) database of Virunga Volcanoes found at Karisoke Research Centre (KRC) and Rwanda Development Board/Tourism and Conservation (RDB). Unfortunately, there was no database available for mapping each vegetation type. Other maps were extracted from literature as listed in the references.

RESULTS

Trap success and species captured

Trapping over 4800 trap nights resulted in the capture of 305 individuals (292 rodents, nine shrews, and one mongoose), giving on overall trap success of 6.4%. The distribution of trapping success at sampling sites (number of individuals caught excluding four recaptures) did not deviate significantly from normality (Shapiro-Wilk W=0.95; p=0.08). These data could, therefore, be analyzed by parametric methods. Of 305 captures, 247 were identified, but 58 (mostly non-adults) were difficult to assign to species with certainty; data for unknown species were excluded from further analysis. 105 of identified individuals were female while 142 were males. A total of eight rodent, three shrew and one mongoose species were recorded (Table 3, see Appendix 1 for taxonomy). All rodents belong to the subfamilies Murinae, Deomyinae and Graphiurinae, and shrews belong to the subfamily of Crocidurinae, while the mongoose belonged to the family of Hespertinae (Wilson & Reeder 2005). The most common species were *Lophuromys aquilus* (N=117) and *Lophuromys woosnami* (N=93), which accounted for 85% of individuals identified. These species were encountered in all habitats, and all other species were rare (N≤ 13, or ≤15% of individuals captured in all habitats).

Table 3. Total numbers of individuals per species captured in the eight habitat types at VNP

Species /habitat types	Alpine	Bamboo	Brush ridge	Hagenia	Herbaceous	Mixed forest	Subalpine	Swamp	Total
Crocidura nigrofusca				1	1				2
Crocidura olivieri	2	1	1		2	3			9
Galerella sanguinea			1						1
Graphiurus murinus				3		3			6
Hylomyscus vulcanorum		1	1	3	5	2		1	13
Lophuromys aquilus	11	8	21	12	30	6	14	15	117
Lophuromys woosnami	1	7	27	12	17	14	7	8	93
Mus bufo		1		1					2
Oenomys hypoxanthus				1					1
Praomys degraaffi			1						1
Sylvisorex vulcanorum				1					1
Tachyoryctes ruandae								1	1
	14	18	52	34	55	28	21	25	247

Mean number of individuals (across the five transects per habitats) was highest in the herbaceous (10.7) and brush ridge (9.5) habitats (Fig. 4) and lowest in the subalpine (4.3) and alpine (2.5) habitats. Differences in small mammal abundances among habitats were significant ($F_{7,32}$=4.81; P=0.0009). Similarly, small mammal numbers varied significantly ($F_{7,37}$=4.81; P=0.0009) among the three altitudinal zones (Fig. 5), and were highest at intermediate altitudes (2860-3255 m).

Tukey HSD tests showed that small mammal numbers differed significantly between the subalpine and herbaceous habitats (p=0.02), between the alpine and brush ridge habitats (p=0.001), and also between the alpine zone and brush ridge habitats (p=0.007). Small mammal numbers also differed significantly between the middle and the upper altitudinal zones (Fig. 6) (p=0.003), and between the lower and middle altitudinal zones (p=0.003)

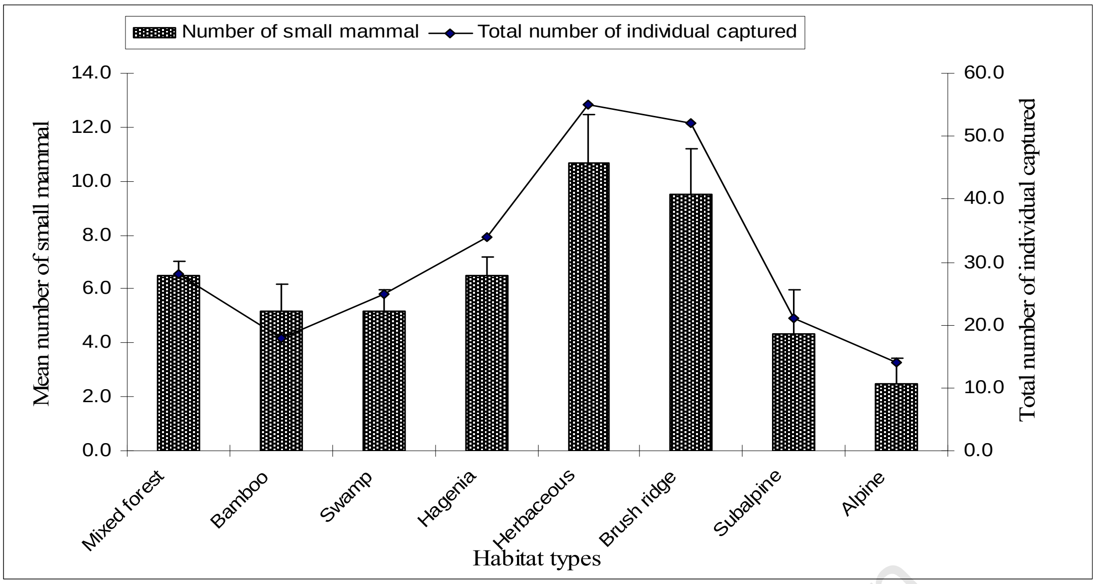

Figure 4. Comparison of mean number of individuals (per 100 trap-nights, expressed as a percentage, excluding recaptures) in eight habitats at VNP averaged across five transects per habitat. Error bars show ± 1 standard deviation.

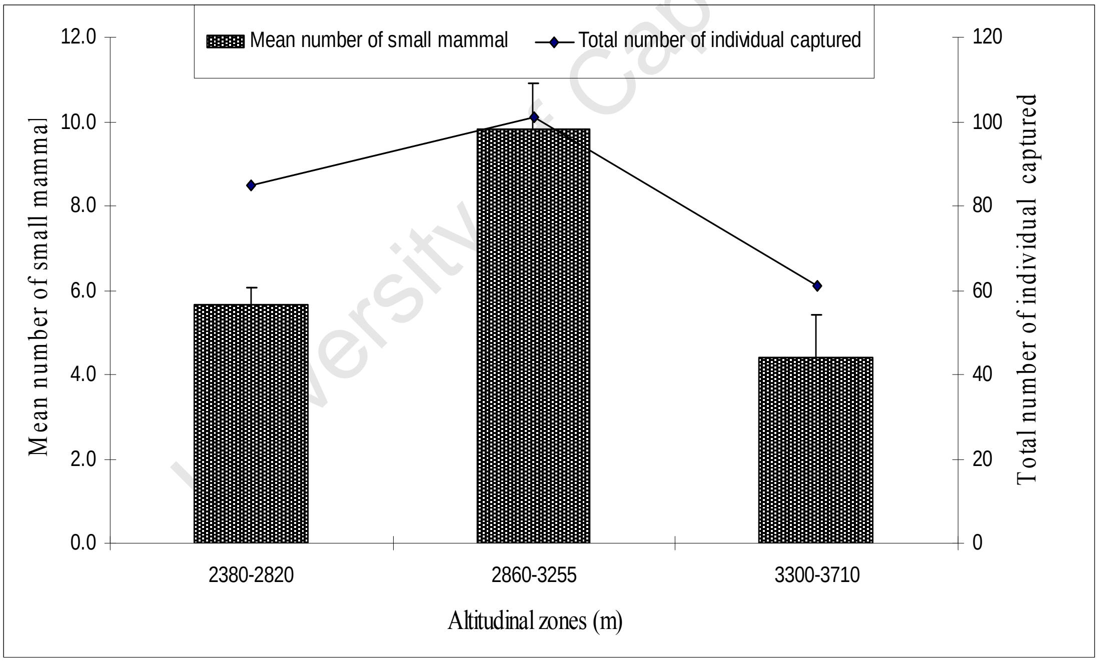

Figure 5.Comparison of mean number of individuals in three altitudinal zones at VNP. Error bars show ± 1 standard deviation.

Lophuromys aquilus and *L. woosnami* were recorded in all habitats. Numbers of *L. aquilus* deviated significantly from normality (Shapiro-Wilk W=0.86; p=0.0002), as did those of *L. woosnami* (Shapiro-Wilk W=0.89; p=0.001). Non-parametric tests showed that the number of *L.woosnami* differed significantly among eight habitat types (Kruskal-Wallis test: $H_{7,40}$=20.75; p =0.004) (Fig. 6), but, there was no significant difference in number of *L. aquilus* across habitats (p=0.07).

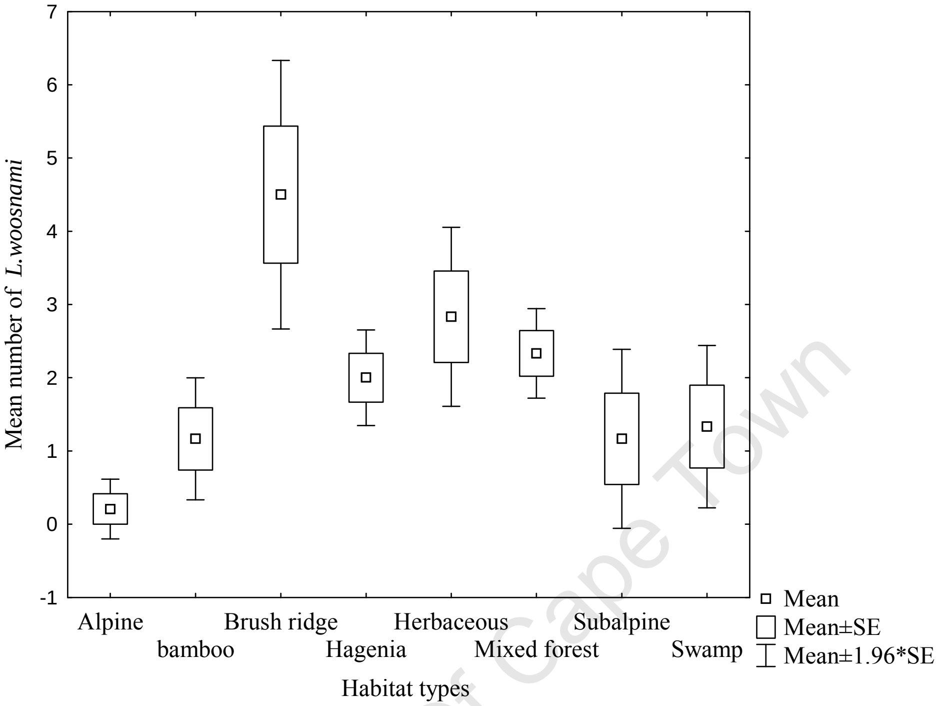

Figure 6. Mean number of *L.woosnami* in eight habitats types at VNP. Error bars show ± 1 standard errors.

The data for small mammal (combined body mass of all individuals excluding recaptures) biomass deviated from normality (Shapiro-Wilk W=0.878; p=.0005). The total biomass (g) per habitat per species is shown in Table 4. The highest biomass (≥2175g) was recorded in the brush ridge and herbaceous habitats, while the lowest biomass was recorded in alpine and bamboo habitats (≤655g). *Lophuromys aquilus* and *Lophuromys woosnami* recorded higher biomass than other species. They were more abundant, and their body mass is also greater than other species, such as shrews.

Table 4. Total standing biomass (g) for each species per habitat types at VNP

Species /Habitats	Alpine	bamboo	Brush ridge	Hagenia	Herbaceous	Mixed forest	Subalpine	Swamp	Total
Crocidura nigrofusca				24	30				54
Crocidura olivieri	54	23	29		67	84			257
Galerella sanguinea			460						460
Graphiurus murinus				60		46			106
Hylomyscus vulcanorum		24	19	59	75	50		25	252
Lophuromys aquilus	451	311	931	510	1272	268	594	640	4978
Lophuromys woosnami	46	289	1121	510	731	596	249	332	3874
Mus bufo		8		13					21
Oenomys hypoxanthus				38					38
Praomys degraaffi			47						47
Sylvisorex vulcanorum				4					4
Tachyoryctes ruandae								200	200
	551	655	2607	1217	2175	1044	843	1197	10290

There was a significant difference in species biomass among habitats, the highest mean species biomass was recorded in brush ridge and herbaceous while the lowest species biomass was recorded in bamboo and alpine (Kruskal wallis: $H_{7,40}$=22.25; p=0.002) (Fig.7). There was also a significant difference in species biomass across altitudes zones (Kruskal wallis: $H_{2,40}$=7.25 p=0.03), the highest species biomass was recorded in mid-altitude zone while the lowest species biomass was in high altitude (Fig.8).

