Communities of small mammals and small carnivores in the Teesta River Basin, Sikkim Himalaya, India

Jaya Thapa

A thesis submitted to the Bharathiar University
for the award of degree of

DOCTOR OF PHILOSOPHY

IN

ZOOLOGY

Division of Conservation Ecology
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CERTIFICATE

This is to certify that the thesis, entitled **"Communities of small mammals and small carnivores in the Teesta River Basin, Sikkim Himalaya, India"** submitted to the Bharathiar University, for the award of the Degree of **Doctor of Philosophy** in **Zoology** is a record of original work done by **Ms. Jaya Thapa** during the period 2004 - 2008 of her study in the Department of Conservation Ecology at Sálim Ali Centre for Ornithology and Natural History, under my supervision and guidance and the thesis has not formed the basis for the award of any Degree/ Diploma/ Associateship/ Fellowship or other similar title to any candidate of any University.

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DECLARATION

I, **Jaya Thapa**, hereby declare that the thesis, entitled **"Communities of small mammals and small carnivores in the Teesta River Basin, Sikkim Himalaya, India"** submitted to the Bharathiar University, in partial fulfillment of the requirements for the award of the Degree of **Doctor of Philosophy in Zoology**, is a record of original and independent research work done by me during 2004 - 2008 under the guidance of Dr. S. Bhupathy, Department of Conservation Ecology, Sálim Ali Centre for Ornithology and Natural History, Coimbatore and with Dr. Ajith Kumar, MSc. Course Director, Centre for Wildlife Studies, Bangalore, as co-guide and it has not formed the basis for the award of any Degree/ Diploma/ Associateship/ Fellowship or other similar title to any candidate in any University.

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SUMMARY

Differences in communities of plants and animals along environmental gradients have been the basis for many ecological theories. Among the first geographical patterns to be recognized in ecology was the climatic gradient in body size of animals, later formalized as the Bergmann's rule. Latitudinal and altitudinal gradients in species richness are other geographical patterns that have long since been recognized. The different nature of gradients and the ecological factors that cause such gradients have both been subjects of considerable debate in recent decades. Community structure in animals can also be influenced by various factors such as vegetation, biological constraints and historical factors, which may not form gradients.

In this dissertation I have examined the influence of altitude and vegetation on communities of small mammals and small carnivores in the Himalayan mountain ranges in the Indian State of Sikkim. The sharp altitudinal gradient from 230 m to 8586 m and the variety of vegetation types in this small state, whose geographical area is only 7096 sq km, make it an ideal study area. Sikkim also has very high diversity of flora and fauna due to its location at the junction of three biogeographical realms - Palearctic, Indo-Malayan and Afrotropic. I selected small mammals consisting of murid rodents (Family Muridae) and ground shrews (Family Soricidae) and small carnivores consisting of civets (Family Viverridae), martens and weasels (Family Mustelidae), jackals and foxes (Family Canidae) and small cats (Family Felidae) for this study as they show high species richness and diversity. Being small, they are also sensitive to environmental and habitat features, forming distinct assemblages.

The overall goal of this study was to examine the influence of altitude and vegetation on the organization of the small mammal community in Sikkim Himalaya, with respect to its species richness, composition, distribution, and abundance. The specific objectives of this study were:

a. To test the hypothesis that the body weight of murid rodents and shrews should respond to the sharp altitudinal gradient;
b. To identify the pattern of variation in the community structure of the murid rodents and shrews along an altitudinal gradient and among different vegetation types;
c. To test the hypothesis that murids and shrews differ in microhabitat use in a manner that is consistent between vegetation types; and
d. To examine the influence of altitude and vegetation types on the composition and relative abundance of the small carnivore community, as well as their diet.

This study was carried out in the North and South Districts of Sikkim in the Teesta River Basin, between 230 m to 3700 m altitude, from June 2003 to April 2004 and from May 2005 to December 2005. For sampling small mammals, I set 28 trap lines distributed among tropical semi-deciduous, tropical broadleaf, temperate broadleaf and coniferous forests. Each trap line had 30 to 60 Sherman live traps placed on alternate sides at an interval of 5 m, and one trapping session lasted for 3 to 5 days. The relative abundance of small carnivores was assessed using scat encounter rate along belt transects. Belt transects of 4 m width were laid along all trap lines and several forest trails, covering a total length of 169.89 km. I sampled the vegetation in 181 plots (5 m × 5 m), placed at an interval of 50 m to 100 m, along trap lines.

Live trapping covered 6417 trap nights, when 277 individuals of small mammals were captured giving an overall capture rate of 5.09 %. I captured 13 taxa (11 species and four sub species) from the family Muridae, five species from the Family Soricidae and one species from the Family Tupaiidae. I explored the influence of altitude on body weight within species and among congeneric species. Altitude accounted for 73% of the variation in body weight of murids. The adult males of three murids species (*Niviventer fulvescens*, *Rattus sikkimensis* and *Mus musculus*), showed a decline in body weight from low to high altitude, while one (*Niviventer eha*) did not show any change. A decrease in body weight with altitude was also seen among congeneric murid species (*Niviventer fulvescens* and *N. eha*), but in the ground shrew (*Soriculus nigrescens*) body weight increased with altitude. Data pooled from this study and from other published literature showed that the temperate murid genera increased in body weights with an increase in altitude (Bergmann's rule), whereas tropical genera showed a decrease.

I also examined observed and estimated species richness, widely perceived to decline with increasing altitude, and recently reported by an increasing number of studies to be higher at mid-altitudes. Although several ecological processes have been used to explain the unimodal pattern of species richness, it can also arise due to random processes such as mid-domain effect (MDE). However, the application of MDE as a null model to examine altitudinal gradient in species richness in this study was constrained by two major factors. MDE requires a complete or near complete record of altitudinal ranges of most species in the area. This was clearly not possible, given the low capture rate, lack of prior field studies and poor museum collections. MDE has also been found to be ineffective where the ranges of species are small. Most species of small mammals in Sikkim would possibly have small altitudinal

ranges due to the sharp gradient. Compared to 17 observed species including four subspecies, the species richness estimated using First order Jackknife estimator was 27, although sampling was adequate only in altitudes between 1800 m and 3800 m. The observed and estimated species richness showed a clear mid altitudinal peak, in the altitudinal zone of 900 m to 2800 m. The capture rates, although low compared to many other study sites, showed a gradient of increasing species richness with altitude, in the case of both murids and shrews. The turnover of species between trap lines increased with the increasing altitudinal difference between them. The dominant species in four altitude zones were *Rattus sikkimensis* in <900 m, *Soriculus nigrescens* in 900 m to 1800 m and *Niviventer eha* in 1800 m to 2800 m as well as 2800 m to 3800 m. Species equability also varied among the four altitude zones, whereas capture rate increased significantly with the increasing altitude.

In order to test whether murids and ground shrews differed in their microhabitat use, I compared 15 vegetation attributes of quadrats from where murids were captured (n = 24) to those from where shrews were captured (n = 14). In tropical forest, a combination of tree density and herb cover discriminated between sites from where murids and shrews were captured, the former using sites with higher tree density, higher litter cover and lower herb cover. In the temperate forest, the separation of microhabitats of murids and shrews was not so clear, but murids seemed to use sites with lower tree density and higher herb cover. In the tropical forest, the species richness and capture rate of murids were negatively correlated to canopy height and canopy cover. Lower herb cover and higher litter cover were the only variables significant for species richness and capture rate of murids in the temperate forest. In the temperate forest, *Niviventer eha* significantly differed from other murid species in its use of microhabitat, preferring lower canopy height, number of shrub species and litter cover. Capture rate of *N. eha* was correlated to lower tree density compared to other murids. Thus, the microhabitat use of murids and shrews can be predicted with a combination of vegetation variables in the tropical forest.

I used encounter rates of scats to examine differences in small carnivore communities among eight altitude classes and four vegetation types. I examined the differences among families (Viverridae, Mustelidae, and Canidae together with Felidae) as identification of scats to species level was not possible. Viverrid scats were abundant in the lower altitudes and mustelid scats in the higher altitudes; canid and felid scats were encountered in all altitude classes. Mustelid scats showed the highest correlation with altitude and decreased when the slope increased. The relative percentage of prey items in the scats such as seeds, other plant parts, invertebrates, reptiles, birds, rodents and other mammals considerably varied from tropical to temperate vegetations. Distribution of small carnivores showed clear differences among the three taxa- viverrids from the Indo-Malayan realm being more abundant in the lower altitudes, mustelids from the Palearctic in the higher altitudes, while the canids and felids occurred in all altitudes. A separation of the canids and felids based on scats was not possible. Thus, the distribution and abundance of small carnivores showed clear separation of different communities along an altitudinal gradient.

The results of this study have important implications for conservation of biodiversity in Sikkim. Body size variations along the altitudinal gradient enable us to predict altitudinal migration of species, for example due to climate change. Secondary data on mammals, excluding small mammals and bats, showed species richness in Sikkim to be highest below 900 m and with a second peak between 3800 m to 4500 m primarily due to mountain ungulates and other high altitude mammals in the trans-Himalaya. This study demonstrates a mid altitude peak for small mammals, between

1800 m and 2800 m. Thus different taxa of mammals have different altitudinal gradients. The protected areas in Sikkim mostly cover the temperate and alpine habitats in the higher altitudes, whereas the sub-tropical and tropical habitats are not represented. Therefore, conserving habitats with high species richness in the middle altitudes as well as the tropical forests in the lower altitudes would maintain the high species richness in Sikkim. Furthermore, this study has provided geo-referenced data on the occurrence and morphometry of several species of small mammals in Sikkim, for the first time. These would be of use in re-examining the distribution of these species, and in the analysis of altitude gradients.

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CONTENTS

CHAPTER 1

INTRODUCTION

"To do science is to search for repeated patterns, not simply to accumulate facts, and to do the science of geographical ecology is to search for patterns of plant and animal life that can be put on a map" (MacArthur 1972).

1.1 Geographical patterns in biological communities

Among the first geographical patterns in biology to be recognized was the climatic gradient in body size of animals (Bergmann 1847; translation in James 1970). This later came to be called the Bergmann's rule, according to which "congeneric species increase in body size in cooler climates" (Blackburn *et al.* 1999; Ashton *et al.* 2000). According to the rule, animals in colder regions are larger than those in warmer regions as larger bodies have lesser surface area to volume ratio and hence heat loss is also lower (Mayr 1963). However, this rule was soon challenged as animals in colder climates can have other adaptations to deal with heat absorption, than changing its body size, such as animals can increase the density of fur, hibernation, living in burrows (Scholander 1955; McNab 1971; Porter *et al.* 1994). The general applicability of the Bergmann's rule is still a subject of debate (Ashton *et al.* 2000; Meiri and Dayan 2003; Rodríguez *et al.* 2006). However, although the validity of Bergmann's rule can be questioned the empirical trends cannot be denied (Mayr 1956; in Ashton *et al.* 2000).

For decades, ecologists have also searched for patterns in the structure, composition and dynamics of animal communities as well as explored the underlying rules governing these patterns. The factors that influence the structuring of mammalian communities have been of particular interest in ecological theory and in conservation. Patterns in altitudinal species richness were among the first to be recognized as it would have been easier to visually notice the gradients in altitude, rather than in latitude. Historically, differences in communities of plants and animals along environmental gradients have been one of the bases for theories on the origin of life by Linnaeus (Lomolino 2001). Later, Charles Darwin in his voyage to different continents also noticed the higher species richness in the tropics compared to temperate areas (Darwin 1859).

In recent decades the latitudinal gradient in species richness have received greater attention than altitude gradient perhaps following the formulation of Rapoport's rule which states that, "latitudinal ranges of species are smaller at low latitudes compared to the higher latitudes" (Stevens 1989). This provided "fodder for ears" with a mechanism encouraging latitudinal gradient research and stimulated a consideration of the role of spatial variation in range sizes in several areas of research in ecology and evolution (Gaston *et al.* 1998). Over the years latitude related patterns in diversity attracted more studies in comparison to altitude despite of the latter's historical importance in the development of biogeography, ecology and evolutionary biology (Lomolino 2001). Further research in altitudinal gradient was improved by equating the changes related with altitude to mirror that of latitude (Stevens 1992). The renewed interests in the altitudinal gradient have addressed different issues, such as distribution and diversity of communities, though comparisons on diversity of mammalian patterns are difficult (Brown 2001; Heaney 2001; Md. Nor 2001; Rickart 2001; Sanchez-Cordero 2001; Li *et al.* 2003; McCain 2005).

Species richness was widely perceived to decline with increasing altitude but an increasing number of studies have reported higher species richness at middle altitudes (Rahbek 2005). Although several ecological processes have been used to explain the unimodal pattern of species richness, it can also arise due to random processes such as mid-domain effect (Colwell *et al.* 2004; McCain 2004). The mid-domain effect itself has been a subject of considerable debate (Hawkins and Diniz-Filho 2002; Zapata *et al.* 2003, 2005; Davies *et al.* 2005). Recent studies have tested altitude gradients against the null model arising from mid domain effect (Kessler 2001; Jetz and Rahbek 2002; McCain 2003; Romdal *et al.* 2005).

In an altitudinal gradient, environmental variables such as temperature decrease towards the higher altitude, but temperature may also be affected by the local topography. Interaction of topography, climate and soil determines the distribution of plants leading to a complexity of vegetation types and productivity found in an altitudinal gradient (Brown 2001). Species richness and diversity of communities also vary among different vegetation types depending on the complexity of the habitat (MacArthur *et al.* 1966; Terborgh 1977). A higher complexity of habitat allows species to choose from a greater variety of microhabitats for food and shelter from predators. The ability of species in a community to partition the microhabitats within a vegetation type is known to influence its abundance (Price 1978). However, not all studies have found significant differences among species in their preference of microhabitats. Thus, there are no clear explanations for the co-occurrence of species with apparently the same microhabitat preferences (Morris 1987; Jorgensen *et al.* 1995; Wells *et al.* 2004). Therefore, more studies have been recommended at a finer spatial scale and in more vegetation types, concentrating on populations rather than individuals (Jorgensen 2004).

1.2 Others community patterns

Biological communities could be influenced by many factors that need not form geographical gradients such as habitat, biological constraints, historical factors like colonization and extinction (Pimm 1991). For example, the community structure of small mammals, from three desert regions on two continents, differed even with respect to the underlying mechanism by which they assembled, proving the influence of history as well as geography of the area on biological communities (Kelt *et al.* 1999). Interspecific competition is another major factor that influences the structure of a community (Fox and Brown 1993). Communities can also be limited taxonomically (Elton 1946; in Pimm 1991) as well as morphologically (Lack 1947; in Pimm 1991). Similarly, predation can fluctuate the density of prey communities (Sinclair *et al.* 2003). Communities also change through time, increasing the complexity of its structure (Elton 1946; in Pimm 1991; MacArthur 1955).