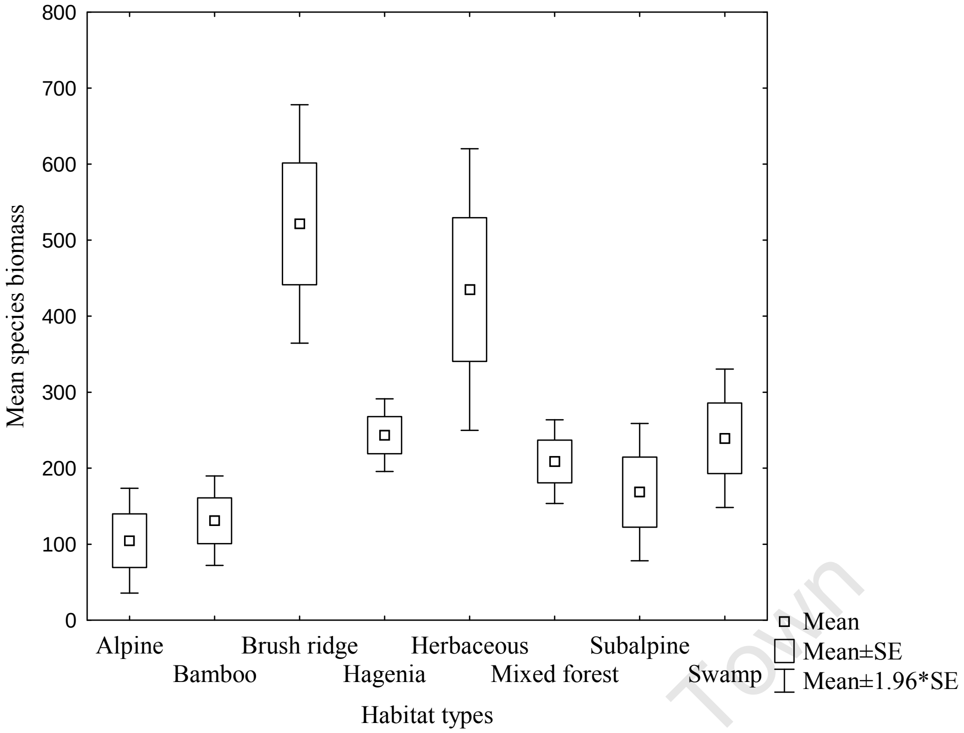

Figure 7. Mean species biomass among habitat types at VNP, errors bars show ± 1 standard errors.

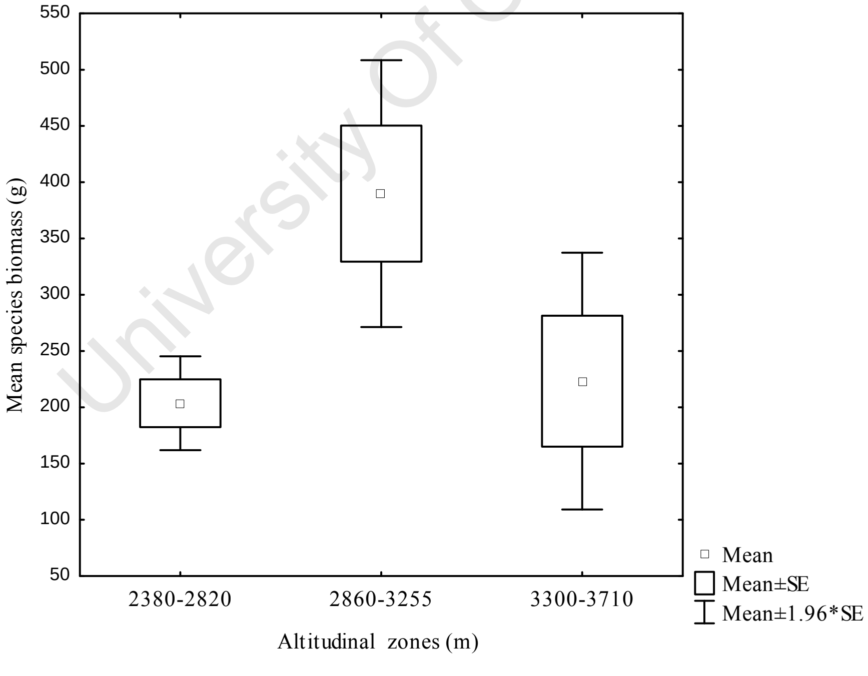

Figure 8. Mean species biomass across altitudinal zones at VNP, errors bars show ± 1 standard errors.

Small mammal species richness

Small mammal species richness (Table 5) was highest in Hagenia woodlands (eight species) intermediate in the bamboo, herbaceous, mixed forest, and brush ridge habitats (5 species each) , and lower in the swamp and subalpine and alpine habitats (2-3 species each). Rodent species were always more numerous than the shrew species. Among the species recorded were four species recorded for the first time in VNP, six species endemic to the Albertine Rift, including one vulnerable species (*P. degraaffi*), and one species classified as near threatened (IUCN 2009) (Table 6)

Table 5. Species richness (rodent and shrews) across habitat zones at VNP

Habitat	Altitude	Average altitude	Species Richness	Rodent species	Shrew species
Mixed forest	2380-2580	2495	5	4	1
Swamp	2540	2540	3	3	0
Bamboo	2540- 2660	2592	5	4	1
Hagenia	2740-3020	2884	8	6	2
Herbaceous	2900-3183	3075	5	3	2
Brush ridge	3220-3400	3304	5	4	1
Subalpine	3420-3600	3508	2	2	0
Alpine	3640-3710	3676	3	2	1

Table 6. The IUCN conservation status and biogeographic status of the species captured at VNP.

Species	IUCN Status	Endemic to Albertine Rift	New for VNP
Crocidura nigrofusca	Least Concern	No	Yes
Crocidura olivieri	Least Concern	No	No
Galerella sanguinea	Least Concern	No	Yes
Graphiurus murinus	Least Concern	No	Yes
Hylomyscus vulcanorum	Least Concern	Yes	No
Lophuromys woosnami	Least Concern	Yes	No
Mus bufo	Least Concern	Yes	Yes
Praomys degraaffi	Vulnerable	Yes	No
Sylvisorex vulcanorum	Near Threatened	Yes	No
Tachyoryctes ruandae	Least Concern	Yes	No

Four species endemic to the Albertine Rift were trapped in Hagenia, three each in the bamboo and brush ridge habitats, with only two endemic species recorded in the herbaceous zone, mixed forest and swamp (Table 7). Five of the six endemic species (including the vulnerable *P. degraaffi*) were recorded between 2860-3255 m, while four were recorded between 2380-2820m. The upper altitude (3300-3710m) zone contained only one endemic species, *L.woosnami.*

Table 7. The number of Albertine Rift Endemic small mammals detected at each altitude level at VNP.

Species/Altitudes	2380-2820	2860-3255	3300-3710
Hylomyscus vulcanorum	5	8	
Lophuromys woosnami	33	39	21
Mus bufo	1	1	
Praomys degraaffi		1	
Sylvisorex vulcanorum		1	
Tachyoryctes ruandae	1		

A regression analysis of species richness against altitude was negative (Fig.9), indicating a reduction in species richness with altitude, but altitude accounted for only 14% (r^2=0.14) of the observed variation in species richness (p=0.01). Although there was a trend for species richness to decrease with increasing altitude, this is an oversimplification of the observed patterns whereby there was considerable variation within altitudinal interval and a tendency for a higher richness at mid-altitudes.

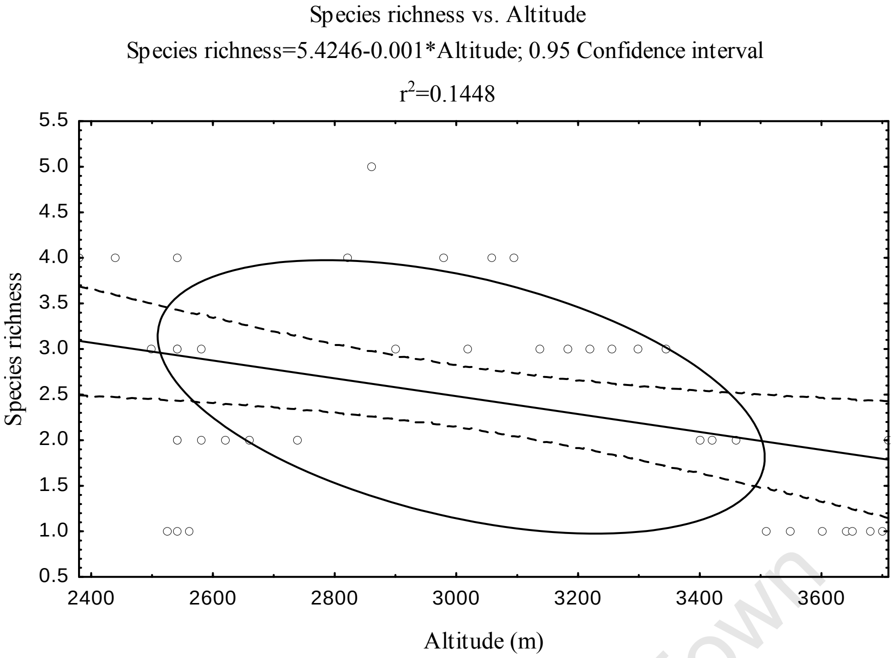

Figure 9. Scatter plot and regression line for small mammal species richness against altitude at VNP. The ellipse shows 75% of the range of species richness. Dots represent mean number of species captured on each habitat.

Species accumulation curves showed an increase in species richness with increasing number of individuals captured (Fig. 10, 11). For subalpine and mixed forest, accumulation curves approached asymptotes, so sampling effort can be considered adequate to reflect actual species richness. Further, the results reliably represent the species richness of the small mammal communities. In other habitats, and all altitude zones, plateaux were not attained. These analyses endorse the need for further trapping to improve knowledge of species documented in these areas. Furthermore, species accumulation curves for habitat types showed that the most species rich habitat types in VNP were Hagenia and brush ridge.

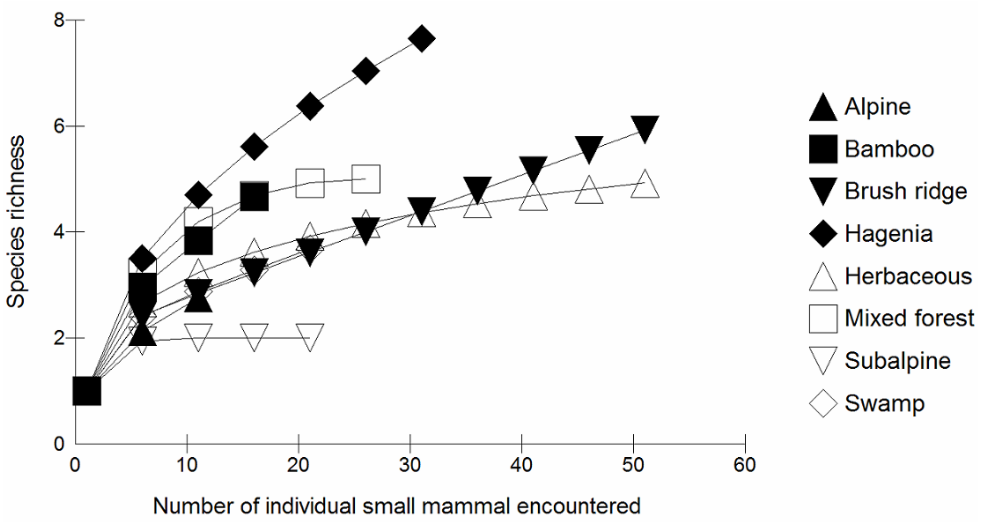

Figure 10. Species accumulation curves for habitat types at VNP

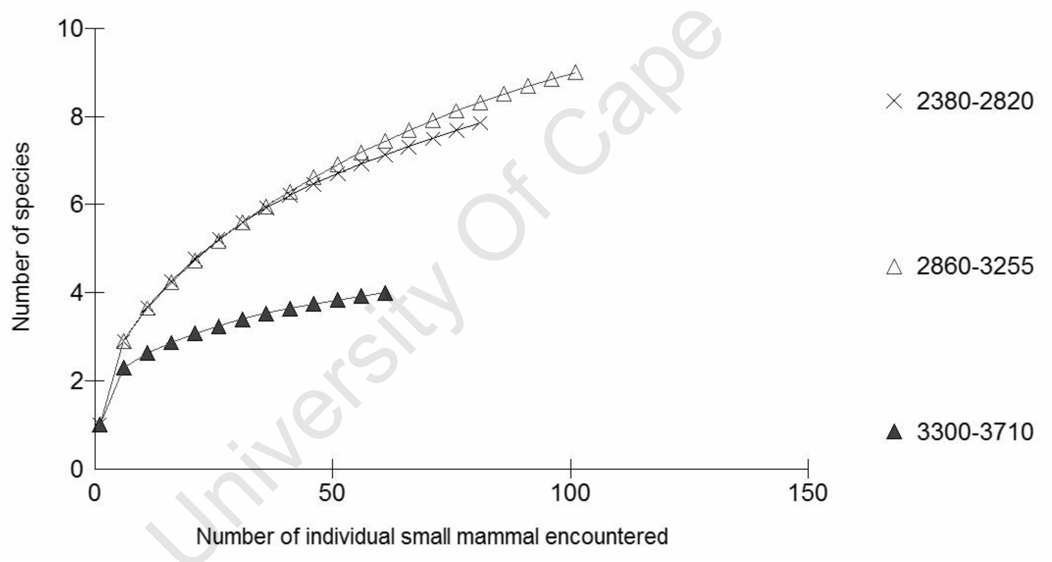

Figure 11. Species accumulation curves for species richness at different altitude zones at VNP.