1.3 Mammalian community patterns in Sikkim

In this dissertation, I examine the pattern of variation in a small mammal community with altitude and vegetation along the steep slopes of the Himalaya in the Indian State of Sikkim. I selected small mammals (consisting of murid rodents and ground shrews) and small carnivores (consisting of Viverrids, Herpestids, Mustelids, Canids and smaller species of Felids) in this study as they show high species richness and diversity. Animals of these taxa often show high regional species richness and, being small, are sensitive to environmental and habitat features. Therefore, they often form distinct assemblages, out of the regional species pool, that reflect their response to several environmental and habitat features. Murids and shrews are thought to be especially sensitive, often showing preferences for particular microhabitats, which explain the variation in their abundance in different macrohabitats.

The Indian State of Sikkim is an ideal area to examine altitudinal and vegetation influence on small mammals. Covering only about 7000 sq km, Sikkim is one of the smallest Indian states, but is among the most species rich. For example, forming only about 5% of the geographical area of the Western Ghats (160,000 sq km), a biodiversity hotspot, Siikim has more percentage of species of plants, herpetofauna mammals than the Western Ghats (Kumar *et al.* 2002). The primary reasons for this high species richness, is the location of Sikkim at the junction of the Palearctic, Indo-Malayan and Afrotropic realms, and the sharp altitudinal gradient it has from about 200 m to more than 8000 m, in the Teesta River basin. The State has relatively low human density, at 76 persons per sq km.

An analysis of secondary data demonstrates the sharp turnover of species with altitude in Sikkim. A compilation of inventory of 169 species of mammals, which have been reported to occur or can occur in Sikkim, shows that information on the distribution and abundance is sparse compared to birds and butterflies. The altitudinal distribution of mammalian species excluding small mammals and bats, available from existing secondary records, shows two peaks (Fig. 1.1). These peaks are evident despite the lack of information on most rodents and bats, which together make up nearly 50% of the mammalian fauna.

The peak in the lower altitude is due to small mammals, while the peak in the higher altitudes is due to several species of high altitude taxa such as mountain ungulates, marmot, pika and their predators such as snow leopard, Tibetan wolf, and Tibetan fox. According to the secondary data, the species richness of mammals is high even in the higher altitudes due to the presence of entirely different group of mammals. In addition, there can be no overlapping of these groups of species with those in the mid altitudes.

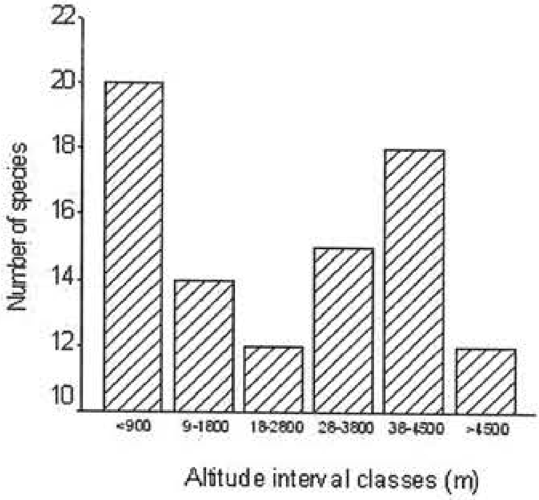


Figure 1.1: Species richness of mammals excluding the non-volant mammals in different altitude classes.
(Note that apart from bats, rodents also have been mostly excluded, due to paucity of data.)

The mammal community in Sikkim has been, however, poorly studied. One of the famous botanical and topographical explorations of Sikkim by J. D. Hooker from 1845 to 1847 contains references to mammals in Sikkim (Hooker 1854). Jerdon's "Mammals of India" (1874) and Blanford's "Fauna of British India, Mammalia, Part I" (1939) mention the presence of 91 species of mammals in Sikkim (Gammie 1894). The small mammal and small carnivore communities are among the least studied.

1.4 Objectives

The major goal of this study is to examine the influence of altitude and vegetation on the organization of the small mammal community in Sikkim Himalaya, with respect to its species richness, composition, distribution, and abundance.

The specific objectives are:

- To test the hypothesis that the body weight of murid rodents and shrews should respond to altitudinal gradient;
- To identify the pattern of variation in the community structure, of the murid rodents and shrews along an altitudinal gradient and among different vegetation types in Sikkim Himalaya.
- To test the hypothesis that murids and shrews differ in microhabitat use in a manner that is consistent between vegetation types.
- Finally, I examine the influence of altitude and vegetation types on the composition and relative abundance of the small carnivore community, as well as their diet.

1.5 Organisation of the thesis

This dissertation is organized into seven chapters as follows:

Chapter 2, describes the Teesta River Basin in Sikkim covering its topography, climate, vegetation, flora and fauna. This Chapter also briefly introduces the study animals i.e. murid rodents, ground shrews, tree shrew, viverrids, canids, felids and mustelids and describes the methods adopted for the study, leaving specific details to later Chapters.

In Chapter 3, I investigate Bergmann's rule, originally used with latitude, here in terms of altitude. Body weights of small mammal species with sufficient sample sizes are analyzed, within species of the same genera and between different species in an increasing altitude. I also investigate the influence of altitude in the structuring of body sizes in small mammal community.

In Chapter 4, I examine differences in community structure, in terms of species richness, in relation to altitude and vegetation types. I use both observed and estimated species richness. I also observed the differences among communities of different altitude zones with respect to the capture rate (%) and composition of the small mammal community.

In Chapter 5, I examine whether the murid rodents and shrews partition the macrohabitat into microhabitat, measured as structural properties of the vegetation. I first examine whether murids and shrews differ in their microhabitat preferences, consistently in different vegetation types. I also examine the microhabitat preference of the most abundant species, *Niviventer eha,* compared to other murids.

In Chapter 6, I examine differences in the small carnivore communities in relation to altitude gradient and vegetation types. Due to difficulties in identifying scats to species level, only differences among families are examined (Viverridae, Mustelidae, and Canidae and Felidae together). The variation in the diet of small carnivores is examined using data from scat analysis.

Finally in Chapter 7, I sum up the influence of altitude and vegetation on community properties, from body size to species richness and abundance in tropical as well as temperate habitats. I also discuss the significance of the findings in terms of conservation.

CHAPTER 2

STUDY AREA AND METHODS

2.1 Study area

This study was conducted in the Teesta River Basin in the North and South Districts of Sikkim in Eastern Himalaya, India. Sikkim is a small Indian state located between 27° 10' N to 28° 5' N and 88° 30' E to 89° E, with Nepal to its west, Tibetan Autonomous Region of the People's Republic of China to its north and east, Bhutan to its south east, and Darjeeling Gorkha Hill Council of West Bengal, India to its south (Fig. 2.1a and b). Sikkim is divided into four districts namely, the North, South, East and West Districts. The North District is the largest district and South District the smallest, accounting for 60% and 11%, respectively, of the total geographical area of 7096 sq km. The total human population of Sikkim is 540493 with a density of 76 persons per sq km, according to the 2001 Census. Most parts of the North District are uninhabited due to extreme climatic conditions, while East District alone accounts for 50% of the total population of the state.

Although one of the smallest states of India, Sikkim has a rich diversity of flora and fauna. Sikkim has at least 4500 species of flowering plants, including 36 species of *Rhododendron* (Tiwari and Chauhan 2006) and more than 500 species of orchids. It also has about 300 species of Pteridophytes. The faunal diversity of Sikkim is represented by more than 689 species of butterflies (Haribal 1992), 48 species of fish (Tamang 1993), 61 species of reptiles, 20 species of amphibians (Jha and Thapa 2002), about 550 species of birds (Ali 1989) and 150 species of mammals (Avasthe and Jha 1999).

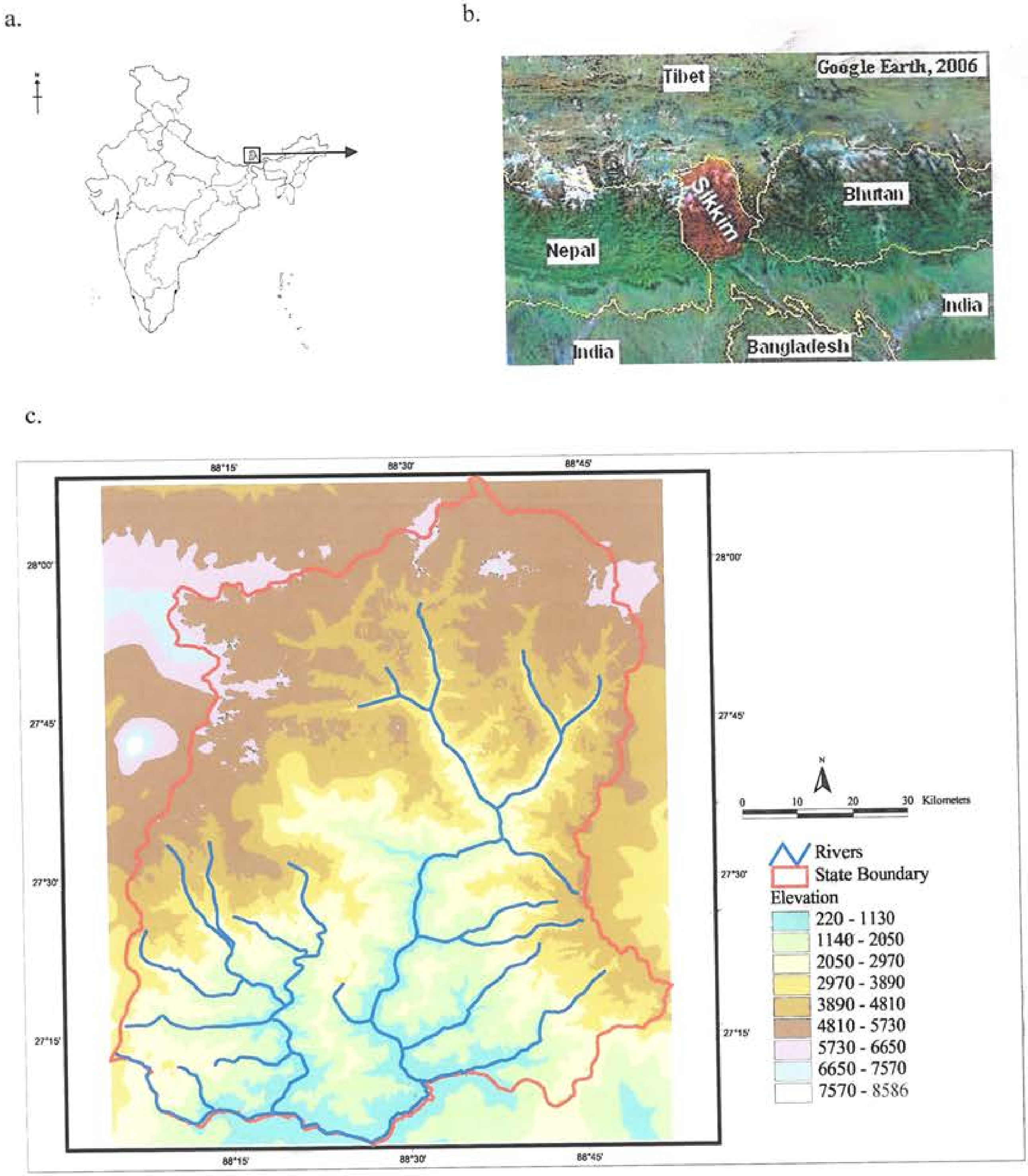


Figure 2.1: (a) Map of India showing Sikkim, (b) Geographical location of Sikkim with neighbouring countries and (c) Digital elevation model of Sikkim.
Source: NASA (2005). Shuttle Radar Topography Mission data V2. Available from ftp://e0srp01u.ecs.nasa.gov/srtm/version2/SRTM3/Eurasia (accessed on 24/12/06).

The populace in Sikkim comprises of people of three major ethnic communities, Lepchas, Bhutias and Nepalese, of which the majority are Nepalese, forming about 70% of the population. The socio-economic bonds among these communities are strong despite different language and social practices (Anon. 2005a). The literacy rate of the state is 70% (2001 Census).

2.1.1 The Teesta River Basin

Sikkim falls almost entirely within the Teesta river catchment, excluding a small area of 75.62 sq km in its south east. Teesta originates from glaciers in the North District at about 5280 m (Anon. 2005b) and flows from the North to the South District, finally emerging as a major tributary of the Brahmaputra River. Teesta traverses a distance of 414 km from its origin before draining off into the Brahmaputra in Bangladesh. Within Sikkim, Teesta's length is about 151 km (Anon. 2005c).

Teesta's runoff and discharge downstream are greatly dependent upon snow cover and glaciers, the largest glacier, Zemu, being 359.85 sq km in area (Krishna 2005). Numerous snow-fed rivers in Sikkim have carved out river valleys in the West and South Districts of the state. These streams drain into the Teesta and its main tributary, the Rangeet. Teesta holds the record for the highest flood in India, when it flowed 18.1 m above the danger level in 1968 (Dhar and Nandargi 2000). The mean annual discharge of Teesta is 580 cusecs (Rudra 2002).

Teesta, till recently, was one of the very few free-flowing rivers in India. However, the recognition of its a hydel power potential of 8000 MW, led to a series of six proposed hydro-electric projects in 2001, of which one, Teesta Stage-V project is nearing completion. Following this a large number of projects have been proposed by various Central and State Government agencies to harness the hydropower potential of Teesta and its tributaries.

2.1.2 Topography

Although only 7096 sq km in area, Sikkim is very diverse with respect to physical features, Mount Khanchendzonga (8586 m), the world's third highest peak is located in the north-western boundary of the State with Nepal. Although extending only 100 km from north to south, and 60 km from east to west, the altitude of the State ranges from 220 m to 8,586 m (Fig. 2.1c). Therefore, the slopes are very steep, with more than 43% of Sikkim having slopes greater than 50° (Anon. 2005d). The slopes of Sikkim are highly susceptible to landslides with the rocks consisting of pyllites and schists (Anon. 2005b). The soil also has large concentrations of iron oxide and has poor organic and mineral nutrients. The state has 28 mountain peaks, 21 glaciers, 227 high altitude lakes, five hot springs and over 1000 rivers and streams (NBSAP 2003).

2.1.3 Climate

2.1.3.1 Temperature

Temperature varies widely over very short distances due to the wide range of altitude in the state (Fig. 2.2a and b). The maximum and minimum temperature of Gangtok, the State capital, has been recorded as 23° C in summer and 6° C in winter. The southern and the middle valleys of Sikkim are hot, humid and wet, whereas the northern parts are dry and cold. In southern Sikkim (Namchi), the maximum summer temperature is 35° C the minimum winter temperature is 6° C. However, the northern part of Sikkim is much colder with temperatures in winter falling much below freezing level and the summer temperatures not exceeding 20° C even below 3000 m (Fig. 2.2a).