Small mammal diversity

There was a significant positive correlation obtained between Shannon-Wienner and Brillouin indices calculated for habitats (Pearson correlation: r=9865; p=0.00) (Fig.12). As Shannon-Wiener indices have higher discriminatory power (Magurran 2005), only these were used in further analyses.

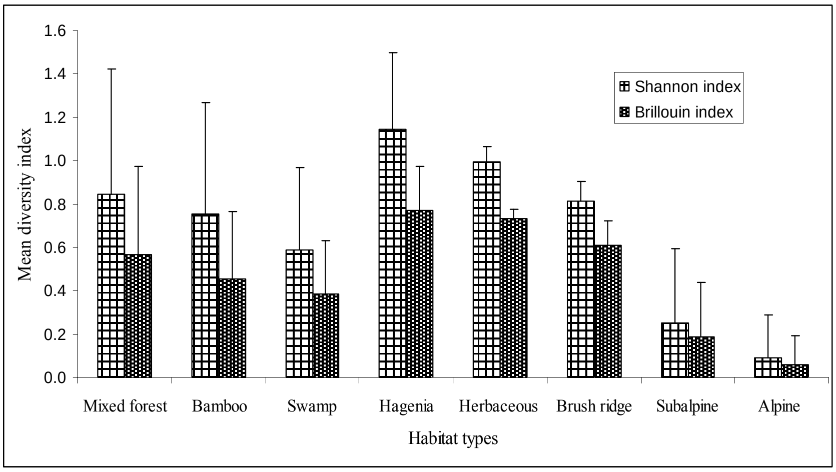

Figure 12. Comparison between Shannon and Brillouin indices for eight habitats at VNP, errors bars denote ±1 standard deviation.

Shannon diversity indices deviated significantly from normality (Shapiro-Wilk W=0.91; p=0.004). Shannon diversity was highest (H>1.0) in Hagenia woodlands and herbaceous habitats, intermediate (0.8 >H<0.6) in bamboo, mixed forest, brush ridge and swamp habitats, and lowest in the subalpine (H=0.2) and alpine habitats (H=0.1) (Fig. 13). These differences in diversity indices were significant (Kruskal-Wallis test: $H_{7,40}$=20.49; p =0.005).

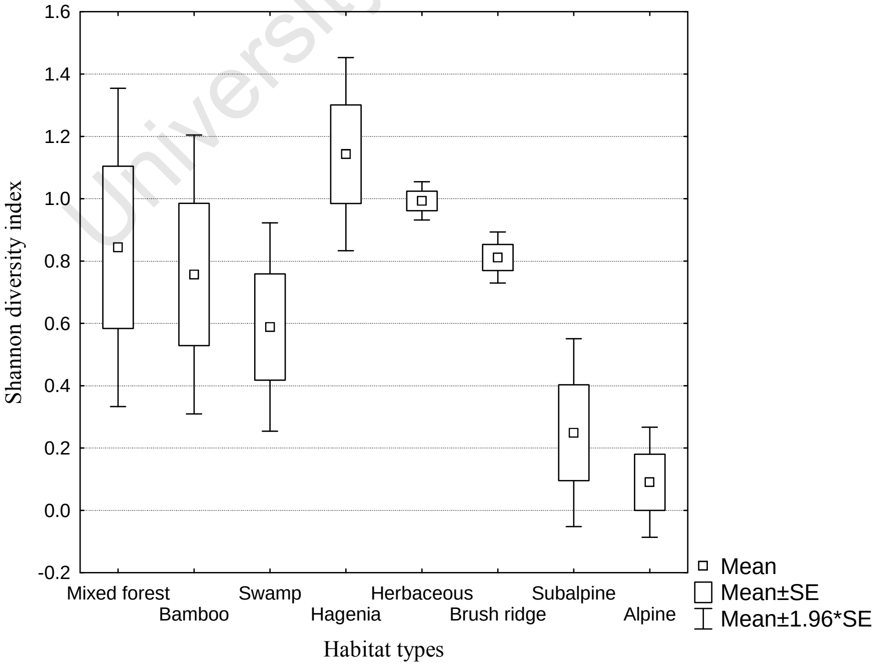

Figure 13. Comparison of the Shannon diversity indices among eight habitats at VNP, vertical bars shows ± 1 standard errors.

Evenness indices also differed significantly among habitats types (Kruskal-Wallis test: $H_{7,40}$=20.49; p=0.005). Shannon diversity is influenced by both low species richness and evenness (Fig.14)

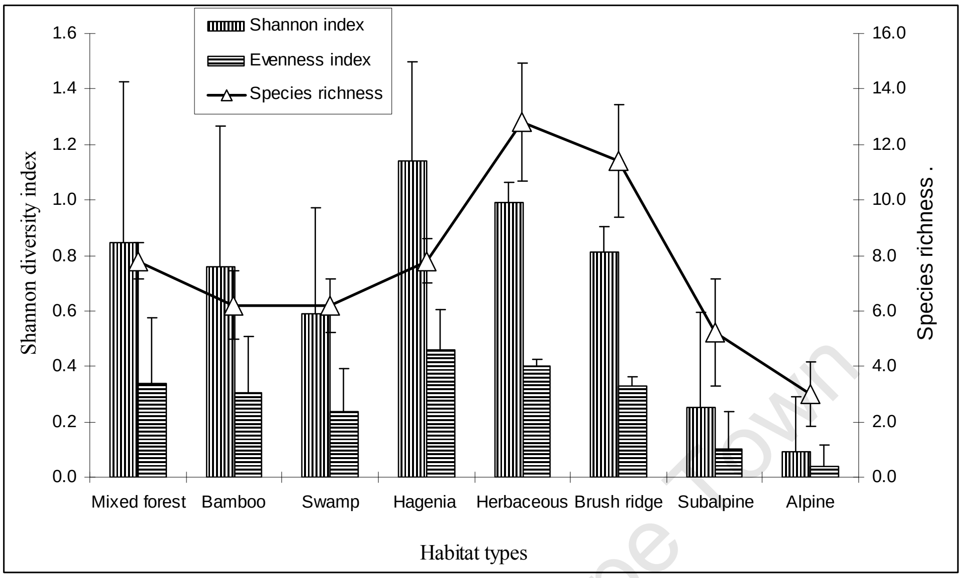

Figure 14. Comparison of the Species richness, Shannon diversity and Evenness indices among eight habitats at VNP, error bars show ±1 standard deviation.

Evenness was generally low (<0.5), indicating that communities in all habitats were dominated by a two species (*Lophuromys aquilus* and *L. woosnami)*. In the subalpine and alpine habitats, species richness was low, and *Lophuromys aquilus* accounted for 14 of the 21 individuals captured, thus Shannon diversity in these habitats reflect both low species richness and evenness. On the other hand, in Hagenia, species richness was high, and while *Lophuromys spp* still dominated the community, two other species were represented by >1 individuals, so the relatively high Shannon index here reflected both elevated species richness and reduced dominance.

A regression analysis of species diversity against altitude was negative, indicating a tendency for species diversity to decline with increasing altitude. Altitude accounted for only 20% of the variation in species diversity with increasing altitude (p=0.004). This is also an oversimplification of the observed patterns whereby there was considerable variation within altitudinal intervals and a tendency for a higher diversity at mid-altitudes (Fig.15).

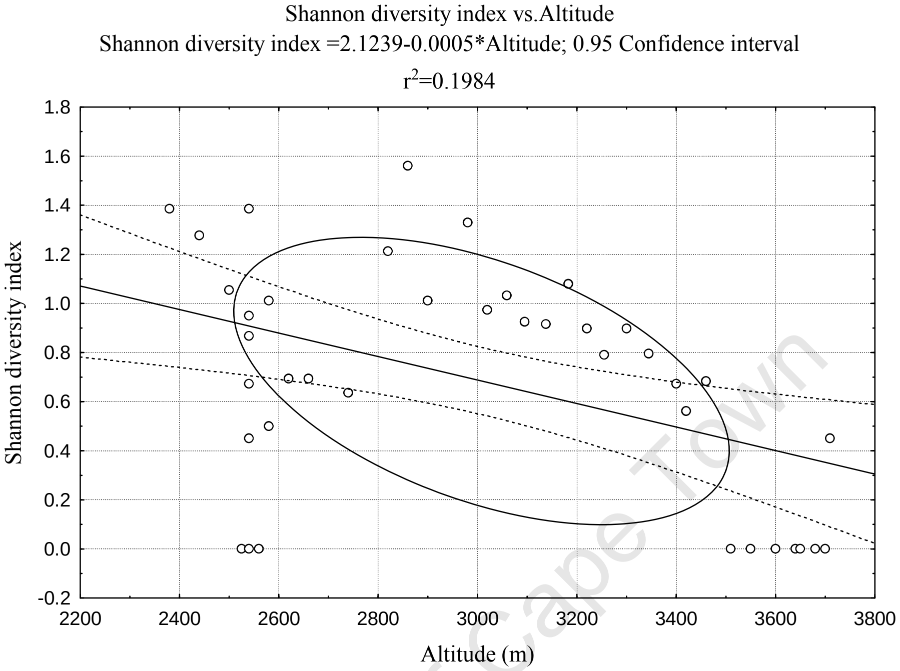

Figure 15. Scatter-plot and regression line of Shannon diversity indices against altitude at VNP. The ellipse shows 75% of the range of Shannon diversity indices.

Similarity of small mammal communities in habitats

A Bray-Curtis dendrogram based on all individuals captured (Fig. 16) showed that the small mammal communities of all habitats were very similar (>62%). The subalpine and swamp habitats had the most similar (91.3%) small mammal communities, followed by bamboo and subalpine (76.92%). The alpine and brush ridge habitats had the least similar mammal communities (39.39%) (Table 8). The herbaceous and brush ridge clustered apart from the other habitat types suggesting that the small mammal community resident there were more distinctive.

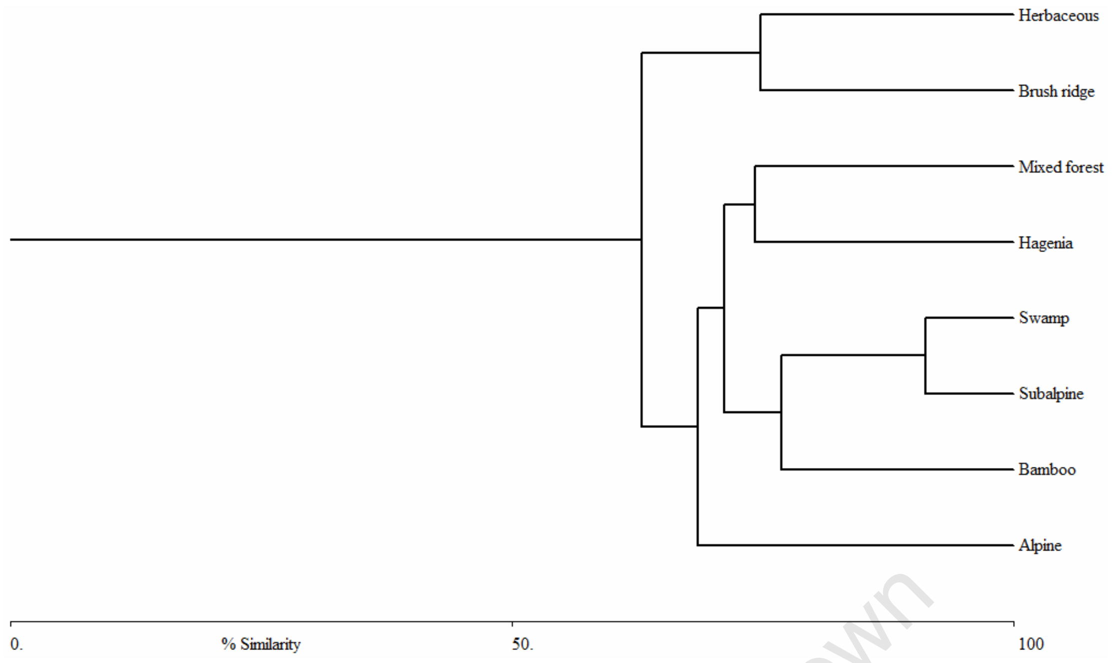

Figure 16. Bray-Curtis linked cluster dendrogram for the habitats at VNP, calculated using total number of small mammals per habitat.

Table 8. Values for percentage similarity of small mammal communities in eight habitat zones at VNP

	Alpine	Bamboo	Brush ridge	Hagenia	Herbaceous	Mixed forest	Subalpine	Swamp
Alpine	*	62.5	39.4	50.0	40.6	42.9	68.6	61.5
Bamboo	*	*	48.6	65.4	46.6	65.2	76.9	74.4
Brush ridge	*	*	*	58.1	74.8	55.0	57.5	62.3
Hagenia	*	*	*	*	62.9	74.2	69.1	71.2
Herbaceous	*	*	*	*	*	57.8	55.3	60.0
Mixed forest	*	*	*	*	*	*	53.1	56.6
Subalpine	*	*	*	*	*	*	*	91.3
Swamp	*	*	*	*	*	*	*	*

Environmental correlates of small mammal community structures

Canopy cover was densest in bamboo (37.62%) followed by mixed forest (24.84%), but absent in the alpine zone (Table 9). Herbaceous cover was highest in the swamp (24.58%), alpine (15.23%) and herbaceous habitats (15.84%). Shrub cover was highest in subalpine (38.11%) and herbaceous habitats (27.61%), but was almost zero in bamboo and swamp. There were significant differences among habitat types for canopy cover (Kruskal-Wallis test: $H_{7,40}$=33.77; p=0.0000), shrub cover (Kruskal-Wallis test: $H_{7,40}$=26.30; p=0.0004) and herbaceous cover (Kruskal-Wallis test: $H_{7,40}$=29.70; p=0.0001), but, there was no significant correlation between habitat cover and small mammal species richness (p>0.05).

Table 9. Distribution of canopy, herbaceous and shrub covers across eight habitat types.

	Canopy	Herbaceous	Shrub
Alpine	0.00	15.23	13.29
Bamboo	37.62	3.26	0.04
Brush Ridge	12.69	15.84	6.58
Hagenia	16.64	10.68	13.17
Herbaceous	2.09	13.93	27.61
Mixed Forest	24.84	8.07	1.20
Subalpine	3.95	8.39	38.11
Swamp	2.17	24.58	0.00

Temperature declined with increasing altitude (r^2= 0.48; p=0.000) (Fig.17) while wind speed increased with increasing altitude (r^2= 0.27; p=0.0006).

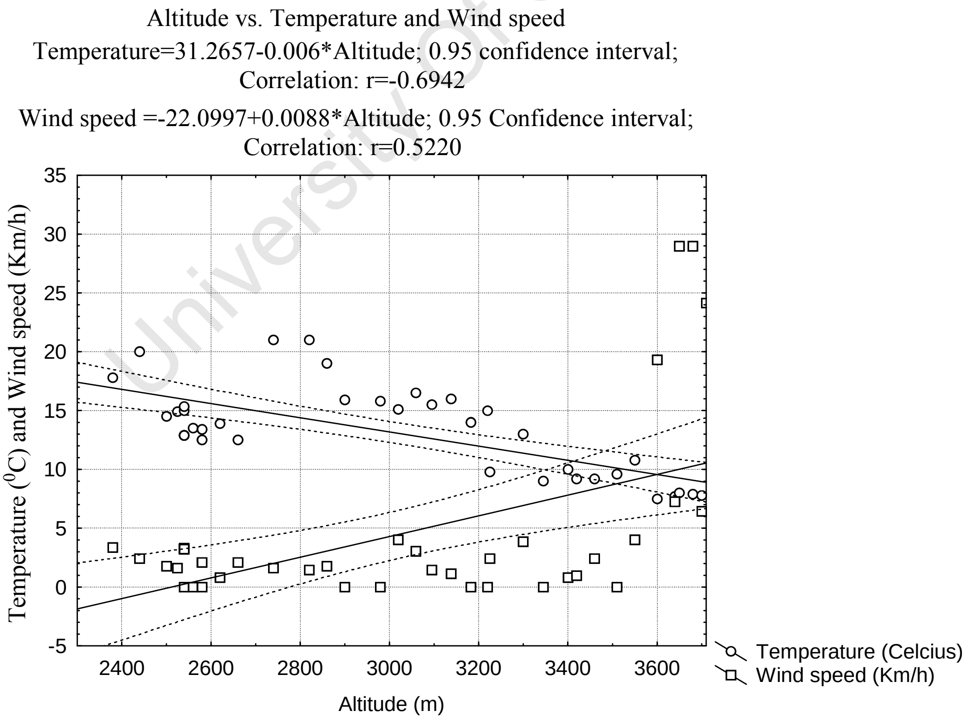

Figure 17. Altitude against temperature and wind speed recorded at VNP study sites.

There was a significant positive relationship between temperature and Shannon diversity (r^2=0.45; p=0.000) (Fig.18), and a negative relationship between wind speed and diversity (r^2=0.20; p=0.003) (Fig.19)

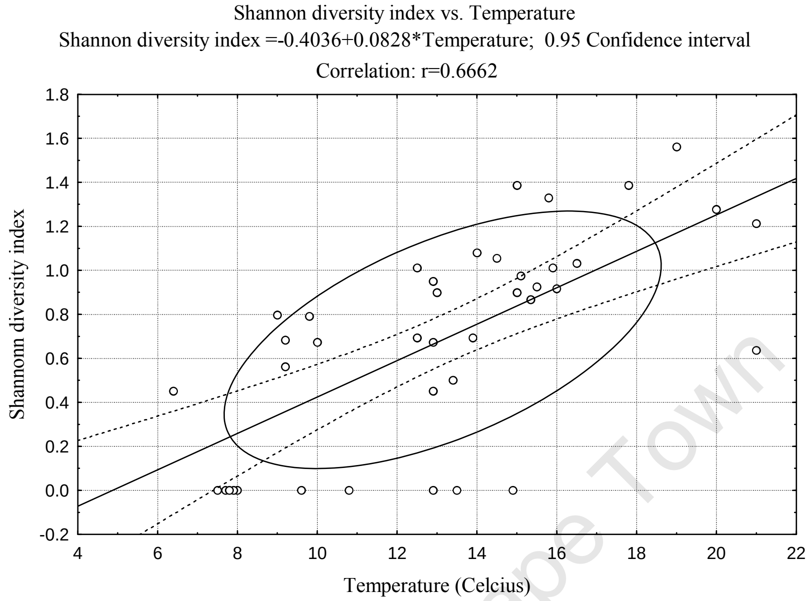

Figure 18. Scatter plot and regression line of Shannon diversity index and against temperature at VNP. The ellipse shows 75% of the range of Shannon diversity indices.

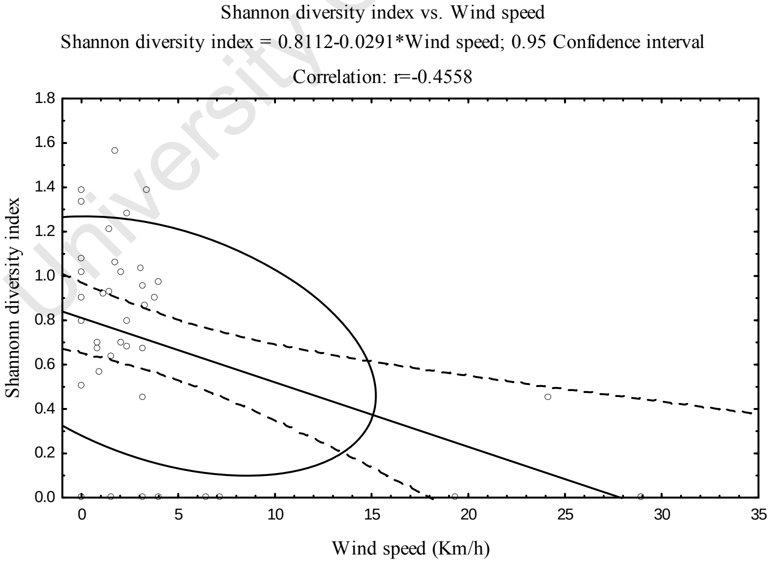

Figure 19. Scatter plot and regression line of Shannon diversity indices against wind speed at VNP. The ellipse shows 75% of the range of Shannon diversity indices.

There was no significant relationship between daily rainfall and captures (p=0.5) (Fig. 20).

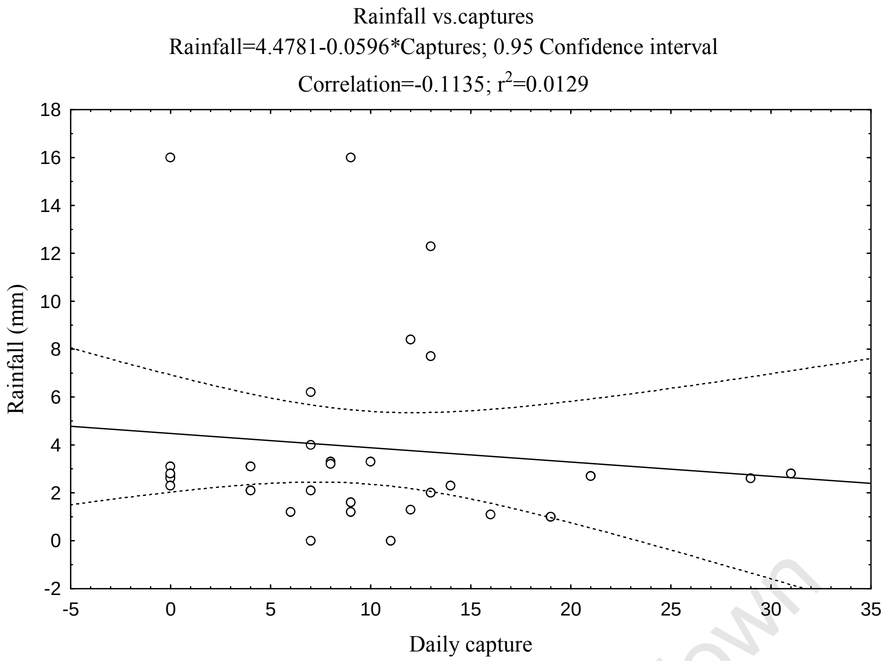

Figure 20. Scatter plot and regression line of rainfall against daily capture at VNP.

The relationship between the six environmental variables (temperature, wind speed, altitude, herbaceous cover, shrub cover and canopy cover), habitat and small mammal abundances were determined with a CCA-biplot (Fig.21). The first two axes explained 17.4+41.3 (equals to 58.7%) of variance in data set. The environmental variables that affected separation of sites and species along axis 1 were temperature, altitude, canopy cover, herbaceous cover and wind speed (Table 10, 11).

Table 10. Eigenvalues of CCA-axis 1 and CCA-axis 2

Eigenvalue	CCA- axis 1	CCA-axis 2
Eigenvalues	0.2	0.1
Percentage	41.3	17.4
Cumulative Percentage	41.3	58.6
Cumulative Constrained Percentage	47.0	66.8
Species-environment correlations	1.0	1.0

Table 11. Intraset correlations between environmental variables and constrained site scores

Environmental variables	Axis 1	Axis 2
Canopy	0.337	0.223
Herbaceous	-0.332	-0.247
Shrub	-0.05	-0.284
Temperature	0.878	0.108
Wind speed	-0.336	0.205
Altitude	-0.416	-0.271

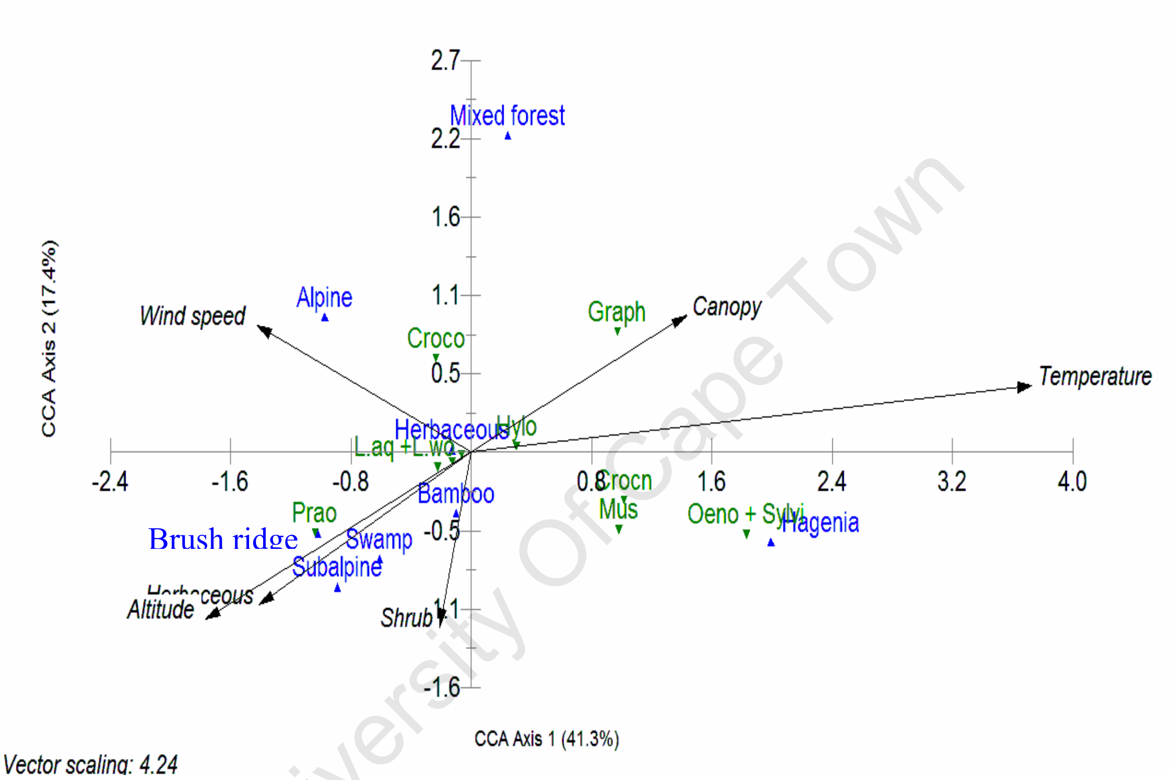

Figure 21. CCA-biplot showing the influence of various environmental variables on small mammal distributions during this study period

Graph: *Graphiurus marinus;* Crocn: *Crocidura nigrofusca;* Croco: *Crocidura olivieri;* Hylo: *Hylomyscus vulcanorum;* L.aq: *Lophuromys aquilus;* L.wo: *Lophuromys woosnami;* Mus: *Mus bufo;* Oeno: *Oenomys hypoxanthus;* Prao: *Praomys degraaffi;* Sylvi: *Sylvisorex vulcanorum.*

Lophuromys aquilus, Lophuromys woosnami and *Hylomyscus vulcanorum* plotted near the intersection of the axes, suggesting that these species are not strongly influenced by any of the six environmental variables, suggesting that they are habitat generalists. Furthermore, *Crocidura olivieri* also seemed to be a generalist, and occurred in five habitat types. *Oenomys hypoxanthus* and *Sylvisorex vulcanorum* preferred the Hagenia habitat, *Crocidura nigrofusca* and *Mus bufo* also preferred habitats with low altitudes. *Praomys degraaffi* preferred the brush ridge. Canopy cover has a greater influence on the distribution of *Graphiurus murinus*, a primarily arboreal species.