2.1.3.2 Rainfall

The mean annual rainfall in Sikkim varies from 1270 mm to 4500 mm, going up to 5000 mm in few areas (Krishna 2005). Thangu in the north receives the minimum mean annual rainfall at 82 mm and Gangtok in the east receives the maximum at 3494 mm. Rainfall is heavy and well distributed during the months from May to early October with July as the wettest month in most places (Fig. 2.2c). The monthly variation in rainy days and rainfall show a similar pattern in different ecozones in Sikkim (Fig. 2.3).

Mean annual rainfall and total number of rainy days (in case of minimum rainfall to be 2.5 mm per day) including precipitation in a year for 1995-96 were 1310.44 mm and 91 in a subtropical location (at 300 m asl), 4327 mm and 190 in a temperate location (at 2000 m), and 4553.09 mm and 198 in a sub-alpine location (3200 m) (Krishna 2005). The North District receives comparatively less rainfall, but is compensated by snowfall; for example Yumthang at 3673 m receives about 1400 mm of snowfall. The perpetual snow line is at 5500 m (NBSAP 2003). Snow cover, including glaciers, spans 20.53% of Sikkim (Krishna 2005).

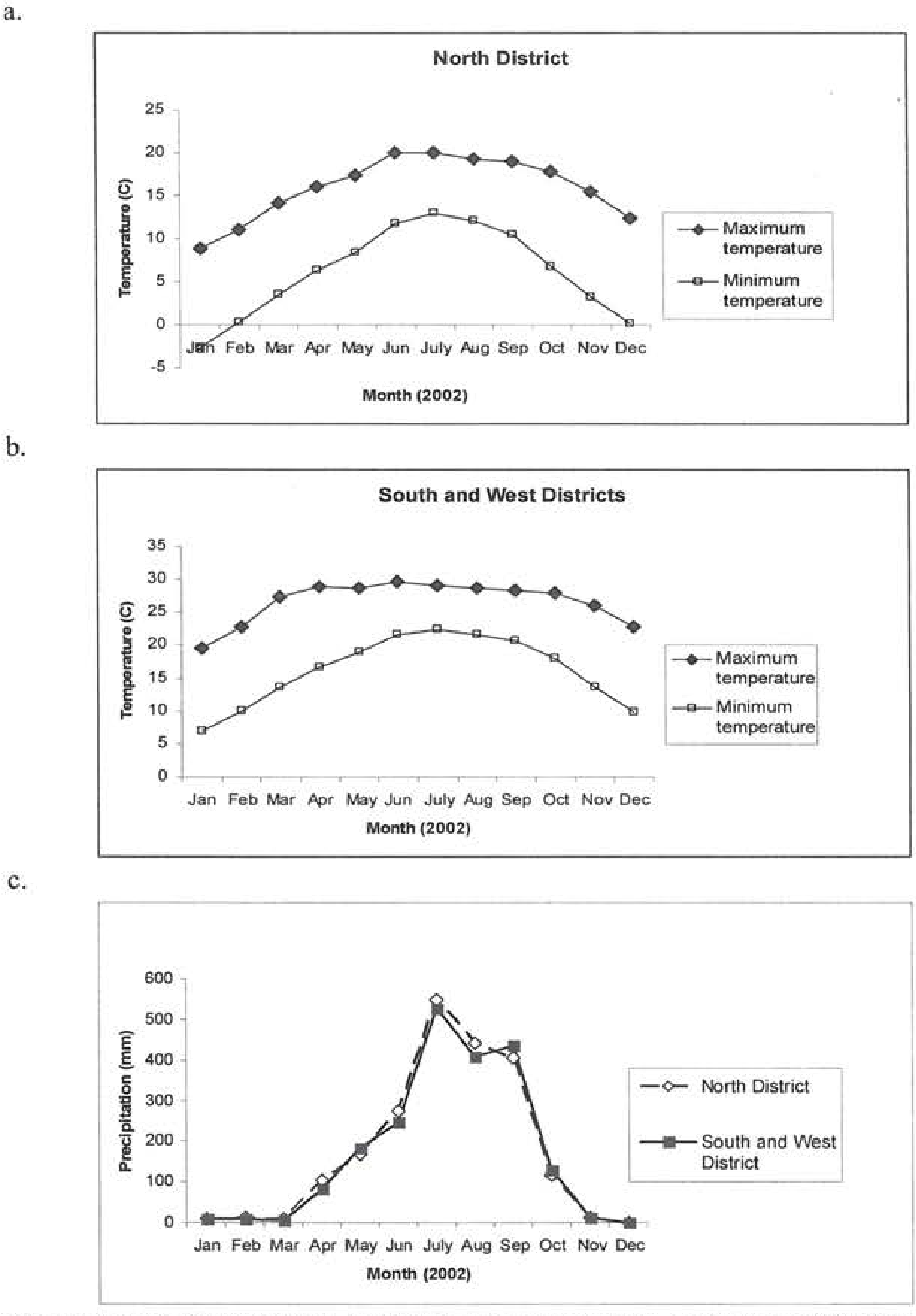


Figure 2.2: (a, b) Maximum and minimum temperatures, and (c) precipitation recorded in the North, South and West Districts of Sikkim.

Source: The graphs are based on data extracted from the global CRU2.1 data set, Tyndall Centre for Climate Research in http://www.waterportal.com (accessed on 10/12/2007).

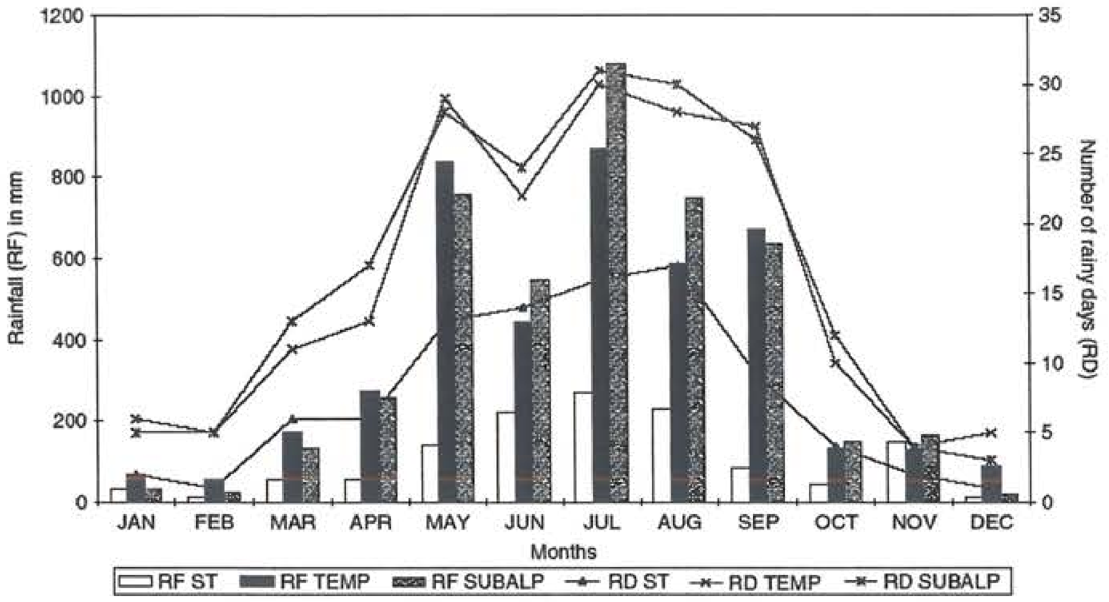


Figure 2.3: Rainfall and rainy days recorded by automatic weather stations in different ecozones of the Teesta river catchment in Sikkim
(*RF= Rainfall, ST= Subtropical, TEMP= Temperate, SUBALP= Sub-alpine; from Krishna 2005, with permission)

2.1.4 Vegetation types

Several types of vegetation are found in Sikkim as shown in Fig. 2.4. On the basis of altitude and composition, Haribal (1992) divided the vegetation into six types, with four major wooded forest types. These are tropical semi-deciduous and wet forest, tropical moist or broad-leaved forests, temperate broad-leaved forests, temperate broadleaf and coniferous forests, sub-alpine vegetation and high altitude desert.

a. ***Tropical semi-deciduous and wet forests*** (<900 m) include deciduous tree species such as *Ceiba malabarica, Ailanthes grandis, Terminalia myriocarpa, Shorea robusta, Duabanga sonnerotoides, Schima wallichii, Gynocardia odorata* and *Amora rohituka.* The dominant undergrowth species includes shrubs in the genera *Strobilanthes, Polygonum, Tridax* and *Barleria. Dioscorea deltoidea,* a rare climber, is also found in this vegetation type. *Pandanus furcatus* along with other species of palms and canes are found in the valleys.

b. ***Tropical moist broad-leaved forests*** (900 m to <1800 m) share some species with tropical semi-deciduous forests such as *Schima wallichii.* The dominant tree species are *Engelhardtia spicata, Alnus nepaulensis, Litsea cistrata, Acer campbelli* and *Castanopsis* sp. The shrubs found in this type of forests are *Girardinia diversifolia, Maesa* sp., *Melastoma* sp., *Edgeworthia* sp., *Ardisia* sp. and the climbers, among many, include *Rhaphidophora decursiva, Smilax* sp. and *Dioscorea* sp.

c. ***Temperate broad-leaved forests*** (1800 m to <2800 m) are dominated by various species of *Michelia* along with *Quercus, Mahonia, Schima, Ilex, Magnolia, Cinnamomum, Betula* and *Rhododendron.* Other tree species found in this vegetation include *Juglans regia, Acer campbelli, Castanopsis indica* with a dense undergrowth of bamboo such as *Arundinaria maling.* Shrub species are *Debregeasia longifolia, Urtica dioica, Gynura cusimbua, Piptanthus* sp., *Berberis* sp., and *Viburnum sp.*

d. ***Temperate broad-leaved and coniferous forests*** (2800 m to <3800 m) consist of few temperate species, with the upper reaches consisting mostly of pine trees. The trees found in this vegetation are *Rhododendron* spp, *Thuja* spp, *Abies densa, Betula utilis* and *Acer sp.* The undergrowth consists mostly of various shrub species of *Rhododendron.* Other shrub species found in this forest type are of the genera *Silene, Astragalus, Fragaria, Impatiens* and *Geranium.*

e. ***Sub-alpine vegetation*** (3800 m to <4500 m) represents a gradual change from the temperate coniferous and broadleaved forests to a vegetation gradually dominated by dwarf *Rhododendron* species and Junipers. Many summer flowers found in the vegetation include species of *Potentilla, Anemone, Primula, Ligularia, Pedicularis, Senecio* and *Aster*. *Rheum nobile* are found on the steep mountain slopes.

f. ***High altitude desert vegetation*** (>4500 m) contain sparse vegetation as small patches of alpine meadows seen only during spring. In order to avoid the strong breeze most of the species grows flat across the land. The high altitude desert vegetation includes species of *Meconopsis, Sedum, Lagotis, Phlomis, Pedicularis, Bistorta, Potentilla, Saxifraga* and *Sassurea*.

Forests in the lower altitudes have largely given way to agriculture, with only small patches of original, though degraded, vegetation on the steep slopes and along streams. In most areas up to 1800 m asl, natural trees have been removed and *Alnus nepalensis* has been planted as shade trees for brown cardamom (*Amomum subulatum*) cultivation. Between 1800 m and 2800 m the original tree cover is mostly intact, except for the removal of the undergrowth for cardamom cultivation in some areas.

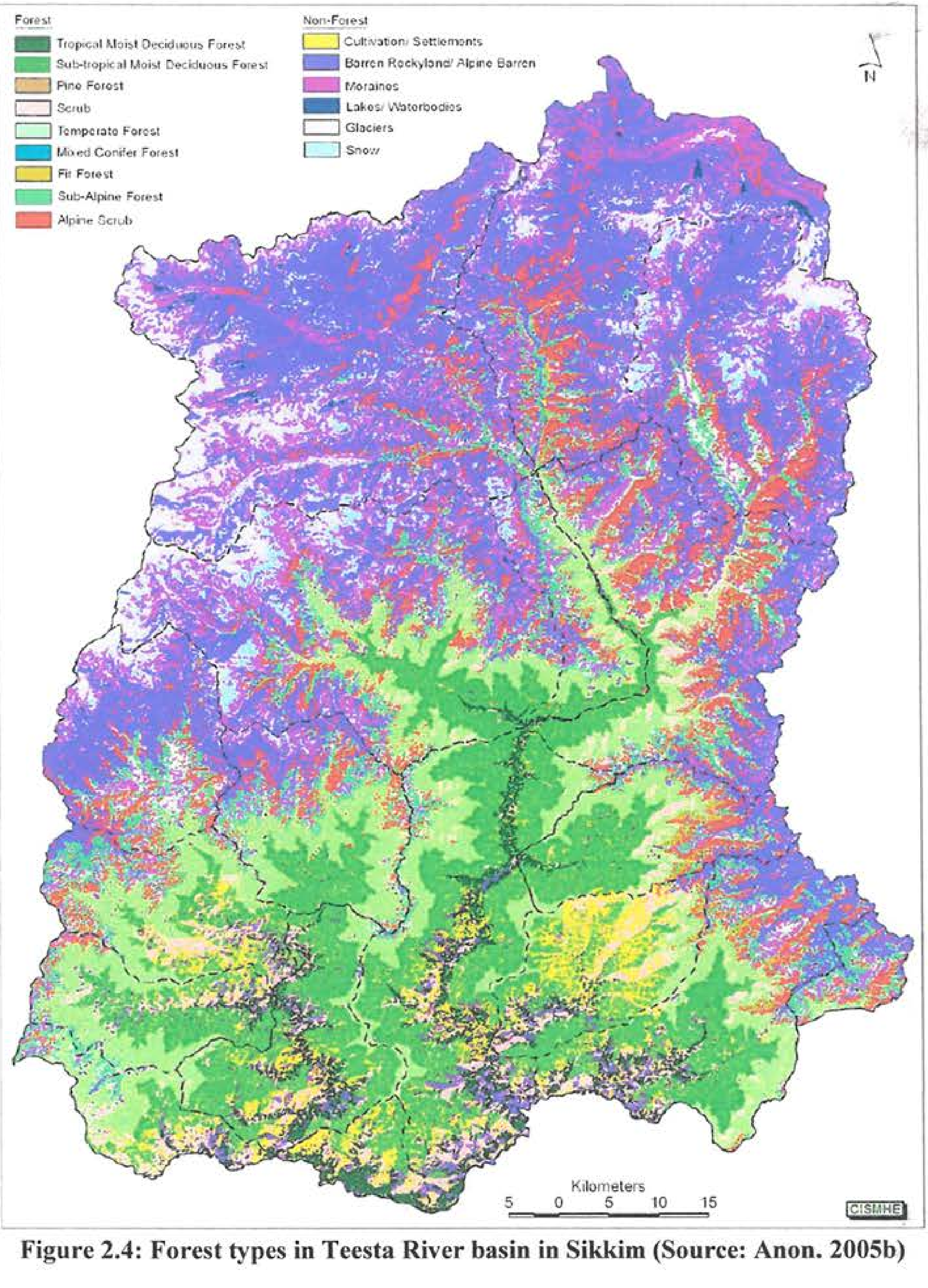


Figure 2.4: Forest types in Teesta River basin in Sikkim (Source: Anon. 2005b)

Plate I

Tropical semi-deciduous forest

View of the tropical semi-deciduous forest in the lower altitudes

Schima wallichi with ground cover of ferns and leaf litter

Plate II

High altitude forests

Temperate broadleaf forest

Coniferous forest

2.1.5 Protected areas

Among the seven protected areas in Sikkim, Khangchendzonga National Park (1784 sq km) covers the largest area but most of it is under snow cover through out the year. Most protected areas in Sikkim are situated at mid to higher elevations (Table 2.1). Three more areas have been proposed by the State Forest Department covering the lower altitude as well as the cold desert areas; namely Tso Lhamo cold desert conservation area (2 sq km in North District), Kitam bird sanctuary (6 sq km in South District) and Rabdentse bird sanctuary (2 sq km in West District; Sharma and Lachungpa 2002). Conservation efforts in this region, in a larger framework, involve twelve protected areas around Mount Kanchenjunga, collectively termed as the Kanchenjunga complex encompassing many ecological zones in Sikkim and Darjeeling in India, eastern Nepal and western Bhutan (Chettri and Sharma 2006).