This analysis did not include *Tachyoryctes ruandae* and *Galerella sanguinea*, as these two species are associated with human activities, and they were recorded in VNP accidently. *Galerella sanguinea* is a highly mobile species, so the single record thereof does not accurately reflect habitat or environmental specificity in the forest. *Tachyoryctes ruandae* is a subterranean species caught outside the sampled habitats and is unlikely to respond to environmental variables in a similar way to terrestrial species, given the microclimatic stability of the subterranean ecotype (Nevo 1979).

DISCUSSION

The number of small mammal species recoded here has increased compared to previous studies. Some species found in the previous surveys such as *Thamnomys venustus, Otomys sp, Leggada triton* and *Dendromus mesomelas* were not recorded during this survey, but new species are also reported for the study area. The VNP supports a diverse community of rodents and shrews. The main factors accounting for the observed diversity could be the wide altitudinal range and the vegetation types. Endemism is critical to the understanding and conservation of biological diversity, since areas with high rates of endemism tend to have high species diversity.

Capture rates and species encountered

Trapping success in this study (6.4%) was similar to overall trapping success at Bwindi impenetrable forest (6.07%, 1392 trap nights) (Kasangaki et al. 2003). In protected areas at Bwindi, trapping success was 3.4% (1200 trap nights) in primary forest at Buhoma, and 5.6% (1937 trap nights) at Kasiresire Bwindi. Gubitsa et al. (1999) reported 3.21% trapping success (1870 trap nights) in mixed patchy forest at Ituri rainforest in DRC, while Kerbis Peterhans et al. (1998) reported 9% trapping success (4601 trap nights) in Rwenzori Mountains (Uganda). Sampling efforts in the present study were thus comparable to other studies on small mammals in the Albertine Rift and Central Africa, but capture rates were slightly higher. Weather could account for the trapping success during the season; we believe that heavy rains in the research areas might reduce activity of animals. Furthermore, species cumulative curves show insufficient sampling effort in six of eight studied habitats, so we can expect that more sampling effort would add more species.

Pitfall traps did not catch any species, which may be because there were only four buckets in a line of 100m each. However, Nicolas and Colyn (2006) argued that pitfall traps are more efficient (higher number of species trapped and higher trap success) for capturing shrews (but not rodents), especially rare species. A combination of more thorough application methods (long drift fence of 10-50 m and grids), is recommended for future studies.

The number of individuals captured and biomass estimates show that small mammals were more abundant in herbaceous and brush ridge habitats. The high number of *Lophuromys* species captured in these habitats increased overall species biomass, because they weighed twice as much as other species like shrews, *Hylomyscus vulcanorum and Mus bufo.*

Species richness and diversity

The number of terrestrial small mammal species encountered at VNP includes eight rodents, three shrews and one carnivore. Eight (excluding the mongoose and the mole rat) of the twelve species were rarely recorded and more work needs to be done to assess their local distributions at VNP. This could either be a result of insufficient sampling effort or because these species naturally occur at low densities. During this study, only six species endemic to the Albertine Rift were recorded within six weeks of data collection in the wet season. Kerbis Peterhans et al. (1998) found twenty-one endemic species in the Ruwenzori Mountains of Uganda; Kaleme et al. (2007) found eighteen species in Kahuzi-Biega forest, and Kasangaki et al. (2003), working in Bwindi forest, found 10 endemic species endemic to the Albertine Rift. Comparatively few endemics were thus recorded at VNP during this study. Five of six endemic species and the one threatened species were found at low and middle altitudes. In order to maximize the maintenance of biodiversity conservation in general and small mammals in particular, conservation efforts need to target both mid elevation and high elevation zones at VNP.

Compared to previous surveys, this study found additional small mammal species of terrestrial small mammals; however, some species previously collected in VNP were not captured during this study, such as *Sylvisorex lunaris* recorded at Karisoke (Hutterer et al. 1987). Furthermore, some rodent species such as *Thamnomys venustus, Otomys sp, Leggada triton* and *Dendromus mesomelas* collected by Kajonjoli (1993) were not encountered in this study. These small mammal species may have been misidentified in 1992, as voucher specimens were not retained. Again, more trapping over different seasons and in more habitats are needed to adequately document small mammal communities at VNP. Also, this study has caught very few species of *Praomys* compared to Bwindi (Kasangaki et al. 2003) and Rwenzori, because these species are rare in the Virunga massif above 3000m altitude, and its reproductive season might results low captures (Kerbis Peterhans et al. 1998).

Small mammal richness (12 species) at VNP is quite similar to other protected areas in Albertine Rift. Kerbis Peterhans and Austin (1996) collected 16 species in a contiguous forest at Mgahinga National Park including five species recorded during the present study: *Hylomyscus vulcanorum, Lophuromys aquilus, L.woosnami, Oenomys hypoxanthus, and Sylvisorex vulcanorum*. Kasangaki et al. (2003) recorded 11 species in a primary forest of Kasiresire and 20 species at Buhoma. Isabirye-Basuta and Kasenene (1987) found 14 species in both felled forest and undisturbed mature forest of Kibale, with many species recorded in felled forest. Gubitsa et al. (1999) recorded nine species in Ituri rainfall forest, while Kaleme et al. (2007) recorded 27 species primary forest at Kahuzi-Biega (DRC), and Kerbis Peterhans et al. (1998) recorded 25 rodents and 9 shrews in the Rwenzori Mountains. Differences in size of the protected areas, trapping periods and habitats sampled may account for differences in species recorded during these studies.

Decline in species richness (14%) with increasing altitude during this study was different from 21% recorded at Bwindi (Kasangaki et al. 2003), and species diversity decline with increasing altitude (20%) was more pronounced than at Bwindi (13%). This difference can be attributed to differing altitudinal ranges in respective study areas (Bwindi 1000-3000m. VNP 2380-3710m), both of these studies, the number of species and diversity decreased with increasing altitudes. Kerbis-Peterhans et al. (1998) found the same pattern in Rwenzori (1900-3800m).

Small mammals showed different habitat preferences in different habitats types. (Kerbis-Peterhans et al. 1998) suggested that both open and closed canopies favour specific species. Mulungu et al. (2008) also found the number of species varied with altitude and vegetation at Mt Kilimanjaro in Tanzania. Isabirye Basuta and Kasenene (1987) suggested that the dense understorey of degraded forest at Kibale had more food resources for rodents and shrews at ground level and that it provided more protective cover and nest sites than the relatively sparse understory of mature forest.

Ecological correlates of abundances of terrestrial small mammals in Volcanoes National Park

The main factors influencing the abundance of small mammal and number of species of small mammals appear to be the seasonal abundances, floristic composition and physiognomy of vegetation resources, and the extent to which the habitat is modified by external factors such as climate change (Monadjem & Perrin 1998). The rich volcanic soil and high rainfall at VNP make the habitat ideal for food resources, in addition the study areas is richer in plant diversity than other region of VNP (Weber 1987; Owiunji et al. 2005), and the changes in altitude result in a series of well-defined vegetation zones (Plumptre et al. 1991). Furthermore, changes in altitude are associated with several important biological changes in VNP. The climate becomes progressively more temperate and alpine as altitude increases, with seasonal or regular frosts at night. The vegetation of the habitat types that house many small mammals were patchy distributed, suggesting that increased habitat complexity represents increased availability of exploitable patches of habitat; and thus promotes species diversity. Increasing altitude results in a decline in temperature, canopy cover, decrease in the number of small mammals, particularly the numerically dominant *Lophuromys spp*, so dominance also decreases with increases in altitude.

These findings suggest that environmental variables (habitat covers) may enhance species diversity at middle altitudes. Furthermore, several important biological conditions might be associated with these altitudinal changes. At higher altitudes, more inclement climatic conditions (lower temperatures) make for a harsher environment in which fewer species can persist. Also, the effects of environmental variation on species richness depend on whether the variation is predictable and environments which are more spatially heterogeneous can be expected to accommodate extra species (Begon et al. 1990). Areas of forest relics interspersed with dense vegetation might have provided numerous microhabitats for different small mammal species, leading to the observed diversity (Begon et al. 1990). Also, species with limited dispersal abilities may not exist at all in landscapes where source habitat is severally diluted in a sea of sink habitat (Dunning et al. 1992).

Habitat heterogeneity is thought to be a major factor affecting small mammal diversity (Isabirye-Basuta & Kasenene 1987). Kasangaki et al. (2003) found that the main factors accounting for observed diversity was wide range altitudinal variation and a complex array of vegetation types. During this study, the most important environmental variables factors that appear to affect the small mammal community were the temperature, habitat cover, wind speed, and altitude. This study also found that certain environmental variables individually, or together with other variables, may influence the distribution of small mammal species. Difference in altitudinal distribution of habitats types may be responsible for the variation of habitat cover and therefore resources available to small mammals.

Implications for the conservations of small mammals

Special protection of endemic and vulnerable species is very important; therefore, their protection is needed in their habitats of VNP. Species from VNP have a high probability of survival owing to international and governmental protection efforts directed at the famous mountain gorilla (*Gorilla beringei beringei*), an umbrella species from conservation perspectives. As the gorillas and the endemic rodents and shrews depend on the same habitats, the conservation of the first acts to ensure includes the conservation of the second. In Rwanda, all endemic species of shrews are found in VNP, Nyungwe National Park and Gishwati forest (Hutterer et al. 1987), however, Gishwati forest was reduced from 329 km^2 in 1990 to 9 km^2 today (Plumptre et al. 2001). Special protection is needed for the remnant part of Gishwati. In view of the size of VNP (150 km^2), the endemic species recorded during this study highlight the importance of the VNP for biodiversity conservation in the Albertine Rift region.

A large proportion of the recently established VNP was previously transformed by agriculture (Weber 1987), so some species with narrow habitats tolerances may have become locally extinct. Furthermore, some habitats (notably wetlands) are drying out, and higher poaching of large mammals and bamboo cutting may affect the habitat ecologically. Global warming may also potentially threaten small mammal communities at VNP. Altitudinal variation in temperature influences the distribution and abundances of habitant species, and also indirectly determines distributions and abundances on population dynamics (Levin 1992). With increasing temperature, formerly low-elevation small mammal species may expand their ranges while those of high-elevation species may contract, leading to changed community composition at mid- and high elevations (Moritz et al. 2008). Environmental changes can shift the range and distribution of pathogens, and they can increase host susceptibility to disease by altering the ability of hosts to resist infection, which in return may affect different levels of organism including human. Combating climate change benefits many mammals, including forest dwelling shrews and rodents, and humans around VNP. More long-term monitoring is challenged to incorporate these factors, and consider how to mitigate these risks

Conclusions and recommendations

There were no obvious geographical barriers to prevent small mammal dispersal between the sites and no reason to believe that any species may have been physically excluded from a site. This study draws comparisons in species richness, relative abundance, and diversity among habitats and altitude zones. The problem of spatial scales is also important, forty trapping lines located at three study areas may not have been sufficient in a protected area of 150 km^2 and 40 km of width. Long-term studies are needed to better understand the effects of climatic events relative to those of local differences related to habitat structure. The findings of species accumulation curves and comparatively low richness during this study indicate that the small mammal species list for VNP is still incomplete and further inventory work is needed. This study does, however show that the small mammal community of the montane forest zone of VNP has a high level of endemism; in that one half of the species recorded are Albertine Rift endemics.