Table 2.1: Protected areas in Sikkim, India

Protected Area	**Area (sq km)**	**District**	**Altitude range (m)**
Khangchendzonga National Park	1784.00	North & West	1829 – 8598
Shingba Rhododendron Sanctuary	43.00	North	3048 - 4575
Barsey Rhododendron Sanctuary	104.00	West	2200 - 4100
Kyongnosla Alpine Sanctuary	31.00	East	3292 - 4116
Fambong Lha Wildlife Sanctuary	51.76	East	1524 – 2749
Maenam Wildlife Sanctuary	35.34	South	2300 – 3263
Pangolakha Wildlife Sanctuary	124.00	East	1200 - 4757

(Source: National Wildlife Database Cell, WII, List of Protected Areas, http://www.wii.gov.in/envis/pa_database.html (accessed in October 2007).

2.1.6 Study sites

Sampling was conducted in several sites in the North and South Districts of Sikkim so as to cover four major vegetation types and maximum possible altitudinal range (Fig. 2.5, and Table 2.2). The fifth and the sixth vegetation could not be sampled due to logistic problems. The sampling sites were primarily the forested areas near the villages of Melli, Singtam, Dzongu, Mangan, Chungthang, Lachung and Yumthang. Large plantations of sal (*Shorea robusta)* and teak (*Tectona grandis)* are found within the tropical semi-deciduous forests of Melli and Singtam. In Singtam sites like Pabong, Dalep and 20th mile were small forest patches used for fodder collection by communities living nearby. Most of the sites in the tropical broadleaf forests in Dzongu (Passingthang, Lingbo and Sankalan) and Mangan (Pakshep, Lantay, Rangang and Singhik) consisted of cardamom plantations with *Alnus nepalensis* (Alder) as the shade tree. The sites in and nearby Chungthang consisted of both tropical broadleaf forest (Rangma) and temperate broadleaf forests (Polay, Khadum, Mensethang, and Dogra-enroute to Lachen). The two sites in Lachung consisted of tropical broadleaf forests mixed with pine at the higher reaches. The six sites in Yumthang consisted of coniferous forests dominated by *Abies densa* and shrubs of *Rhododendron* spp.

2.2 Study animals

The study animals were small mammals, including murid rodents (Order Rodentia, Family Muridae), ground shrews (Order Soricomorpha, Family Soricidae) and tree shrews (Order Scandentia, Family Tupaiidae), and small carnivores of the Order Carnivora which included civets (Family Viverridae), martens (Family Mustelidae), small cats (Family Felidae) and jackal (Family Canidae). I have followed the classification of mammals based on Wilson and Reeder (1993).

Table 2.2 Weather conditions in 28 trap lines in the North and South Districts of Sikkim where small mammals were sampled.

Trap line altitude (m)	Sampling site (trap line no.)	Month of sampling	Rainfall during sampling	Mean temperature for the month of sampling (°C)	
				Min	Max
280	Rangit valley (14)	January	NR	16.8	19.5
370	20th mile (16)	March	NR	21.7	28.6
480	Melli (13)	January	NR	16.8	19.5
600	Pabong (17)	May	NR	18.9	28.7
620	Dalep (18)	January	NR	16.8	19.5
810	Sankalan (15)	April	L	16.7	28.8
960	Rongrong (19)	April	L	16.7	28.8
1000	Pasingthang (27)	November	L	18.0	27.9
1010	Lingbo (28)	November	L	18.0	27.9
1190	Lantey (22)	July	L	21.7	28.6
1200	D-Pakshep (20)	July	NR	22.3	29.0
1250	Pakshep (21)	July	NR	21.7	28.6
1330	Singhik (23)	July	L	21.7	28.6
1500	Rangma-O (24)	November	L	10.4	18.9
1820	Below Bop (6)	June	L	11.8	20.0
1920	Bop (2)	June	H	11.8	20.0
1950	Mensethang (4)	July	L	13.0	20.0
2100	Polay (5)	August	NR	6.8	17.8
2210	Khadum (3)	October	NR	6.8	17.8
2400	Dogra (1)	September	H	12.0	19.3
2520	Lachung-K (25)	October	NR	3.3	15.5
2630	Lachung-H (26)	October	L	3.3	15.5
3340	Singba start (9)	September	L	10.4	18.9
3460	Singba end (10)	September	L	10.4	18.9
3480	Yumthang -2 (8)	September	L	10.4	18.9
3500	Near hot spr (12)	September	NR	6.8	17.8
3520	Yumthang -1 (7)	September	L	10.4	18.9
3700	Above rest hs (11)	September	NR	6.8	17.8

(Rainfall given is during sampling (H= Heavy rain, L=Light rain, NR=No rain), while maximum and minimum temperatures are for the month of sampling for the nearest weather station obtained for year 2002, from http://www.indiawaterportal.org accessed on 10/12/2007).

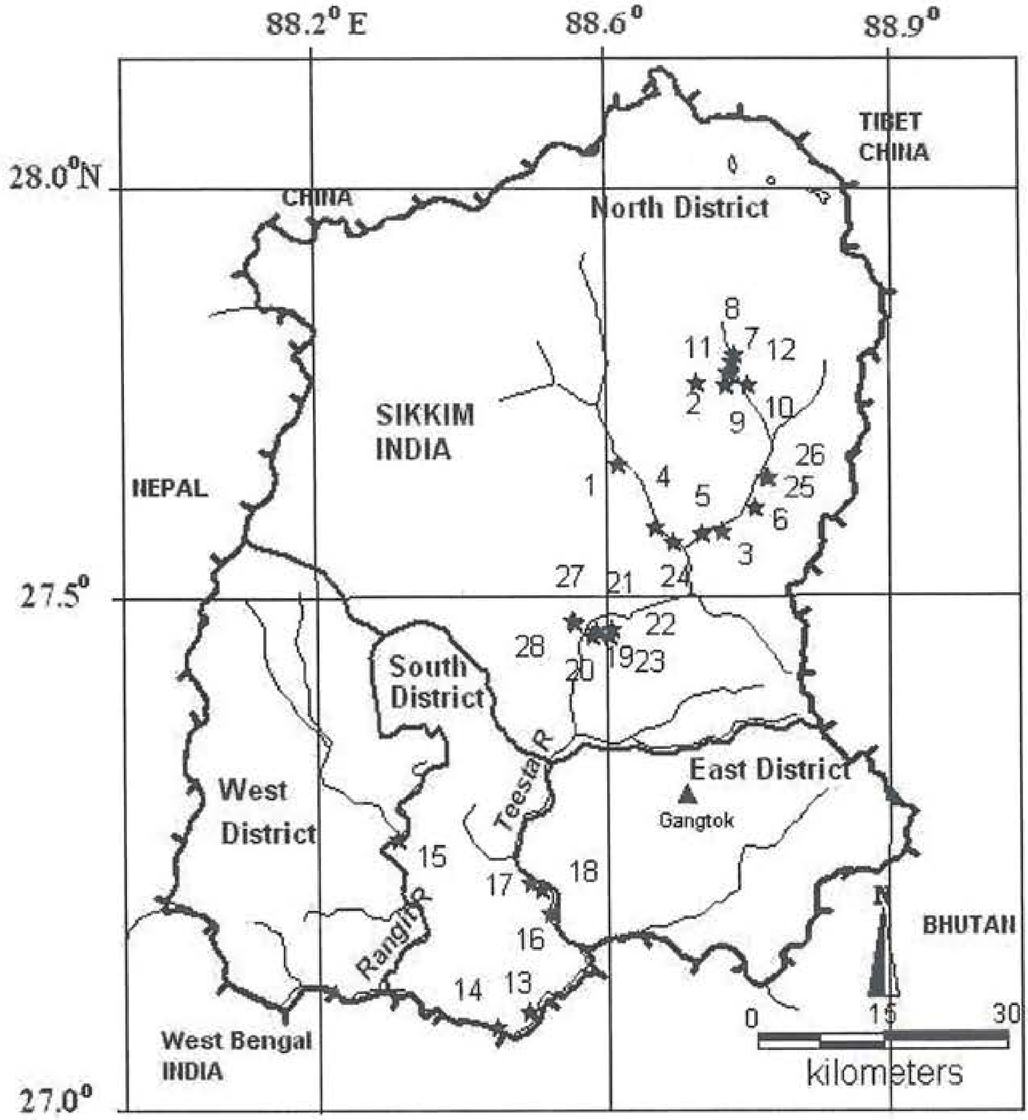


Figure 2.5: Map of Sikkim showing the location of traplines in the North and South Districts along the Teesta River Basin.

2.2.1 Small mammals

2.2.1.1 Murid rodents

Rodents are characterized by the presence of two continuously growing incisors in the upper and lower jaw, which are maintained by gnawing. Molecular studies suggest that modern rodents appeared in the late Cretaceous period (65 MYA) (Douzery *et al.* 2003). The fossil records of murid rodents, although poor, suggest that 23 MYA, *Mus* and *Rattus* diverged (Adkins *et al.* 2001). Due to their high species richness, high adaptability and convergent evolutionary trends, the systematic relationships among many families and subfamilies are complex and unresolved (Musser and Carleton 1993). Many subfamilies have been elevated to the status of family but the key taxa composing them have remained largely the same irrespective of their taxonomic rank within the superfamily Muroidea (Steppan *et al.* 2004). The precursors of rodents are not yet known adequately (van Valen 2004). One possible reason could be that the dental characters, on which the morphological systematics is based, undergo adaptive convergence particularly in rodents (Steppan *et al.* 2004).

Rodentia is the largest order of mammals consisting of 2277 species, 40% of all mammalian species (Wilson and Reeder 2005). Muridae is largest of the 33 families in the Order, accounting for 32.06% of the species (Table 2.3) and consists of 5 subfamilies (Wilson and Reeder 2005). Literature on murid rodents from Sikkim is very scarce and without any publication of primary data.

The murid rodents are found throughout the Old World tropics and have been dominant in Asia since Miocene (Darlington 1959; in Lomolino *et al.* 2004). They are distributed worldwide in Africa, Europe, Asia, Australia and many oceanic islands excepting Antarctica (Nowak 1999). The habitat of murids varies from dry sandy deserts to wet tropical forests, including agricultural fields. Their food habits are also diverse, ranging from vegetable matter to insects and vertebrates, but are they predominantly vegetarian.

Table 2.3 Diversity of the murid rodents, shrews and small carnivore Families reported in India and Sikkim. Compiled from Hussain 1999, Avasthe and Jha 1999, Agrawal 2000, Kumar *et al.* 2002, Wilson and Reeder 2005.)

Family	**No of Genera**			**No of species**		
	World	**India**	**Sikkim**	**World**	**India**	**Sikkim**
Muridae	149	20	7	730	54	17
Tupaiidae	4	2	1	19	3	1
Soricidae	26	NA	6	376	26	7
Viverridae	15	7	6	35	9	6
Mustelidae	22	7	6	59	16	10
Canidae	13	3	3	35	5	5
Felidae (only small cats)	14	10	4	22	15	10
Herpestidae	14	1	1	33	7	3

Murids play an important ecological role in forests as seed dispersers (Forget and Milleron 1991; Brewer and Rejmanek 1999; Zhang and Wang 2001; Midgley *et al.* 2002; Xiao *et al.* 2005) and seed predators (Xiao *et al.* 2005). They also form the main prey base for many species of small carnivores (Mukherjee *et al.* 2004) as well as birds (Norrdahl and Korpimaki 1995). A few species of murids are pests and vectors for many diseases (Myers 2000).

2.2.1.2 Ground shrews

The order Soricomorpha, to which ground shrews belong, consists of four families and 428 species (Wilson and Reeder 2005). Shrews do not fossilize well due to their small and delicate bones, but some European fossils are known from as early as the late Eocene period (Myers *et al.* 2006). Shrews are primarily insectivores and the most speciose family Soricidae, in the Order Soricomorpha, consists of three subfamilies: Crocidurinae (9 genera; 210 species), Soricinae (14 genera; 148 species) and Myosoricinae (3 genera; 18 species).

Some of the ground shrew genera are widely distributed excepting the Polar Regions, Australia and southern South America (Ciszek and Myers 2002). The genus *Crocidura* or the white-toothed shrew is one such genus, found in many African countries, continental Europe and parts of Southeast Asia (IUCN 1995). Another genus *Sorex* or the red-toothed shrew ranges from Central America to Israel, Kashmir, Myanmar, Thailand and Vietnam. *Soriculus* is found mainly in Bhutan, Northern India, Sikkim, Nepal, China, Myanmar, Vietnam and Taiwan (IUCN 1995). The largest of the true shrews belongs to the genus *Suncus* which also contains one of the smallest known mammals in the world, *S. etruscus* (Nowak 1999).

One of the main characteristics of shrews is their high metabolic rate which makes them voracious feeders (Churchfield 1990). They eat frequently, primarily on invertebrates, and are active throughout the day and night. Moist microhabitats are preferred by shrews though a few species are found in deserts as well. A few species are aquatic (Myers *et al.* 2006).

2.2.1.3 Tree shrews

Historically tree shrews have been grouped with Macroscelidea (elephant shrews) and even Primates. More recent studies on their behaviour and reproduction have led to them being placed in a distinct order, Scandentia. It consists of two families, Tupaiidae and Ptilocercidae, comprising of a total of five genera and 20 species (Wilson and Reeder 2005). Tree shrews are found in deciduous and tropical forests of central and southeastern Asia, ranging from India and Southwest China through Malaysia, Indonesia and the Philippines. Three genera and 10 species occur on the island of Borneo alone. In India, three species namely *Anathana ellioti, Tupaia belangeri* and *Tupaia nicobarica* are found (Ommer 2000) of which *T. belangeri* is found in Sikkim (Avasthe and Jha 1999).

Tree shrews are similar to squirrels in external shape and size but differ in having five functional toes compared to four in squirrels. They also do not possess the long vibrissae of squirrels (Myers 2000). All species of tree shrews are forest-dwelling, but few species have adapted to living in secondary forest as well as rural gardens (IUCN 1995). Tree shrews are omnivorous and often active during the day. Their diet consists mainly of insects and fruit, but also includes various types of plant matter (IUCN 1995). Some species of tree shrews are solitary, others are found in pairs or even in small groups. There has been little research on the ecology and behavior of tree shrews in the wild. Some species are thought to be endangered while other species have restricted ranges and some are island species (Nowak 1999).

2.2.2 Small carnivores

2.2.2.1 Order Carnivora

The Order Carnivora evolved in the early Tertiary Period (65 MYA) in the Paleocene Epoch and at present consists of 15 families (Wilson and Reeder 2005). Due to their small size, species belonging to Viverridae, Mustelidae, Canidae, Herpestidae and the smaller species of Felidae are often referred to as small carnivores. A total of 52 species of small carnivores, including the family Herpestidae and small cats are found in India, and 34 species occur in Sikkim (Avasthe and Jha 1999; Table 2.3).

Mustelids (martens, weasels, badgers and otters) occur throughout the world except in Australia and Antarctica (Eisenberg 1989). They are terrestrial, arboreal or aquatic in nature (Hussain 1999). Most of them are solitary and they feed primarily on meat. Viverrids (civets, palm civets, linsang and binturong) are found in tropical and subtropical Africa and Asia. They are terrestrial or arboreal and have an omnivorous diet consisting primarily of fruits and invertebrates (Mudappa 1999; Chiang 2007). Herpestidae (mongooses) are found in Africa with one genus also found in Asia and Europe (Hussian 1999). Few species of herpestids live in colonies, whereas others are solitary. They feed on a variety of prey items such as small mammals, birds, eggs, reptiles, invertebrates and crabs (Hussain 1999; Chiang 2007). Felidae (small cats) are found in diverse habitats like deserts, forests and mountains and are distributed through out all continents except Australia and Antarctica. They are the most specialised hunters among carnivores and are usually solitary (Eisenberg 1989). They require a high carnivorous diet for energy and mostly feed on small mammals. Canidae (wild dogs, jackal, foxes and wolves) are the only carnivores found in Australia, and are distributed throughout except Antarctica (Hussain 1999). Though primarily flesh eaters, canids also feed on plant matter and invertebrates, and are the most omnivorous of all carnivores.

Human beings use the fur, meat, scent gland secretion, and other body parts of small carnivores and keep them as pets as well. Despite their usefulness to humans, small carnivores are the least known with many species known only from a few museum skulls or skins.

2.3 Sampling methods

Sampling methods included live trapping of small mammals, belt transects for sampling scats of small carnivores, vegetation plots for measuring attributes of the vegetation, scat analysis for examining diet of small carnivores and analysis of fecal DNA to identify species. The sampling sites have been described in Section 2.1.6 and

Fig. 2.5. The methods of sampling are broadly described below, leaving the specific details to the relevant chapters. Sampling was carried out from June 2003 to April 2004 and from May 2005 to December 2005.

2.3.1 Small mammals

For sampling purposes, the study area was divided, based on altitude and composition of the vegetation type, into four zones, zone I (230 m to <900 m), zone II (>900 m to <1800 m), zone III (>1800 m to <2800 m) and zone IV (>2800 m to <3800 m). In order to sample murid rodents and shrews, I laid trap lines, varying in length from 200 m to 300 m, in the different altitudinal zones along existing or freshly cut trails. I used 30 to 60 Sherman live traps (7.5 cm × 9 cm × 23 cm), placed at a distance of 5 m on alternate side of the trap lines. I laid six trap lines each in zones I and IV, and eight trap lines each in zones II and III (Table 2.4, Fig. 2.5)

The traps were checked every morning and captured animals were measured, weighed, photographed and released at a distance from transects. Each trapping session comprised of three to five consecutive nights. In cases where there was no capture, the trapping session was repeated. One individual of each species was collected as a voucher specimen. External body measurement, skull measurement, and morphological characters were used as the basis for species identification. External body measurements including head and body, tail, ear, hind limb were taken (Agrawal 2000). One individual for each species was collected as a voucher specimen. Species were identified using Ellerman (1961) and Agrawal (2000). Unidentified species were initially considered as morpho-species and numbered according to genera. However, most species were identified towards the end of the study.

Sampling in the lower altitudes was conducted during November to April and in the higher altitudes during May to October, when small mammal abundances were expected to be the highest (Table 2.2). I used this data set to estimate species richness, capture rates and species composition, the methods of which are given in the relevant chapters.

Table 2.4: Total sampling effort in the four altitudinal zones

Altitude zone (m)	Number of trap lines	Trap nights	Number of vegetation plots (5 m x 5 m)	Belt transect length (km)
<900 (I)	6	1773	39	29.67
900 to 1800 (II)	8 (7 for belt transects)	1641	57	30.35
1800 to 2800 (III)	8	1786	50	81.41
2800 to 3800 (IV)	6	1217	35	20.61

2.3.2 *Small carnivores*

Since small carnivores generally occur in low densities and are mostly nocturnal (Kumar and Yoganand 1999), I used encounter rate of their scats in belt transects as an indicator of their abundance. A total of 27 belt transects were sampled in the four major vegetation types. The transects covered 2 m on either side of the trap lines or trails in the forest, and varied from 200 m to 1 km in length (Table 2.4). Droppings of small carnivores encountered along transects were photographed and collected. The location of the scats (vegetation type and altitude), length and diameter, and contents, were recorded. Identification of species based on scat was difficult in the field. Therefore, each scat was identified as belonging to one of the three groups (Viverrids, Mustelids or Canids together with Felids) based on physical appearance, shape, size and its location. All scats were collected in paper envelopes in the field and then were dried in the sun to be examined later.

2.3.2.1 Scat analysis

Content of the scats were examined in the field initially and later in the lab to arrive at the diet of the small carnivores. Prey items in the scats were categorized into seven types- rodents, other mammals, birds, reptiles, invertebrates and seeds along with other plant parts. Few of the scats were used to identify species based on fecal DNA.

2.3.3 Vegetation

Structural vegetation was measured along all 28 trap lines. Quadrats of 5 m × 5 m were laid at intervals of 50 m to 100 m depending on the length of the trap line from the starting point of the trap line and on alternate sides (Table 2.4). In each quadrat, 15 parameters were measured including altitude, number of tree species, girth at breast height of trees, shrub species and number, canopy height, canopy cover, slope and the percentages of ground cover for herbs, litter, rock, soil, fern and *Ageratum*. More details on the method of measurement of vegetation parameters have been given in Chapter 5. Due to malfunctioning of our data loggers (Hobotemp, Onset), maximum and minimum temperature during the month of sampling were obtained from the nearest weather station available at www.indiaportal.org for 2002.

2.4 Data analysis

Depending on the sample size requirements for different analysis, the data have been pooled in different ways in the following chapters. Thus, the 28 trap lines have been treated separately (Chapter 4 and 6), pooled into two altitude classes (Chapter 3), and two vegetation types (Chapter 5), pooled into four vegetation types or altitude classes (Chapter 4), or into eight altitude classes (Chapter 6). Similarly, data on different taxa have also been pooled depending on sample size requirements. Similarly, species have been treated separately (Chapter 4), or pooled into genera or higher taxonomic groups (Chapter 3, 5 and 6). Data pooling is described in detail in the relevant chapters. I have used the software SPlus (version 6.1; Insightful Corporation, Seattle, USA) for bootstrapping, SPSS (version 11.5; Incorporated, Chicago, USA) for most statistical analysis, EstimateS (version 6b, Colwell 2004) to estimate species richness and evenness of communities, and Mid Domain Null Program (McCain 2004) for examining altitude gradient in species richness.

Whenever the distribution of the parameter were unknown with low sample sizes, I have used non-parametric tests; otherwise I have used parametric tests. Partial correlations are used to examine the effect of vegetation, by controlling the altitudinal effect; and in order to find the separation of murids and shrews as well as within murids with reference to microhabitat variables, discriminant function analysis are used.

CHAPTER 3

ALTITUDINAL VARIATION IN BODY WEIGHT OF SMALL MAMMALS

3.1 Introduction

In mammals, body size correlates strongly with many aspects of metabolism (McNab 1966), digestion (Clauss *et al.* 2003), life history (Calder 1996; Webster *et al.* 2004) and ecology (Peters 1983). Body size, in turn, is influenced by climatic and other gradients. One of the best known pattern is Bergmann's rule, where congeneric species increase in body size in cooler climates (Blackburn *et al.* 1999; Ashton *et al.* 2000). Although Bergmann discussed changes in body weight with reference to environmental temperature, latitude was later widely accepted as an easily measurable surrogate for temperature and hence a determinant of body weight (Bergmann 1847; in James 1970; Ashton *et al.* 2000). Many studies have concluded Bergmann's rule to be valid among bird taxa (YomTov 2001; Ashton 2002; Meiri and Dayan 2003; Lizabeth *et al.* 2008), but there are exceptions in several mammalian taxa such as Mustelids, *Microtus* and *Dipodomys* (Ashton *et al.* 2000), and herbivores (Rodríguez *et al.* 2006). The validity of the rule has been questioned for rodents in general (Meiri and Dayan 2003). The rule has been questioned on the basis of physiological mechanisms (Scholander 1955), behavioral mechanisms such as hibernation (Smith *et al.* 2004). Suggestions have been made to modify the rule by restricting comparisons within monophyletic higher taxon (Blackburn *et al.* 1999), but even then the results remain ambiguous. For example, analyses of published data on small mammals did not show any clear relationship (Ashton *et al.* 2000).

Latitude and altitude have similar effects on many climatic characteristics, for example, an increase in both latitude and altitude leads to a decline in mean temperature (Stevens 1992). Therefore, changes in body size associated with both altitudinal and latitudinal variations should be the same (Blackburn and Ruggiero 2001). Taylor *et al.* (1985) found a negative relationship between body size and altitude among *Rattus* in New Guinea. Thus, the above mentioned ambiguity in Bergmann's rule can be fruitfully explored with reference to altitude in a given locality. In this chapter, I investigate the applicability of Bergmann's rule on the body size of a small mammal community (murid rodents and shrews) among congeneric and non congeneric species.

The correlation of body size with resource requirement makes the former an important factor in the assembly of local communities (Kelt and Brown 1999). Thus Bergmann's rule, through its influence on body size, can also be expected to affect the assemblage of animal communities. Therefore, I also examine the influence of altitude in the structuring of small mammal community with reference to body weight range.

3.2 Methods

3.2.1 Sampling

Small mammals were sampled in a total of 28 trap lines, set between 280 m to 3700 m altitude, in North and South Districts of Sikkim (Section 2.3.1). Sherman traps (30 – 60 for each trap line) were used and were placed 5 m apart using peanut butter as the bait for small mammals. The traps were set in the evening and checked every morning there after. The trapping period lasted for 3 to 5 days for each trap line. The captured animal was weighed with Pesola spring balance (30 g, 100 g and 1000 g). Standard external measurements (including head-body, tail, hind limb and ear), required for identification of rodents, along with the morphological characters were noted for identification (Agrawal 2000). Four standard external measurements were taken with digital vernier caliper (Mitutoyo) and they are

a. Length of head and body: from the tip of nose to the anterior end of anus.
b. Length of tail: from the ventral root of the tail above the anus to the tip of the tail vertebrae excluding the pencil of hairs, if any.
c. Length of hind foot: from the outer surface of the hell to the tip of the longest toe, excluding the claw or nail.
d. Length of ear: from the intertragal notch to the farthest edge of the pinna.

Pregnant females as well as juveniles were excluded from the analysis. The captured animal was released away from the trap line after identification.

3.2.2 Data analysis

Since the reproductive cycles, and hence the body weights, of small mammals were expected to differ with seasons, the variation in body weight with altitude was examined primarily within the two altitude classes, <1800 m and >1800, which were sampled in different seasons (Table 2.2, Section 2.1). Within these broad altitude classes, the altitudes of trap lines were grouped into intervals of varying width in order to obtain sufficient samples for comparison. The body weights were bootstrapped using SPlus (version 6.1, Insightful Corporation, Seattle, USA) to obtain standard errors. Mann-Whitney U test was used to test for significant difference in body weight between two altitude classes, and Kruskal-Wallis test was used when more than two altitude classes were compared. If this test was significant, I used Mann-Whitney U-test for pairwise comparisons. At the inter-species (congeneric) level, comparisons have been made between two species in each of two genera.

3.3 Results

I captured 277 individual murids and shrews in 6417 trap nights, consisting of 13 taxa (11 species including four subspecies) of murids (Order Rodentia, Family Muridae) and five species of ground shrews (Order Soricomorpha, Family Soricidae) and one species of tree shrew (Order Scandentia, Family Tupaiidae, *Tupaia belangeri,* Tree shrew). The capture rate on a trap line varied from 0% to 8.44% (mean = 4.03%, SE = 1.62). Of 19 taxa captured (Table 3.1), only four murids (*Niviventer fulvescens, N. eha, Rattus sikkimensis* and *Mus musculus*) and one shrew (*Soriculus nigrescens*) had more than two captures in two altitude classes. Only these species were therefore used in analysis.

In this study all the species of small mammals captured are referred according to the older classification of mammals (Wilson and Reeder 1993). However, taxonomy of few species has changed according to recent classification of mammals (Wilson and Reeder 2005; Appendix I).

Table 3.1 Body weight and morphometric measurements of murid rodents and shrews captured in Sikkim Himalaya.