This study was conducted to fill a gap in knowledge and of baseline data about the distribution and ecology of terrestrial small mammals at different elevations and habitats in the park. It further provides new insights into levels of endemism. The specimen collection (total of 247 voucher specimens) constitutes an important foundation for future referrals and comparisons.

But since this work was limited to a small portion of the park and was carried out in one season only, further studies will provide a comprehensive species list for VNP. The numbers of endemics for VNP will surely increase if small mammals are sampled in different seasons. Annual and climatic oscillations may also affect small mammal activity patterns and abundance (Isabirye-Basuta & Kasenene 1987) and seasonal surveys may add additional small mammal species to the list for VNP. Further research is also needed on both forest and commensal species or species that prefer secondary growth. Surveys should be repeated every five years to evaluate the status of endemic and threatened species as well as monitor impacts of Global Warming. This study was conducted on a short time scale, thus long-term studies should provide opportunities to examine demographic processes over various scales of time. This type of study can provide significance of changes in numbers and periodicity of small mammal that may experience oscillations over long intervals.

It is important to compile small mammal lists for protected areas in Rwanda that complement, and are integrated with national knowledge about Albertine Rift habitats in the DRC and Uganda. Arboreal and subterranean small mammals ideally need to be surveyed, and the status of endemic species may provide information for long-term monitoring. This study provides an updated species list for VNP. It also complements a recent survey of small mammals in Nyungwe National Park. Future plans include survey work in Gishwati Forest and Akagera National Park, Rwanda.

Literature cited

Alper, J. 1998. Ecosystem “engineers” shape habitats for other species. Science **280**: 1195-1196

Barrière, P., R. Hutterer, V. Nicolas, S. Quérouil and M. Colyn. 2005. Investigating the role of natural gallery forests outside the Congolese rainforest as a refuge for African forest shrews. Belgium Journal of Zoology **135**: 21-29

Begon, M., J.L. Harper and C.R. Townsend. 1990. Ecology; individuals, populations and communities. Blackwell Scientific Publications, Oxford.

Bourlière, F. 1975. Mammals, small and large: the ecological implications of size. Pages 1-8 in Golley, F.B., K. Petrusewicz & L. Ryskowski. Eds. Small mammals: their productivity and population dynamics, Cambridge University Press, Cambridge.

Brown, H. 1971. Mammals on mountaintops: Nonequilibrium insular biogeography. The American Naturalist **105**: 467-478

Burgess, N., E. Underwood, J. D’Amico, D. Olson and E. Dinerstein. 2004. An assessment of the terrestrial ecoregions of Africa and Madagascar: a conservation assessment. Island press, Washingtown, D.C.

Carleton, D.M., J.C. Kerbis Peterhans and W.T. Stanley. 2006. Review of the *Hylomyscus denniae* group (Rodentia: Muridae) in eastern Africa, with comments on the generic allocation of *Epimys endorobae* Heller. Proceedings of the Biological Society of Washington **119**: 293-325

Davies, G. 2002. African forest biodiversity. A field survey manual for vertebrates. Earthwatch, London.

De Graaff, G. 1981. The rodents of southern Africa. Butterworth, Durban.

Dunning, J.B., B.J. Danielson and H.R. Pulliam. 1992. Ecological processes that effect populations in complex landscapes. Oikos **65**: 169-175

Entwistle, C.A. and P.J. Stephenson. 2000. Small mammal and the conservation agenda. Pages 119-140 in Entwistle C.A., N. Dunstone. Eds. Priorities for conservation of mammalian diversity. Cambridge University Press, Cambridge.

Fischer, E. and H. Hinkel. 1992. Natur Rwandas. Ministerium des Innern und fur sport, Rheinland-Pfalz, Mainz.

Fossey, D. and A.H. Harcourt. 1977. Feeding ecology of free-ranging mountain gorilla. Pages 415-447 in Clutton-Brock. Eds. Primate Ecology. Academic Press, London.

Fowler, J. and L. Cohen. 1996. Practical statistics for field biology. John Wiley and Sons, New York.

French, N.R., D.M. Stoddart and B. Bobek. 1975. Patterns of demography in small mammal populations. Pages 73-102 in Golley, F.B., K. Petrusewicz and L. Ryskowski. Eds. Small mammals: their productivity and population dynamics. Cambridge University Press, Cambridge.

French, N.R., W.E. Grant, W. Grodzinski and D.M. Swift. 1976. Small mammal energetic in Grassland Ecosystems. Ecological Monographs **46**: 201-220

Gauch, H.G. and R.H. Whittaker. 1972. Comparison of ordination techniques. Ecology **53**: 868-875

Golley, F.B., L. Ryskowski and J.T. Sokur. 1975. The role of small mammals in temperate forest, grasslands and cultivated fields. Pages 223-241 in Golley, F.B., K. Petrusewicz and L. Ryskowski. Eds. Small mammals: Their productivity and population dynamics. Cambridge University Press, Cambridge.

Gray, M., A. McNeilage, K. Fawcett, M.M. Robbins, B. Ssebide, D. Mbula and P. Uwingeli. 2005. Virunga volcanoes range mountain gorilla census. Report to UWA/ORTPN/ICCN, Ruhengeri.

Groves, C. 200. Primate taxonomy. Smithsonian Institution Press, London.

Grubb, P., T.M. Butynski, J.F. Oates, S. K. Bearder, T.R. Disotell, C.P. Groves. and T.T. Struhsaker. 2003. Assessment of the diversity of African primates. International Journal of Primatology **24**: 549-555

Gubista, K.R. 1999. Small mammals of the Ituri forest, Zaire: Diversity and abundance in ecologically distinct habitats. Journal of Mammalogy **80**: 252-262

Horner, D.S., K. Lefkimmiatis, A. Reyes, C. Gissi, C. Saccone and G. Pesole. 2007. Phylogenetic analyses of complete mitochondrial genome sequences suggest a basal divergence of the enigmatic rodent *Anomalurus*. BioMed Central Evolutionary Biology **7**: 16-28

Hutterer, R., E. van der Straeten and W.N. Verheyen. 1987. A checklist of the shrews of Rwanda and biogeographical considerations of African Soricidae. Bonn Zoologishe Beitrage **38**: 155-172

Institute of Resource Assessment (IRA) and the Pan-African START Secretariat (PASS). 2007. Building African capacity for conserving biodiversity in a changing climate in the Albertine region. University of Dar es Salaam, Dar es Salaam.

Isabirye-Basuta, G. and J.M. Kasenene. 1987. Small rodent populations in selectively felled and mature tracts of Kibale forest, Uganda. Biotropica **19:** 260-266

Jansa, S.A. and M. Weksler. 2004. Phylogeny of muroid rodents: relationships within and among major lineages as determined by IRBP gene sequences. Molecular Phylogenetic Evolution **31**: 256-276

Kajonjoli, S. 1993. Inventaire systématiques et répartition altitudinale des rongeurs dans un écosystème montagnard des volcans. Unpublished BSc thesis NUR, Butare.

Kaleme, P.K., J. Bates, J.C. Kerbis Peterhans, M.M. Jacques and B.R. Ndara. 2007. Small mammal diversity and habitat requirements in the Kahuzi- Biega National Park and surrounding areas, eastern Democratic Republic of Congo. Integrative Zoology **2**: 239-246

Kasangaki, A., R. Kityo and J.C. Kerbis Peterhans. 2003. Diversity of rodents and shrews along an elevational gradient in Bwindi Impenetrable National Park. African Journal of Ecology **41**: 115-123

Kerbis Peterhans, J.C. and R. Hutterer. 2009. The description of a new species of *Suncus* (Soricidae, Mammalia) from central Africa. In Thorn, E., & J.C. Kerbis Peterhans. Eds. Small mammals of Uganda. Zoologisches Forschungsmuseum Alexander Koenig, Bonn.

Kerbis Peterhans, J. C., R. M. Kityo, W. T. Stanley and P. K. Austin. 1998. Small mammals along an elevational gradient in Rwenzori Mountains National Park, Uganda. Pp. 149-171 In: The Rwenzori Mountains National Park, Uganda. Exploration, environment & biology. Conservation, management and community relations (H. Osmaston, J. Tukahirwa, C. Basalirwa, H. Nyakaana, eds.) Makerere University, Kampala.

Kerbis Peterhans, J.C. 1998. Updated list of small mammals documented with voucher specimens from Bwindi Impenetrable National Park and its immediate environs. Unpublished list, ITFC, Kampala.

Kerbis Peterhans, J.C. and P.K. Austin. 1996. Small mammal component of the biological inventory of Kabiranyuma swamp, Mgahinga National Park, Uganda. Unpublished Report, ITFC, Kampala.

Kingdon, J. 1974. East African Mammals: An Atlas of Evolution. Academic Press, London.

Kingdon, J. 2004. Kingdon field guide to African mammal. Academic Press, London.

Krebs, J.C. 1 989. Ecological methodology. Harper Collins, NewYork.

Kruskal, W. and W.A. Wallis. 1952. Use of ranks in one-criterion variance analysis. Journal of the American Statistical Association **47**: 583-621

Levin, S. 1992. The problem of pattern and scale in ecology: Robert H. MacArthur award lecture. Ecology **73**: 1943-1967

Lomolino, V.M. 2001. Elevation gradients of species density: Historical and prospective views. Global ecology and biogeography **10**:3-13

MacArthur, R.H. and E.O. Wilson. 1967. An equilibrium theory of insular zoogeography. Evolution **17**: 373-387

Magurran, A.E. 2005. Ecological diversity and its measurement. Croom-Helm, London.

McAleece, N., P.J.D. Lambshead, J.L.D. Paterson and J.D. Gage. 1997. BioDiversity Pro. The Natural History Museum and the Scotish Association for Marine Science, London.

Monadjem, A. and M.R. Perrin. 1998. Effects of supplemental food on the habitat selected *Mastomys natalensis* (Muridae:Rodentia) in a subtropical grassland in Swaziland. South African Journal of Zoology **33**: 172-177

Moritz, C.J., L. Patton, C.J. Conroy, J.L. Parra, G.C. White and S.R. Beissinger. 2008. Impact of a century of climate change on small mammal communities in Yosemite National Park, USA. Science **322**: 261-264

Morrone, J.J. 2009. Evolutionary biogeography: an integrative approach with case studies. Columbia University Press, New York.

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

Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. da Fonseca and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature **403:** 853-858

Myers, P., R. Espiona, C.S. Parr, T. Jones, G.S. Hammond and T.A. Dewey. 2006. The animal diversity web. www.animaldiversity.org

Nevo, E. 1979. Adaptive divergence and convergence of subterranean mammals. Annual review of ecology and systematics **10**: 269-308

Nicolas, V. and M. Colyn. 2006. Relative efficiency of three types of small mammal traps in an African rainforest. Belgium Journal of Zoology **136**: 107-111

Olff, H. and M.E. Rictchie. 1998. Effects of herbivores on grassland plant diversity. TREE **13**: 261-265

Owiunji, I., D. Nkuutu, D. Kujirakwinja, I. Liengola, A. Plumptre, A. Nsanzurwimo, K. Fawcett, M. Gray and A. McNeilage. 2005. The biodiversity of the Virunga Volcanoes. Technical Report www.wcs.org/Albertine_Rift

Pickford, M. 1990. Uplift of the roof of Africa and its bearing on the evolution of mankind. Human Evolution **5**: 1-20.

Plumptre, A.J. 1991. Plant-herbivores dynamics in the Virungas, PhD thesis submitted to the University of Bristol, Bristol, England.

Plumptre, A.J., M. Masozera and A. Vedder. 2001. The Impact of war on the conservation of protected areas in Rwanda. Biodiversity support program, Washington, D. C.

Plumptre, A.J., M. Behangana, T.R.B. Davenport, C. Kahindo, R. Kityo, E. Ndomba, D. Nkuutu, I. Owiunji, P. Ssegawa and G. Eilu. 2003. The Biodiversity of the Albertine Rift. Albertine Rift Technical Report N-3 www.wcs.org/Albertine_Rift

Plumptre, A.J., R.B. Tim, R.B.T. Davenport, M. Behangana, R. Kityo, G. Eilu, P. Ssegawa, C. Ewango, D. Meirte, C. Kahindo, M. Herremans, J.C. Kerbis Peterhans, J.D. Pilgrim, M. Malcolm Wilson, M. Languy and D. Moyer. 2007. The biodiversity of the Albertine Rift. Biological Conservation **134**: 178-194.

Saundry, P. 2009. World database on protected areas and central intelligence agency. Environmental Information Coalition, National Council for Science and the Environment. http://www.eoearth.org/article/Albertine_Rift

Shanker, T. 2000. Small mammal trapping in tropical montane forests of the upper Nilgiris, Southern India: An evaluation of capture-recapture models in estimating abundance. Journal of Biosciences **25**: 99-111

Shannon, C.E. 1948. A mathematical theory of communication. Bell System Technical Journal **27**: 379-423

Skinner, J.D. and R.H.N. Smithers. 1990. The mammals of southern African subregion. Pretoria University Press, Pretoria.