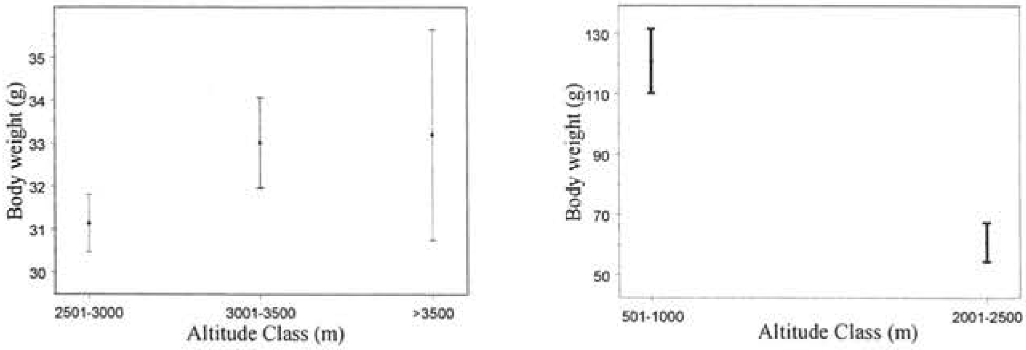
Order: Family species	**Sex**	**n**	**body weight (g)**		**Head-body length (mm)**		**Tail length (mm)**	
			Mean	**SE/ range (low high)**	**Mean**	**SE/ range (low high)**	**Mean**	**SE/ range (low high)**
Rodentia: Muridae								
Rattus turkestanicus	♂	2	69.00	38.0-100.0	138.3	99.5-177.0	161.8	81.2-142.3
Rattus rattus	♂	4	28.75	2.39	101.0	5.7	137.5	11.93
	♀	3	35.00	-	110.3	96.0-120.0	163.3	152.0-177.0
Rattus blanfordi	♂	7	30.29	3.85	114.3	2.33	186.1	5.70
	♀	2	30.00	25.0-35.0	110.1	101.7-118.4	221.5	166.18-276.71
Rattus sikkimensis	♂	17	76.33	11.85	141.9	9.30	154.1	8.82
	♀	6	111.2	14.75	173.1	10.82	186.3	11.24
Rattus nitidus	♂	1	90.00	-	140.6	-	131.7	-
Mus pahari	♂	4	28.75	2.59	91.78	1.23	85.85	2.04
	♀	1	40.00	-	100	-	80.70	-
Mus muscuius	♂	11	12.55	1.25	79.82	3.06	72.27	3.39
	♀	1	5.00	-	60.79	-	55.65	-
Niviventer fulvescens	♂	12	92.89	10.71	158.1	8.51	192.5	4.47
	♀	5	78.74	22.11	143.7	16.07	186.8	11.20
Niviventer niviventer	♂	4	54.50	12.22	124.2	13.45	152.4	18.04
	♀	1	55.00	-	125.6	-	169.8	-
Niviventer eha	♂	74	32.28	0.65	107.9	0.86	173.9	1.59
	♀	3	33.33	25.0-40.0	110.7	104.1-115.0	180.8	177.1-185.7
Pitymys sikkimensis	♂	5	29.40	2.94	101.7	3.64	82.35	26.81
Soricomorpha: Soricidae								
Soriculus nigrescens	♂	10	15.70	0.88	75.99	2.94	41.77	0.81
	♀	21	15.38	0.99	73.04	1.70	40.28	1.00
Soriculus candalus	♀	8	5.11	0.32	54.30	5.65	58.50	5.11
Sorex sp.	♂	1	15.00	-	70.00	-	32.00	-
Crocidura sp.	♂	1	9.77	-	66.00	-	70.00	-
Suncus murinus	♂	1	29.25	-	116.1	-	80.00	-
Scandentia: Tupaiidae								
Tupaia belangeri	♂	3	128.3	120.0-140.0	166.1	153.0-175.0	169.4	163.0-180.0

3.3.1 Altitudinal effect on intra-species body weight

The effect of altitude on body weight within species was examined for *N. eha* (♂), *N. fulvescens* (♂ and ♀), *Rattus sikkimensis* (♂ and ♀), *Mus musculus* (♂) and *Soriculus nigrescens* (♂ and ♀). These species were captured only in two altitude classes, except *N. eha* which was captured in three altitude classes. In male *N. eha,* the body weight in 2501 - 3000 m altitude was slightly smaller than that in the higher altitude classes (Fig. 3.1a) but not significantly so, even between the first (2501 - 3000 m) and the second (3001 - 3500 m) altitude classes.

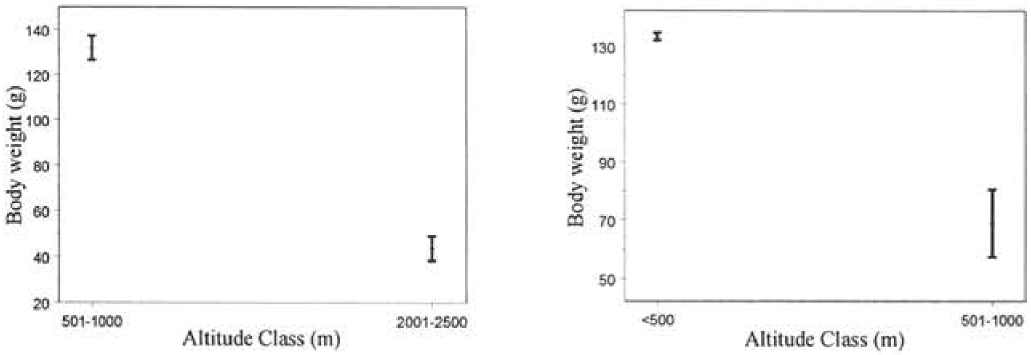
In contrast, body weights of both males (Mann-Whitney U test; $U = 0$, $P = 0.01$, Fig. 3.1b) and females ($U = 0$, $P = 0.07$, Fig. 3.1c) of *N. fulvescens* were lower at the higher altitude class. Four out of five *Rattus* spp were limited to the lower altitudes except for *Rattus sikkimensis*. The mean body weight among male *Rattus sikkimensis* significantly declined in the altitude class 5001 - 1000 m ($U = 2$, $P = 0.01$, Fig. 3.1d) whereas among females, there was no significant decline ($P = 0.65$, Fig. 3.1e). The body weight of male *Mus musculus* was lower but not significant so at the altitude class 501 - 1000 m than <500 m ($U = 3$, $P = 0.18$, Fig. 3.1f).

In *Soriculus nigrescens,* the most common shrew, body weight of males was significantly greater at the higher altitude class ($U = 3$, $P = 0.09$), but in females there was no variation in the altitude classes examined (Fig. 3.2a and b). Thus, at the intra-species level, three murids showed a decline, whereas one murid and a shrew (only male) showed an increase in body weight at the higher altitude.



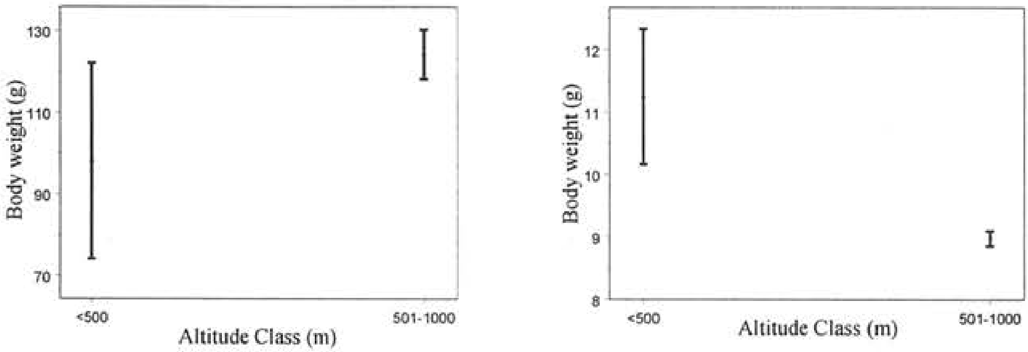
a. *Niviventer eha* (♂)

b. *Niviventer fulvescens* (♂)



c. *Niviventer fulvescens* (♀)

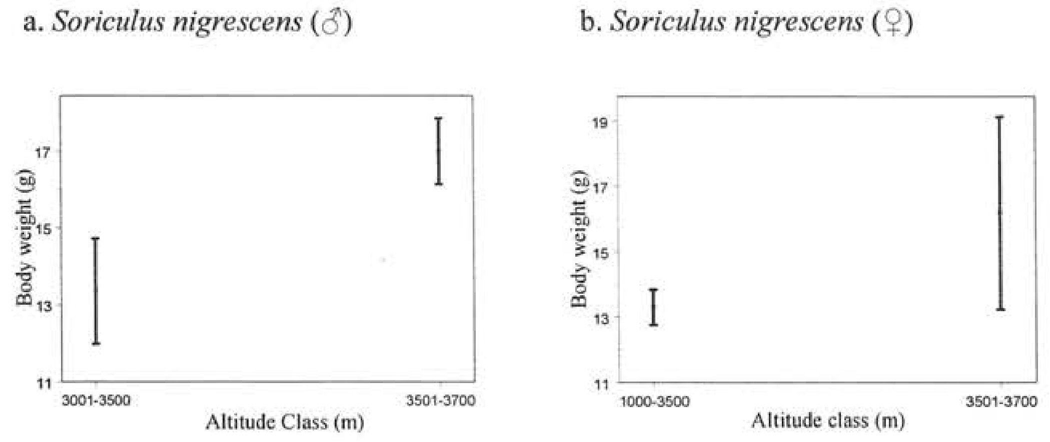
d. *Rattus sikkimensis* (♂)



e. *Rattus sikkimensis* (♀)

f. *Mus musculus* (♂)

Figure 3.1: The body weight of murids in different altitude classes (a) *Niviventer eha* ♂, (b) *N. fulvescens* ♂, (c) *N. fulvescens* ♀, (d) *Rattus sikkimensis* ♂, (e) *R. sikkimensis* ♀ and (f) *Mus musculus* ♂.



a. *Soriculus nigrescens* (♂)

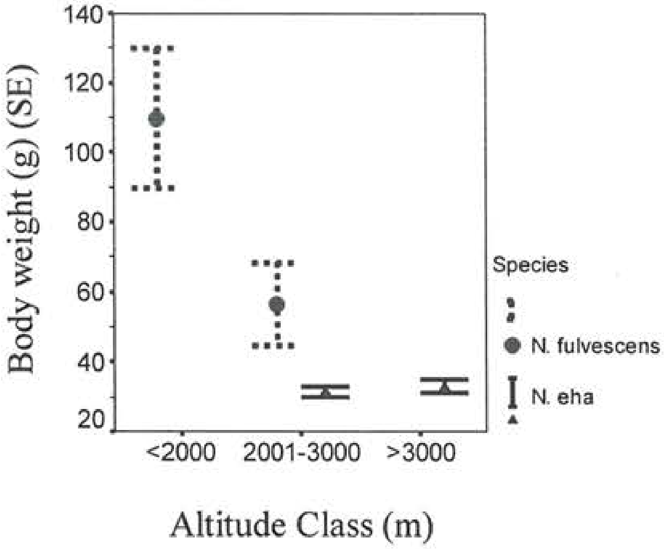
b. *Soriculus nigrescens* (♀)

Figure 3.2: The body weights of (a) male and (b) female *Soriculus nigrescens*, in different altitude intervals.

3.3.2 Altitudinal effect on congeneric body weight variation

Congeneric variation of body weight with altitude was examined among males in *Niviventer* and *Rattus*. *N. fulvescens* occurring in low and mid altitude classes (<2500 m) were heavier than *N. eha* occurring in the higher altitudes (>2500 m) (between altitudes <2000 and 2001 - 3000, U = 0.5, P = 0.01; between altitudes 2001 – 3000 and >3000, U = 775, P = 0.27, Fig. 3.3a). In *Rattus* also the species in the lower altitude was heavier (U = 44, P = 0.01, Fig. 3.3b). *R. sikkimensis* was captured only up to 1000 m altitude, whereas *Rattus blanfordi* was captured above 3000 m. Thus, both the genera (*Niviventer* and *Rattus)* gave a pattern opposite to that predicted by Bergmann's rule.

a. *Niviventer fulvescens & N. eha* (♂)



b. *Rattus blanfordi & R. sikkimensis* (♂)

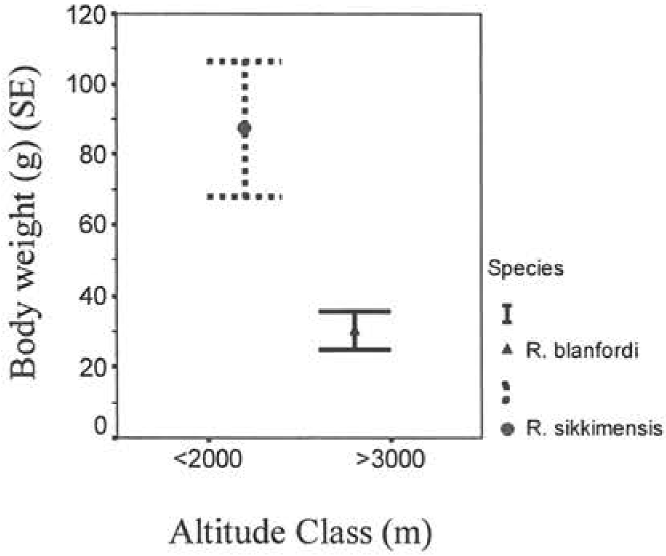


Figure 3.3: The body weights of males of two species the genera *Niviventer* and *Rattus* in different altitude classes.

3.3.3 Effect of altitude on body weight range

As altitude increased, among the murids, *Niviventer* replaced the genera *Rattus* and *Mus*. Different genera of shrews were captured in the low and high altitudinal areas such as *Suncus* and *Tupaia* were captured only in the lower altitude whereas *Sorex* and *Crocidura* were captured in the higher altitudes. *Soriculus* was captured both in the lower and higher altitudes. The number of murid species recorded in each of the six altitude classes varied from two to four. There was a decline in body weight range of murids with increasing altitude, accounting for nearly 73% of the variance in body weight range (Fig. 3.4a), where the body weight range were taken as the difference between the lowest and the highest body weight in each altitude class.

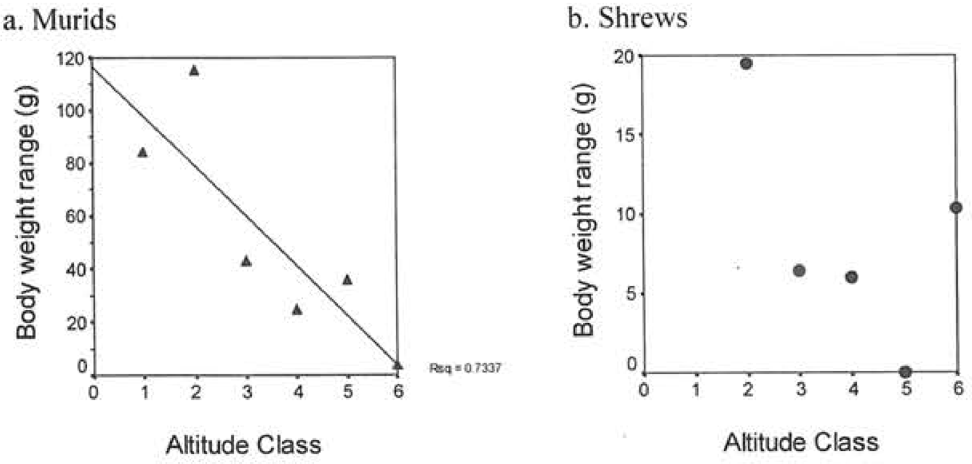


Figure 3.4: The range in body weights of murids and shrews in six altitude classes (1 = <600 m, 2 = 601 - 1200 m, 3 = 1201 - 1800 m, 4 = 1801 - 2400 m, 5 = 2401 - 3000 m and 6 = >3000m).