Sutherland, W.J. 2008. Ecological census techniques. Cambridge University Press, Cambridge.

Tews, J., U. Brose, V. Grimm, K. Tielborger1, M.C. Wichmann1, M. Schwager1 and F. Jeltsch. 2004. Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. Journal of Biogeography **31**: 79-92

Thorn, E. and J.C. Kerbis Peterhans. 2009. Small mammals of Uganda. Zoologisches Forschungsmuseum Alexander Koenig, Bonn.

Townsend, C.R., M. Begon and H.J. Harper. 2008. Essentials of ecology. Third Edition, Blackwell, London.

Troupin, G. 1977-1988. Flore du Rwanda. Spermatophytes vols. I-IV. Musée Royal de l'Afrique Centrale, Tervuren.

Van der Staeten, E. and J.C. Kerbis Peterhans. 1999. *Praomys degraffi*, a new species of Muridae (mammalian) from central African. South Africa Journal of Zoology **34**: 80-91

Vander Wall, S.B., K.M. Kuhn and J.R. Gworek. 2005. Two-phase seed dispersal: linking the effects of frugivorous birds and seed-caching rodents. Oecologia **145**: 282-287

Vermaak, A. 2000. Community dynamics and demography of small mammal populations in natural grasslands and rehabilitation ash dams. Unpublished MSc thesis, Potchefstroom University, Potchefstroom.

Weber, A.W. 1987. Ruhengeri and its resources: an environmental profile of the Ruhengeri Prefecture. ETMA/USAID, Kigali.

White, L. and A. Edwards. 2000. Conservation research in the African rain forests: a technical handbook. WCS, New York.

Wilson, D.E. and D.M. Reeder. 2005. Mammal species of the world: A taxonomic and geographic reference. Third edition. Johns Hopkins University Press, Baltimore, Maryland.

World Conservation Union (IUCN). 1992. Protected areas of the World. A review of national systems. Afrotropica **3:** 225-230

World Conservation Union (IUCN). 2009. IUCN Red List of Threatened Species. Version 2009.2. www.iucnredlist.org.

Zar, J.H. 1999. Biostatistical Analysis; fourth edition. Prentice Hall, New Jersey.

Dedication

This dissertation is dedicated to my mother Kezia Uwihoreye and late father Daniel Ntibikwira, and late Dr. Michael Majerus, former professor at Cambridge University, UK. To the biodiversity of Rwanda and all the people who have worked untiringly to protect and conserve them to this present day. May they never be denied the privilege of experiencing God's little creatures lest they be forgotten.

Deogratias Tuyisingize

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.Appendix 1. Taxonomy of small mammal captured in VNP , following Wilson and Reeder (2005)

Order	**Suborder**	**Superfamily**	**Family**	**Subfamily**	**Genus**	**Subgenus**	**Species**
Rodentia	Myomorpha	Muroidea	Muridae	Murinae	*Hylomyscus*		*vulcanorum*
Carnivora	Feliformia		Herpestidae		*Galerella*		*sanguinea*
Rodentia	Sciuromorpha		Gliridae	Graphiurinae	*Graphiurus*	*Graphiurus*	*murinus*
Soricomorpha			Soricidae	Crocidurinae	*Crocidura*		*nigrofusca*
Soricomorpha			Soricidae	Crocidurinae	*Crocidura*		*olivieri*
Soricomorpha			Soricidae	Crocidurinae	*Sylvisorex*		*vulcanorum*
Rodentia	Myomorpha	Muroidea	Muridae	Murinae	*Oenomys*		*hypoxanthus*
Rodentia	Myomorpha	Muroidea	Muridae	Deomyinae	*Lophuromys*	*Lophuromys*	*aquilus*
Rodentia	Myomorpha	Muroidea	Muridae	Deomyinae	*Lophuromys*	*Kivumys*	*woosnami*
Rodentia	Myomorpha	Muroidea	Muridae	Murinae	*Praomys*		*degraaffi*
Rodentia	Myomorpha	Muroidea	Muridae	Murinae	*Mus*	*Nannomys*	*bufo*
Rodentia	Myomorpha	Muroidea	Spalacidae	Tachyoryctinae	*Tachyoryctes*		*ruandae*

Appendix 2: List of specimens collected during this study.

Field Code	Species Name	Sex	Transect number	Altitudes	Museum host	Voucher Number	Age
1	*Hylomyscus vulcanorum*	M	5	2980	Chicago Museum	Pending	Uncertain
2	*Lophuromys woosnami*	M	6	3020	Chicago Museum	Pending	Uncertain
3	*Lophuromys aquilus*	F	6	3020	Chicago Museum	Pending	Uncertain
4	*Lophuromys woosnami*	F	6	3020	Chicago Museum	Pending	Uncertain
5	*Hylomyscus vulcanorum*	M	2	2820	Chicago Museum	Pending	Uncertain
6	*Lophuromys aquilus*	M	4	2900	Chicago Museum	Pending	Uncertain
7	*Oenomys hypoxanthus*	M	2	2820	Chicago Museum	Pending	Uncertain
8	*Lophuromys woosnami*	F	5	2980	Chicago Museum	Pending	Uncertain
9	*Lophuromys woosnami*	F	1	2740	Chicago Museum	Pending	Uncertain
10	*Lophuromys aquilus*	M	2	2820	Chicago Museum	Pending	Uncertain
11	*Lophuromys woosnami*	M	5	2980	Chicago Museum	Pending	Uncertain
12	*Lophuromys aquilus*	F	1	2740	Chicago Museum	Pending	Uncertain
13	*Lophuromys aquilus*	F	1	2740	Chicago Museum	Pending	Uncertain
14	*Lophuromys woosnami*	F	3	2860	Chicago Museum	Pending	Uncertain
15	*Lophuromys woosnami*	M	3	2860	Chicago Museum	Pending	Uncertain
16	*Lophuromys woosnami*	M	4	2900	Chicago Museum	Pending	Uncertain
17	*Hylomyscus vulcanorum*	M	3	2860	Chicago Museum	Pending	Uncertain
18	*Lophuromys woosnami*	F	6	3020	Chicago Museum	Pending	Uncertain
19	*Lophuromys woosnami*	M	6	3020	Chicago Museum	Pending	Uncertain
20	*Mus bufo*	M	3	2860	Chicago Museum	Pending	Uncertain
21	*Lophuromys aquilus*	M	4	2900	Chicago Museum	Pending	Uncertain
22	*Lophuromys aquilus*	M	2	2820	Chicago Museum	Pending	Uncertain
23	*Lophuromys woosnami*	M	2	2820	Chicago Museum	Pending	Uncertain
24	*Praomys degraaffi*	F	11	3220	Chicago Museum	Pending	Uncertain
25	*Lophuromys aquilus*	M	8	3095	Chicago Museum	Pending	Uncertain
27	*Lophuromys aquilus*	M	7	3059	Chicago Museum	Pending	Uncertain
28	*Lophuromys woosnami*	M	8	3095	Chicago Museum	Pending	Uncertain

29	*Lophuromys woosnami*	M	9	3138	Chicago Museum	Pending	Uncertain
30	*Lophuromys woosnami*	M	11	3220	Chicago Museum	Pending	Uncertain
31	*Lophuromys aquilus*	M	9	3138	Chicago Museum	Pending	Uncertain
32	*Hylomyscus vulcanorum*	M	10	3183	Chicago Museum	Pending	Uncertain
33	*Lophuromys woosnami*	M	11	3220	Chicago Museum	Pending	Uncertain
34	*Lophuromys aquilus*	M	7	3059	Chicago Museum	Pending	Uncertain
35	*Lophuromys aquilus*	F	7	3059	Chicago Museum	Pending	Uncertain
37	*Lophuromys aquilus*	F	8	3095	Durban Museum	Pending	Uncertain
38	*Lophuromys woosnami*	F	8	3095	Chicago Museum	Pending	Uncertain
39	*Lophuromys aquilus*	F	8	3095	Chicago Museum	Pending	Uncertain
40	*Lophuromys aquilus*	M	8	3095	Chicago Museum	Pending	Uncertain
41	*Lophuromys aquilus*	F	8	3095	Chicago Museum	Pending	Uncertain
42	*Lophuromys woosnami*	M	9	3138	Chicago Museum	Pending	Uncertain
43	*Lophuromys aquilus*	F	11	3220	Chicago Museum	Pending	Uncertain
44	*Lophuromys aquilus*	F	9	3138	Chicago Museum	Pending	Uncertain
45	*Lophuromys aquilus*	M	9	3138	Durban Museum	Pending	Uncertain
46	*Hylomyscus vulcanorum*	M	10	3183	Chicago Museum	Pending	Uncertain
47	*Hylomyscus vulcanorum*	F	9	3138	Chicago Museum	Pending	Uncertain
48	*Lophuromys woosnami*	F	9	3138	Chicago Museum	Pending	Uncertain
49	*Lophuromys aquilus*	F	10	3183	Chicago Museum	Pending	Uncertain
50	*Lophuromys aquilus*	M	8	3095	Chicago Museum	Pending	Uncertain
51	*Lophuromys woosnami*	M	10	3183	Chicago Museum	Pending	Uncertain
52	*Lophuromys aquilus*	F	10	3183	Chicago Museum	Pending	Uncertain
53	*Lophuromys woosnami*	M	8	3095	Chicago Museum	Pending	Uncertain
54	*Lophuromys aquilus*	M	8	3095	Chicago Museum	Pending	Uncertain
55	*Lophuromys woosnami*	F	11	3220	Chicago Museum	Pending	Uncertain
58	*Lophuromys aquilus*	M	11	3220	Chicago Museum	Pending	Uncertain
59	*Lophuromys aquilus*	M	11	3220	Chicago Museum	Pending	Uncertain
60	*Lophuromys aquilus*	F	10	3183	Chicago Museum	Pending	Uncertain
61	*Lophuromys aquilus*	F	8	3095	Chicago Museum	Pending	Uncertain
62	*Lophuromys woosnami*	M	11	3220	Chicago Museum	Pending	Uncertain

65	*Lophuromys woosnami*	M	7	3059	Chicago Museum	Pending	Uncertain
66	*Lophuromys woosnami*	M	10	3183	Chicago Museum	Pending	Uncertain
67	*Hylomyscus vulcanorum*	F	7	3059	Chicago Museum	Pending	Uncertain
68	*Lophuromys aquilus*	F	11	3220	Chicago Museum	Pending	Uncertain
69	*Lophuromys aquilus*	F	11	3220	Chicago Museum	Pending	Uncertain
70	*Lophuromys woosnami*	F	7	3059	Chicago Museum	Pending	Uncertain
71	*Hylomyscus vulcanorum*	F	8	3095	Chicago Museum	Pending	Uncertain
72	*Lophuromys aquilus*	M	15	3400	Chicago Museum	Pending	Uncertain
73	*Lophuromys woosnami*	F	13	3300	Chicago Museum	Pending	Uncertain
74	*Lophuromys woosnami*	M	13	3300	Chicago Museum	Pending	Uncertain
75	*Lophuromys woosnami*	M	14	3345	Chicago Museum	Pending	Uncertain
76	*Lophuromys woosnami*	M	15	3400	Chicago Museum	Pending	Uncertain
77	*Lophuromys woosnami*	F	12	3255	Chicago Museum	Pending	Uncertain
78	*Lophuromys woosnami*	M	12	3255	Chicago Museum	Pending	Uncertain
80	*Lophuromys aquilus*	M	18	3510	Chicago Museum	Pending	Uncertain
81	*Lophuromys aquilus*	M	17	3460	Chicago Museum	Pending	Uncertain
82	*Lophuromys aquilus*	M	17	3460	Chicago Museum	Pending	Uncertain
83	*Lophuromys woosnami*	M	17	3460	Chicago Museum	Pending	Uncertain
84	*Lophuromys woosnami*	M	17	3460	Durban Museum	Pending	Uncertain
85	*Lophuromys aquilus*	M	16	3420	Chicago Museum	Pending	Uncertain
86	*Lophuromys aquilus*	F	16	3420	Chicago Museum	Pending	Uncertain
87	*Lophuromys aquilus*	F	16	3420	Chicago Museum	Pending	Uncertain
90	*Lophuromys aquilus*	M	16	3420	Chicago Museum	Pending	Uncertain
92	*Lophuromys aquilus*	M	13	3300	Chicago Museum	Pending	Uncertain
93	*Lophuromys woosnami*	M	12	3255	Chicago Museum	Pending	Uncertain
94	*Lophuromys woosnami*	M	12	3255	Chicago Museum	Pending	Uncertain
95	*Lophuromys aquilus*	F	13	3300	Chicago Museum	Pending	Uncertain
96	*Lophuromys aquilus*	M	15	3400	Chicago Museum	Pending	Uncertain
97	*Lophuromys aquilus*	M	12	3255	Chicago Museum	Pending	Uncertain
98	*Lophuromys woosnami*	F	13	3300	Chicago Museum	Pending	Uncertain
99	*Lophuromys aquilus*	M	15	3400	Chicago Museum	Pending	Uncertain