The highest body weight range of murids was observed in altitude class between 601 m and 1200 m, and the lowest in the highest altitude class of >3000 m. Among shrews also the highest body weight range was observed between 601 m and 1200 m, but the lowest body weight range was in between 2401 m and 3000 m (Fig. 3.4b). However, there was no clear pattern in the distribution of body weight range in the case of shrews.

3.4 Discussion

3.4.1 Body weight and altitude

Among males, three out of four murid species that I examined showed a significant reduction in body weight with altitude, against the Bergmann's rule, while one did not show a clear pattern. Two murid species (*Niviventer fulvescens* and *Rattus sikkimensis*) decreased in body weight in the higher altitude class, showing opposing trends to the Bergmann's rule, but only the males of both species showed showing a significant decline. It is possible that the body weight of females may be influenced by factors such as reproductive status. The only murid species (*N. eha)* that did not show any change occur in the higher altitudes (>2500 m). A seasonal synchrony in population cycles of rodents have been reported from the high altitudes of Western Ghats (Shanker and Sukumar 1999). However, in this study sampling in the higher altitudes were restricted during the same season.

The only species of male ground shrew examined showed an increase of body weight with altitude but was not significant. Thus at intra-specific level, 3 out of 4 murid species did not follow the Bergmann's rule, when examined, in terms of probability and 95% confidence interval. Congeneric species of both *Niviventer* and *Rattus* also showed the same pattern. However, Smith *et al*. (1995) found that within *Neotoma cinerea* (bushy-tailed woodrat) the body weight followed the Bergmann's rule by decreasing with increasing temperature over a large geographical area. Among congeneric species, Smith *et al*. (2004) found no significant relationship of body sizes for mammals under ~18 gm.

Ashton *et al*. (2000) compiled data on the response of 17 species of rodents of the family Cricetidae, out of which all five *Microtus* species (Vole, Subfamily Arvicolinae) showed a decline in body weight with increasing latitude, while other 12 species (belonging to three subfamilies) showed an increase (Table 3.1). One *Rattus sp.* also increased in body weight with latitude. However, the response of these species to altitude is not known, although responses similar to that to latitude are expected (Stevens 1992). In contrast, in Taylor *et al.* (1985), which was not included in the review bv Ashton *et al.* (2000) review, out of ten species of the family Muridae, body weights of four species remained unchanged and six species showed a decline in body weight with altitude (Table 3.2). In this study also, I found a decline in body weight with altitude in three out of four species examined, while the evidence in remaining one species (*N. eha*) examined was ambiguous. The only ground shrew (*Soriculus nigrescens*) examined showed an increase in body weight along with altitude.

In large mammals, heat insulation can be achieved by increasing the density of the fur, whereas it is easier for small mammals to change its body size (Steudel *et al.* 1994). Large and small mammals may be differently adapted, for example, altitudinal migrations of these two groups can differ greatly in terms of range. But the small mammal's ability to avoid climatic extremes and its small size may also be the reason for the lack of change in body sizes (Jansen 1929; in Taylor *et al.* 1985), for instance, living in burrows where temperatures are higher. While Ashton *et al.* (2000) could not establish any relationship between body size and temperature among small mammals, Freckleton *et al.* (2003) added more species specific data to Ashton *et al.* (2000) and demonstrated that larger species of mammals follow the rule more than the smaller ones. When data were compiled, a taxonomic basis for the response of body weight to altitude emerged (Table 3.2).

Table 3.2 Murids of different species and genera showing their relationship (positive, + and negative, -) of body size with latitude and altitude.
(*Ashton *et al.* 2000; #Taylor *et al.* 1985; @ this study; 0 = no change).

Family/Species	**Study area**	**Latitude**		**Altitude**	
		+	-	+	-
Family: Cricetidae					
*Microtus longicaudatus**	New Mexico		1		
M. mexicanus *	New Mexico		1		
M. montanus *	New Mexico		1		
M. montebelli *	Japan		1		
M. pennsylvanicus *	British Columbia		1		
Neotoma albigula *	Arizona, US	1			
N. cinerea *	California, US	1			
N. floridana *	Las Vegas, US	1			
N. lepida *	California, US	1			
N. magister *	Eastern US	1			
Peromyscus californicus *	Las Vegas, US	1			
P. crinitus *	Las Vegas, US	1			
P. eremicus *	Las Vegas, US	1			
P. leucopus *	New, England	1			
P. maniculatus *	Las Vegas, US	1			
Beamys hindei *		1			
Sigmodon hispidus *		1			
Family Muridae					
Rattus rattus *	New Zealand	1			
R. verecundus #	New Guinea				1
R. richardsoni #	New Guinea				1
R. mordax #	New Guinea				1
R. praetor #	New Guinea				1
R. novaeguineae #	New Guinea				1
R. sordidus #	New Guinea				1
R. sikkimensis @	Sikkim, India				1
R. niobe #	New Guinea			0	0
R. steini #	New Guinea			0	0
R. leucopus #	New Guinea			0	0
R. giluwensis #	New Guinea			0	0
Mus musculus @	Sikkim, India				1
N. fulvescens @	Sikkim, India				1
Niviventer eha @	Sikkim, India			0	0

Twelve out of seventeen species of Cricetidae (a temperate family), except for the *Microtus* spp (subfamily Arvicolinae), increased in body size with increasing altitude and 9 out of 11 species of Muridae (tropical family) decreased. A pattern seems to appear where most temperate families follow the Bergmann's rule, whereas most of the tropical families do not. Among the 12 species of *Rattus*, only one species (*R. rattus)* showed a trend opposite to the other six congeneric species, probably because it was reported from a temperate area; and the remaining five species did not show any pattern. An increase in body weight with altitude was found even among the ground shrews.

3.4.2 Body weight range and altitude

In this study, murid community showed a steep decrease in body weight range with increasing altitude, whereas among shrews the decrease was not clear, probably due to inadequate capture of some species. Compared to the latitudinal range, studies of altitudinal variation in body size are few.

Average body sizes of species in assemblages decline towards lower latitudes (Stevens 1992). Smaller species also occur in a narrow range of latitudes (Brown and Maurer 1989). Similarly, smaller sized species also may have a narrow range of altitude. There are no published studies on changes in body size range with respect to altitude. One factor which may play a role in the changes in body sizes is competition. However, selection pressures to avoid competition could also lead to divergent body sizes. But, ecological conditions of the trap lines from a very wide altitudinal range in Sikkim may not be similar. Species richness may unlikely be a factor for the decline in body weight range in the higher altitudes, because species richness of small mammals is highest in the mid altitudes (Section 4.3). Since the body weight among murids decreased with an increase in altitude, the same selection pressures might be responsible for the smaller body weight range in the higher altitudes.

3.5 Summary

Greater body weight with increasing latitude is widely accepted as the reformulation of Bergmann's rule. Altitude is often considered an equivalent to latitude and, therefore, body weight should increase with increasing altitude. Conformity with this rule is highly variable in small mammals. I tested this hypothesis at both intra and inter-species level in four species of murid rodents and one ground shrew in Sikkim Himalaya. I live trapped murids and shrews along trap lines laid in an altitude range of 230 m to 3800 m. A total of 277 individuals of 13 taxa (11 species including four subspecies) of murids and 6 species of shrews were recorded in 6417 trap-nights. The adult males of three murids species, (*Niviventer fulvescens*, *Rattus sikkimensis* and *Mus musculus)* showed a decline in body weight from low to high altitude, while *N. eha* did not show any change. A decrease in body weight with altitude was also seen among two congenerics (*Niviventer* and *Rattus)*. However, the ground shrew *(Soriculus nigrescens*) showed an increase in body weight with altitude. Data from this as well as other published studies show that while most rodents of the family Cricetidae from the temperate region follow the Bergmann's rule, those of the family Muridae from the tropics do not. Small mammal communities also have a narrower body weight range in higher altitude.

CHAPTER 4

COMMUNITY STRUCTURE OF SMALL MAMMALS IN AN ALTITUDINAL GRADIENT

4.1 Introduction

Altitudinal gradient in species richness has been a matter of much debate, especially in the last few years. A monotonic decrease in species richness with increasing altitude, reported first among tropical birds (Terborgh 1977), was a widely accepted pattern for many years until more studies on altitudinal gradients followed. Subsequent evidence from research on several taxa including palms (Kessler 2000), vascular plants (Grytnes 2003), ferns (Bhattarai *et al.* 2004), trees (Bhattarai and Veetas 2005), birds (Terborgh 1977; Rahbek 1997) and small mammals (Brown 2001; Li *et al.* 2003; McCain 2005) indicated a humped or unimodal distribution of species richness with altitude. In his review, Rahbek (1995) found more than 50% of studies on altitudinal gradient exhibiting higher species richness at mid-altitudes. Several hypotheses have been advanced to explain this pattern. These include a mid-altitude peak in productivity (Rahbek 1997; Brown 2001), rescue effect (Brown and Kodric-Brown 1977), mass effect (Shmida and Wilson 1985) and climate and habitat heterogeneity (Brown 2001). Biological and historical processes acting on individual species and clades can also produce spatial patterns in species richness (Colwell *et al.* 2004). It is likely that all these factors in combination influence the species richness pattern in an altitude gradient (Whittaker *et al.* 2001; Jetz and Rahbek 2002; Oommen and Shanker 2005).

The widely reported mid-altitude peak in species richness can merely be an artefact of random distribution of species when their ranges are geometrically constrained, called the mid-domain effect or MDE (Colwell and Hurtt 1994; Colwell and Lees 2000; Jetz and Rahbek 2001). MDE models are similar to null models where the assumptions are that the biological gradient does not have any effect on the patterns of species richness. Therefore, even in the absence of any influence of biological gradient, the MDE models show maximum species overlapping their ranges in the middle altitudes.

Colwell and Lees (2000) referred to four studies (Rahbek 1997; Pineda and Caswell 1998; Willig and Lyons 1998; Lees *et al.* 1999) as strongly confirming the mid-domain effect in shaping geographic patterns of richness, when evaluated against biological and climatic hypotheses. Subsequently there have been many studies that have conformed to these results (Kessler 2001; Jetz and Rahbek 2002; McCain 2003; Romdal *et al.* 2005). However, there are other studies where altitudinal variation in species diversity was not explained by the MDE (Diniz-Filho *et al.* 2002; Laurie and Silander 2002; McCain 2005, 2007; Currie and Kerr 2007). It has been observed that the MDE is less likely to predict the spatial patterns of communities with species that have narrow altitudinal ranges than those with broader ranges (Dunn *et al.* 2006). Thus, if the ranges and the spatial analysis are both large, the MDE can be expected to explain accurately observed patterns of species richness (Dunn *et al.* 2006).

Small mammals, particularly murid rodents and ground shrews, have been a favourite taxon of research in this respect, primarily because of their high species richness. Higher species richness in small mammal communities have been reported at middle altitudes from Philippines (Heaney 2001), Borneo (Md. Nor 2001), Southern Mexico (Sanchez-Cordero 2001), Malaysia (Rickart 2001) and China (Li *et* *al*. 2003). Whether the patterns observed are due to the MDE or in spite of it has been a matter of debate recently, as evidenced by a special issue of *Global Ecology and Biogeography* dedicated to this issue (Volume 10, No. 1). McCain (2004) showed that geometric constraints did influence diversity patterns in small mammals, but climatic conditions were also correlated with species richness pattern.

In this chapter, I test the hypothesis that the community structure of small mammals changes with altitude. More specifically, I first examine whether the observed species richness pattern conforms to the predictions made by the MDE with respect to altitude. Since observed species richness is very often an underestimate of true species richness, I examine the pattern of estimated species richness in an increasing altitude gradient. I also investigate the pattern of altitudinal variation in species composition and abundance of the small mammal community.

4.2 Methods

4.2.1 Sampling

Data on small mammal community was collected through live trapping using Sherman traps s*et al*ong 28 trap lines in altitudinal range of 280 m to 3700 m, divided into four altitudinal zones and referred to as Zone I, II, III, and IV (Section 2.3.1). Traps were set in six to eight trap lines, in each of the four zones, at a distance of five m on alternate sides. The trapping period lasted for three to five days for each trap line, and the traps were checked every morning. Animals captured in the traps were measured, identified depending on the morphological characters as well as the external measurements, and then were released away from the trap lines.

4.2.2 Data analysis

4.2.2.1 Estimation of species richness

Since the observed species richness often underestimates the true species richness of a community, I attempted to estimate the true species richness in the four altitudinal zones using various estimators (Colwell and Coddington 1994) that take into account the presence of species untrapped by the observer. Considering many singletons in the data, the first order Jackknife estimator was considered to be most suitable. This is given by: $S_{jack1} = S_{obs} + Q_1 (n-1)/n$, where, S_{jack1} is the estimated species richness, S_{obs} is the observed species richness, Q_1 is the number of species occurring as single sample i.e. the number of singletons, and n represents the total number of samples. Software *EstimateS,* (version 6b, Colwell 2004), was used to calculate this estimator. The rarefaction curves also generated from *EstimatesS* were observed graphically to examine the species richness.

4.2.2.2 Mid-domain effect

The mid-domain effect based null model (Colwell 2004) was used to examine the influence of the MDE on the patterns of species richness in an altitudinal gradient. Based on the observed extent and midpoint of the altitudinal ranges of 17 species, the expected species richness was generated in the five altitudinal domains within the range of 280 m to 3700 m using the software Mid Domain Null (McCain 2004). The altitudinal range of species that were captured only at a single trap line or more than one trap line but in the same altitude was taken to be 50 m. The simulations were iterated 100 times without replacement. The observed pattern of species richness was graphically compared with the pattern generated from the null model.

4.2.2.3 Abundance and composition

I divided the sampled area into four altitudinal zones in order to compare the variation in abundance and composition with altitude (Table 4.2). Capture rate percentage or capture per hundred traplines was taken as an index of species abundance, calculated for each trap line as, $C_a = (N_a / T_a D) \times 100$, where, N_a is the total number of animals captured in the trap line a, T_a is the total number of traps set in number of D days (Cunningham and Moors 1983).