101	*Hylomyscus vulcanorum*	M	12	3255	Chicago Museum	Pending	Uncertain
102	*Lophuromys woosnami*	M	14	3345	Chicago Museum	Pending	Uncertain
103	*Lophuromys woosnami*	F	14	3345	Chicago Museum	Pending	Uncertain
104	*Lophuromys aquilus*	F	12	3255	Chicago Museum	Pending	Uncertain
105	*Lophuromys woosnami*	F	15	3400	Chicago Museum	Pending	Uncertain
106	*Lophuromys woosnami*	M	12	3255	Chicago Museum	Pending	Uncertain
107	*Lophuromys woosnami*	M	12	3255	Chicago Museum	Pending	Uncertain
108	*Lophuromys aquilus*	F	13	3300	Chicago Museum	Pending	Uncertain
109	*Lophuromys woosnami*	F	14	3345	Chicago Museum	Pending	Uncertain
110	*Lophuromys woosnami*	F	13	3300	Chicago Museum	Pending	Uncertain
111	*Lophuromys aquilus*	F	18	3510	Chicago Museum	Pending	Uncertain
112	*Lophuromys woosnami*	F	16	3420	Durban Museum	Pending	Uncertain
113	*Lophuromys aquilus*	M	16	3420	Chicago Museum	Pending	Uncertain
114	*Lophuromys aquilus*	M	14	3345	Chicago Museum	Pending	Uncertain
115	*Lophuromys woosnami*	M	17	3460	Chicago Museum	Pending	Uncertain
117	*Lophuromys aquilus*	M	16	3420	Chicago Museum	Pending	Uncertain
118	*Lophuromys woosnami*	M	16	3420	Chicago Museum	Pending	Uncertain
119	*Lophuromys woosnami*	M	14	3345	Chicago Museum	Pending	Uncertain
120	*Lophuromys aquilus*	F	20	3600	Chicago Museum	Pending	Uncertain
121	*Lophuromys aquilus*	M	13	3300	Chicago Museum	Pending	Uncertain
122	*Crocidura olivieri*	F	13	3300	Chicago Museum	Pending	Uncertain
123	*Lophuromys aquilus*	M	25	3710	Durban Museum	Pending	Uncertain
124	*Galerella sanguinea*	F	14	3345	Chicago Museum	Pending	Uncertain
125	*Lophuromys aquilus*	F	13	3300	Chicago Museum	Pending	Uncertain
126	*Lophuromys aquilus*	M	17	3460	Chicago Museum	Pending	Uncertain
127	*Lophuromys woosnami*	M	17	3460	Chicago Museum	Pending	Uncertain
128	*Lophuromys woosnami*	M	19	3550	Chicago Museum	Pending	Uncertain
130	*Lophuromys woosnami*	M	24	3700	Chicago Museum	Pending	Uncertain
131	*Lophuromys aquilus*	M	25	3710	Chicago Museum	Pending	Uncertain
132	*Lophuromys aquilus*	F	20	3600	Chicago Museum	Pending	Uncertain
133	*Lophuromys aquilus*	M	21	3640	Chicago Museum	Pending	Uncertain

134	*Lophuromys aquilus*	M	25	3710	Chicago Museum	Pending	Uncertain
135	*Lophuromys aquilus*	F	21	3640	Chicago Museum	Pending	Uncertain
137	*Lophuromys aquilus*	F	25	3710	Durban Museum	Pending	Uncertain
138	*Lophuromys aquilus*	M	25	3710	Chicago Museum	Pending	Uncertain
139	*Lophuromys aquilus*	M	20	3600	Chicago Museum	Pending	Uncertain
140	*Lophuromys aquilus*	M	21	3640	Chicago Museum	Pending	Uncertain
141	*Lophuromys aquilus*	F	7	3059	Chicago Museum	Pending	Uncertain
142	*Lophuromys aquilus*	F	7	3059	Chicago Museum	Pending	Uncertain
143	*Lophuromys aquilus*	F	8	3095	Chicago Museum	Pending	Uncertain
144	*Lophuromys aquilus*	F	8	3095	Chicago Museum	Pending	Uncertain
145	*Lophuromys aquilus*	M	23	3680	Chicago Museum	Pending	Uncertain
146	*Lophuromys aquilus*	M	23	3680	Chicago Museum	Pending	Uncertain
147	*Lophuromys aquilus*	M	21	3640	Durban Museum	Pending	Uncertain
148	*Crocidura olivieri*	M	25	3710	Chicago Museum	Pending	Uncertain
149	*Crocidura olivieri*	F	7	3059	Chicago Museum	Pending	Uncertain
150	*Crocidura olivieri*	F	8	3095	Chicago Museum	Pending	Uncertain
151	*Lophuromys aquilus*	M	7	3059	Chicago Museum	Pending	Uncertain
152	*Crocidura olivieri*	F	22	3650	Chicago Museum	Pending	Uncertain
153	*Hylomyscus vulcanorum*	F	1	2440	Chicago Museum	Pending	Uncertain
156	*Graphiurus murinus*	F	6	3020	Chicago Museum	Pending	Uncertain
158	*Crocidura nigrofusca*	F	4	2900	Chicago Museum	Pending	Uncertain
159	*Lophuromys aquilus*	M	1	2740	Chicago Museum	Pending	Uncertain
160	*Lophuromys aquilus*	F	5	2980	Chicago Museum	Pending	Uncertain
161	*Crocidura nigrofusca*	M	3	2860	Chicago Museum	Pending	Uncertain
162	*Sylvisorex vulcanorum*	M	5	2980	Chicago Museum	Pending	Uncertain
163	*Lophuromys aquilus*	M	5	2980	Chicago Museum	Pending	Uncertain
164	*Lophuromys aquilus*	F	5	2540	Chicago Museum	Pending	Uncertain
165	*Lophuromys aquilus*	F	4	2540	Chicago Museum	Pending	Uncertain
166	*Lophuromys aquilus*	M	5	2540	Chicago Museum	Pending	Uncertain
167	*Lophuromys woosnami*	F	1	2540	Durban Museum	Pending	Uncertain
168	*Lophuromys woosnami*	M	1	2540	Chicago Museum	Pending	Uncertain

169	*Lophuromys aquilus*	M	1	2540	Chicago Museum	Pending	Uncertain
170	*Lophuromys aquilus*	M	2	2540	Chicago Museum	Pending	Uncertain
171	*Lophuromys woosnami*	M	2	2540	Durban Museum	Pending	Uncertain
172	*Lophuromys aquilus*	M	3	2540	Chicago Museum	Pending	Uncertain
173	*Lophuromys aquilus*	M	2	2540	Chicago Museum	Pending	Uncertain
174	*Lophuromys aquilus*	M	4	2540	Chicago Museum	Pending	Uncertain
175	*Lophuromys woosnami*	M	4	2540	Chicago Museum	Pending	Uncertain
176	*Lophuromys aquilus*	F	1	2540	Chicago Museum	Pending	Uncertain
177	*Lophuromys woosnami*	M	5	2540	Chicago Museum	Pending	Uncertain
178	*Lophuromys woosnami*	M	4	2540	Chicago Museum	Pending	Uncertain
179	*Lophuromys woosnami*	M	1	2540	Chicago Museum	Pending	Uncertain
180	*Lophuromys aquilus*	M	3	2540	Chicago Museum	Pending	Uncertain
181	*Lophuromys woosnami*	F	1	2540	Chicago Museum	Pending	Uncertain
182	*Lophuromys woosnami*	F	1	2540	Chicago Museum	Pending	Uncertain
184	*Tachyoryctes ruandae*	F	1	2540	Chicago Museum	Pending	Uncertain
189	*Lophuromys aquilus*	M	4	2540	Chicago Museum	Pending	Uncertain
191	*Lophuromys aquilus*	M	5	2540	Chicago Museum	Pending	Uncertain
192	*Lophuromys aquilus*	F	4	2540	Chicago Museum	Pending	Uncertain
194	*Lophuromys aquilus*	M	3	2540	Chicago Museum	Pending	Uncertain
195	*Mus bufo*	M	1	2540	Chicago Museum	Pending	Uncertain
196	*Hylomyscus vulcanorum*	F	1	2540	Chicago Museum	Pending	Uncertain
197	*Hylomyscus vulcanorum*	M	2	2540	Chicago Museum	Pending	Uncertain
199	*Lophuromys woosnami*	F	2	2580	Chicago Museum	Pending	Uncertain
200	*Lophuromys woosnami*	M	2	2580	Chicago Museum	Pending	Uncertain
201	*Lophuromys aquilus*	M	5	2540	Chicago Museum	Pending	Uncertain
202	*Lophuromys aquilus*	M	5	2540	Chicago Museum	Pending	Uncertain
205	*Lophuromys woosnami*	F	2	2580	Chicago Museum	Pending	Uncertain
206	*Crocidura olivieri*	F	2	2580	Chicago Museum	Pending	Uncertain
209	*Lophuromys woosnami*	F	3	2620	Chicago Museum	Pending	Uncertain
210	*Lophuromys woosnami*	F	4	2660	Chicago Museum	Pending	Uncertain
212	*Lophuromys aquilus*	M	5	2560	Chicago Museum	Pending	Uncertain

213	*Lophuromys aquilus*	F	2	2580	Chicago Museum	Pending	Uncertain
214	*Lophuromys woosnami*	M	3	2620	Chicago Museum	Pending	Uncertain
215	*Lophuromys aquilus*	M	2	2580	Chicago Museum	Pending	Uncertain
216	*Lophuromys aquilus*	M	2	2820	Chicago Museum	Pending	Uncertain
219	*Lophuromys aquilus*	F	1	2380	Chicago Museum	Pending	Uncertain
220	*Lophuromys aquilus*	F	1	2380	Chicago Museum	Pending	Uncertain
222	*Lophuromys woosnami*	M	1	2380	Chicago Museum	Pending	Uncertain
223	*Lophuromys woosnami*	F	2	2440	Chicago Museum	Pending	Uncertain
224	*Lophuromys woosnami*	F	4	2525	Chicago Museum	Pending	Uncertain
225	*Lophuromys woosnami*	F	3	2500	Chicago Museum	Pending	Uncertain
227	*Lophuromys aquilus*	F	5	2560	Durban Museum	Pending	Uncertain
229	*Lophuromys aquilus*	F	4	2660	Chicago Museum	Pending	Uncertain
233	*Lophuromys aquilus*	M	3	2620	Chicago Museum	Pending	Uncertain
234	*Lophuromys aquilus*	M	3	2620	Chicago Museum	Pending	Uncertain
235	*Lophuromys woosnami*	M	5	2580	Chicago Museum	Pending	Uncertain
238	*Hylomyscus vulcanorum*	F	1	2500	Durban Museum	Pending	Uncertain
242	*Lophuromys woosnami*	F	2	2440	Chicago Museum	Pending	Uncertain
243	*Lophuromys woosnami*	M	2	2440	Chicago Museum	Pending	Uncertain
245	*Lophuromys woosnami*	F	4	2525	Chicago Museum	Pending	Uncertain
247	*Lophuromys aquilus*	M	2	2440	Chicago Museum	Pending	Uncertain
248	*Lophuromys woosnami*	M	4	2525	Durban Museum	Pending	Uncertain
249	*Lophuromys aquilus*	F	3	2500	Chicago Museum	Pending	Uncertain
250	*Lophuromys aquilus*	M	3	2500	Chicago Museum	Pending	Uncertain
251	*Lophuromys aquilus*	M	4	2900	Chicago Museum	Pending	Uncertain
253	*Lophuromys woosnami*	M	3	2500	Chicago Museum	Pending	Uncertain
257	*Lophuromys woosnami*	M	1	2580	Chicago Museum	Pending	Uncertain
258	*Graphiurus murinus*	F	6	3020	Chicago Museum	Pending	Uncertain
259	*Graphiurus murinus*	M	6	3020	Chicago Museum	Pending	Uncertain
261	*Crocidura olivieri*	F	1	2380	Chicago Museum	Pending	Uncertain
262	*Lophuromys woosnami*	F	1	2580	Durban Museum	Pending	Uncertain
263	*Graphiurus murinus*	M	1	2380	Durban Museum	Pending	Uncertain

264	*Lophuromys woosnami*	M	1	2580	Chicago Museum	Pending	Uncertain
265	*Lophuromys woosnami*	M	1	2380	Durban Museum	Pending	Uncertain
266	*Graphiurus murinus*	M	1	2580	Chicago Museum	Pending	Uncertain
267	*Graphiurus murinus*	F	1	2380	Chicago Museum	Pending	Uncertain
268	*Crocidura olivieri*	F	1	2380	Chicago Museum	Pending	Uncertain
269	*Lophuromys aquilus*	M	2	2440	Chicago Museum	Pending	Uncertain
270	*Crocidura olivieri*	F	2	2440	Chicago Museum	Pending	Uncertain