The capture rate of small mammals being low, I used the resampling method of bootstrapping with software S-Plus (version 6.1, Insightful Corporation, Seattle, USA). I used Sorensen's index (Looman and Campbell 1960) to estimate species overlap between altitudinal zones, using software *EstimateS* (version 6b, Colwell 2004). Sorensen's index is represented by the equation, $I_{Sor} = 2C/(A+B)$ where, A and B are the species number in two samples A and B respectively, and C is the number of species shared by both the samples (Sorensen 1948; in Looman and Campbell 1960). The Kruskal-Wallis test was used to test for significance of differences in the capture rate among altitude zones.

I also estimated species turnover between all pairs of altitude zones, as 1-Sorensen's index, and the evenness index for each zone. The species evenness was calculated as, $E = H' / H_{max} = [-\Sigma p_i \ln(p_i)]/\ln S$ where, H' is the Shannon-Wiener index (which measures diversity in categorical data, Shannon 1948), p_i is the proportion of ith species from total species S and H_{max} is equal to $\ln S$.

4.3 Results

4.3.1 Observed species richness

A total of 19 taxa were captured in 6417 trap nights from 28 trap lines, which included 13 taxa (11 species) of murids (Order Rodentia, Family Muridae) from four genera, five species of ground shrews (Order Soricomorpha, Family Soricidae) from four genera, and one species of tree shrew (*Tupaia belangeri*, Order Scandentia, Family Tupaiidae) (Table 4.1).

Table 4.1 Small mammal taxa captured in the North and South Districts of Sikkim.

Order	Family	Species	Individuals
Rodentia	Muridae	*Rattus turkestanicus*	2
		Rattus rattus tistae	1
		Rattus rattus brunneusculus	6
		Rattus sikkimensis	26
		Rattus nitidus	1
		Rattus blanfordi	11
		Mus pahari	6
		Mus musculus castaneus	9
		Mus musculus homourus	3
		Niviventer fulvescens	18
		Niviventer niviventer	12
		Niviventer eha	79
		Pitymys sikkimensis	5
Soricomorpha	Soricidae	*Soriculus nigrescens*	80
		Soriculus caudatus	12
		Suncus murinus	1
		Sorex sp.	1
		Crocidura sp.	1
Scandentia	Tupaiidae	*Tupaia belangeri*	3

Among murids, *Rattus* was the most speciose (5 species, 6 taxa including two subspecies) followed by *Niviventer* and *Mus* (2 species, 3 taxa including two subspecies) (Table 4.1). Among shrews, two species of the genus *Soriculus* and one species each of other genera *Crocidura, Suncus,* and *Sorex* and one species of tree were captured (Table 4.1). The total number of taxa including subspecies captured in each of the four zones varied from 6 to 9 (Table 4.2).

Table 4.2 Small mammals trapped in the four altitudinal zones ranging from 280 m to 3700 m.

Zone	**Vegetation type (Alt. m)**	**Trap line**	**Indivi-duals**	**No. of Obs. spp (Exp. spp)**	**Species**
I	Tropical semi deciduous (<900)	6	37	6 (8)	*Niviventer fulvescens, Rattus nitidus, R. sikkimensis, Mus muscular castaneus, Crocidura* sp. and *Tupaia belangeri.*
I	Tropical moist broadleaf (<900 – 1800)	8	54	6; 7 taxa (11 taxa)	*Niviventer fulvescens, Rattus sikkimensis, Mus musculus castaneus, M. m. homourus, Soriculus nigrescens, S. caudatus* and *Suncus murinus.*
III	Temperate broadleaf (1800 – 2800)	8	85	8; 9 taxa (13 taxa)	*Niviventer fulvescens, N. niviventer, N. eha, Rattus turkestanicus, R. rattus tistae, R. r. brunneusculus, Mus pahari, Soriculus nigrescens* and *S. caudatus.*
IV	Coniferous (2800 – 3700)	6	101	6 (7)	*Niviventer eha, Rattus blanfordi, Pitymys sikkimensis, Soriculus nigrescens, S. caudatus* and *Sorex* sp.

(* Obs. - Observed and Exp. - Expected species number)

4.3.2 Estimated species richness

Species richness was estimated for each of four altitude zones separately. The sample sizes for the four zones are given in Table 4.2. The abundance distribution of the captured species for all altitude zones together exhibited Poisson distribution (Fig. 4.1a). First order Jackknife estimator estimated a total of 28 (± 1.77, SE) species collectively for all four zones. The rarefaction curve and the estimated species richness curve did not plateau within the sampled data (Fig. 4.1b).

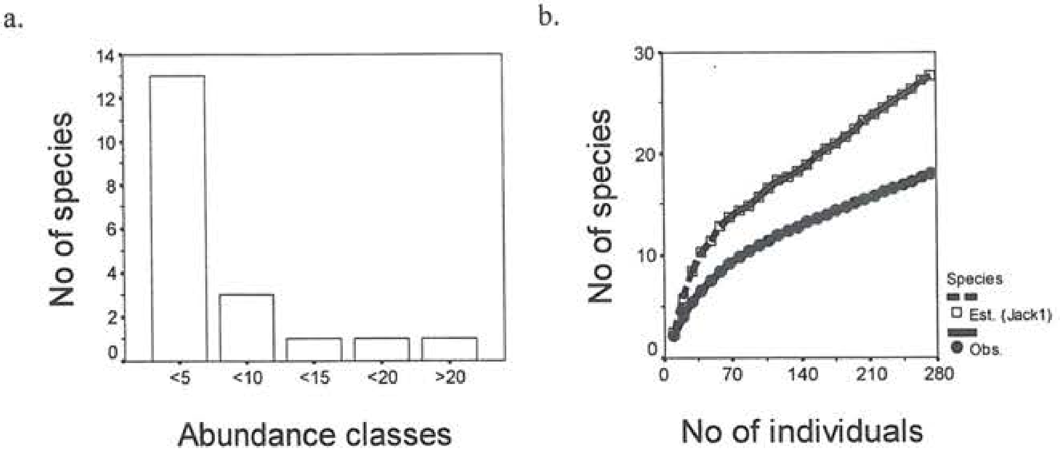


Figure 4.1: (a) Abundance distribution for all 18 taxa, with 277 individuals; (b) Rarefaction curve for observed species richness, and estimated species richness (Jackknife-1 estimator) for the entire study area.

When observed within each altitude zone, the same pattern of continuous rise in the rarefaction curve as well as estimated species richness curve was observed in Zones I and II, where fewer individuals were captured (37 and 54, respectively, Fig. 4.2). However, in Zones III and IV the number of individuals captured was higher (85 and 101, respectively), and both the rarefaction and estimated species richness curves reached an asymptote (Fig. 4.2).

The estimated species richness for Zones I to IV were 8, 11, 13 and 7, respectively, showing a clear mid altitude peak in Zone II and III (Fig. 4.3). Both the observed and the estimated species richness were highest in Zone III.

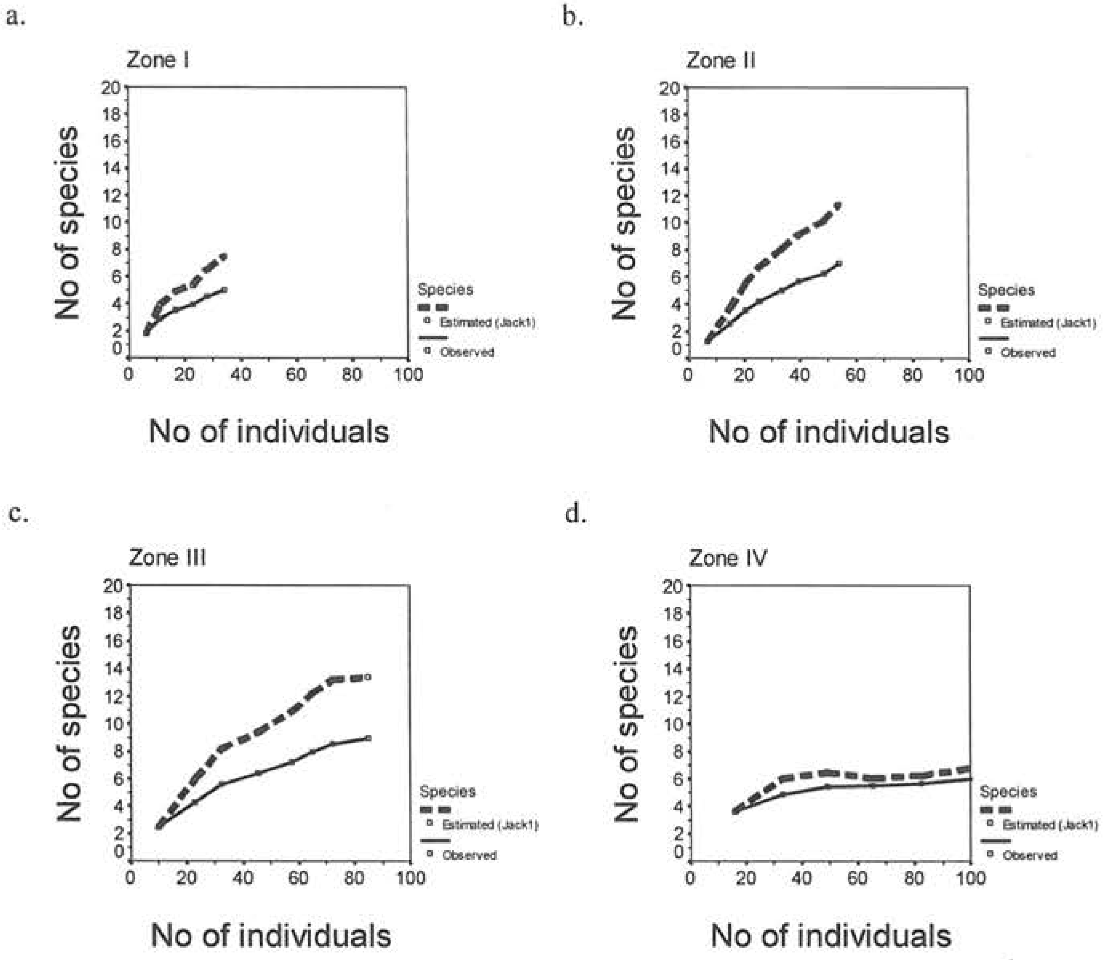


Figure 4.2: Rarefaction curve of observed species richness, and estimated species richness curve (Jackknife 1 estimator) in four altitude zones; (a) I (<900 m), (b) II (900 m to 1800 m), (c) III (1800 m to 2800 m) and (d) IV (2800 m to 3800 m).

4.3.3 Pattern of species richness with altitudinal gradient

The altitudinal ranges of all 17 species of small mammals captured in Sikkim are given in Fig. 4.4. If a species was captured in two discontiguous trap lines, it was inferred to occur in the altitudes in between. Ten species were captured from only one trap line. *Soriculus nigrescens* had the largest altitudinal range of about 2700 m, followed by *S. caudatus* (2000 m) and *Niviventer fulvescens* (1800 m).

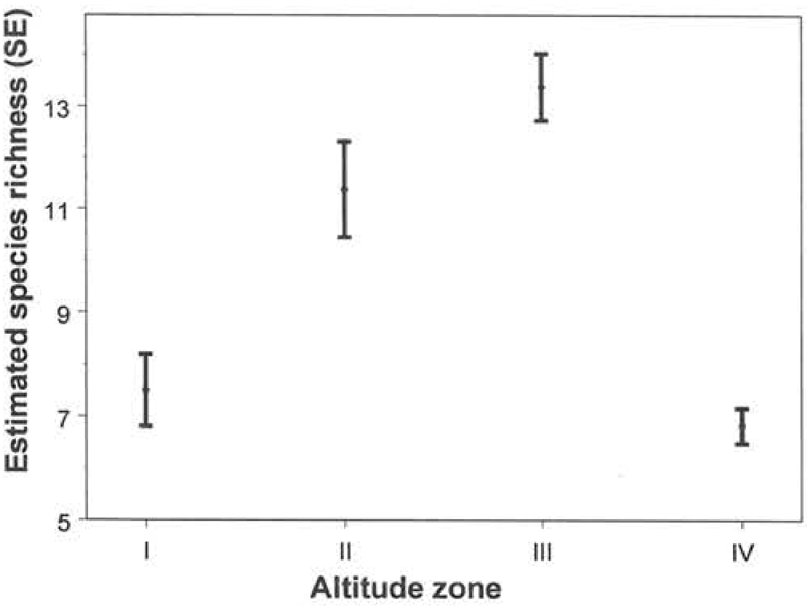


Figure 4.3: Estimated species richness of small mammals for four altitudinal zones (I <900, II >900 to <1800, III >1800 to <2800 and IV >2800 to <3800) along with their standard error.

The altitudinal range and midpoints of all the 17 species were used in the Mid Domain Null program to generate the species richness within the total altitudinal range of their capture. The generated empirical species richness in five altitude domains fell within the 95% CI obtained from the null model (Fig. 4.5). The empirical species richness curve was more or less flat in altitudes ranging from 280 m to 3700 m. The altitude gradient generated from the MDE-based null model showed a lower species richness at mid-altitudes.

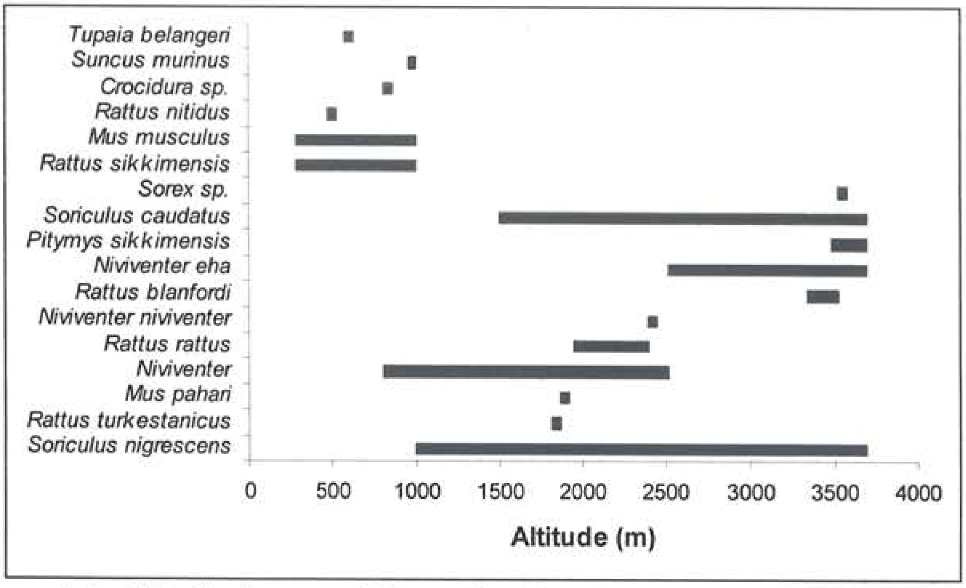


Figure 4.4: Altitudinal range of 17 species of murids and shrews captured between 280 m and 3700 m along the Teesta River Basin.

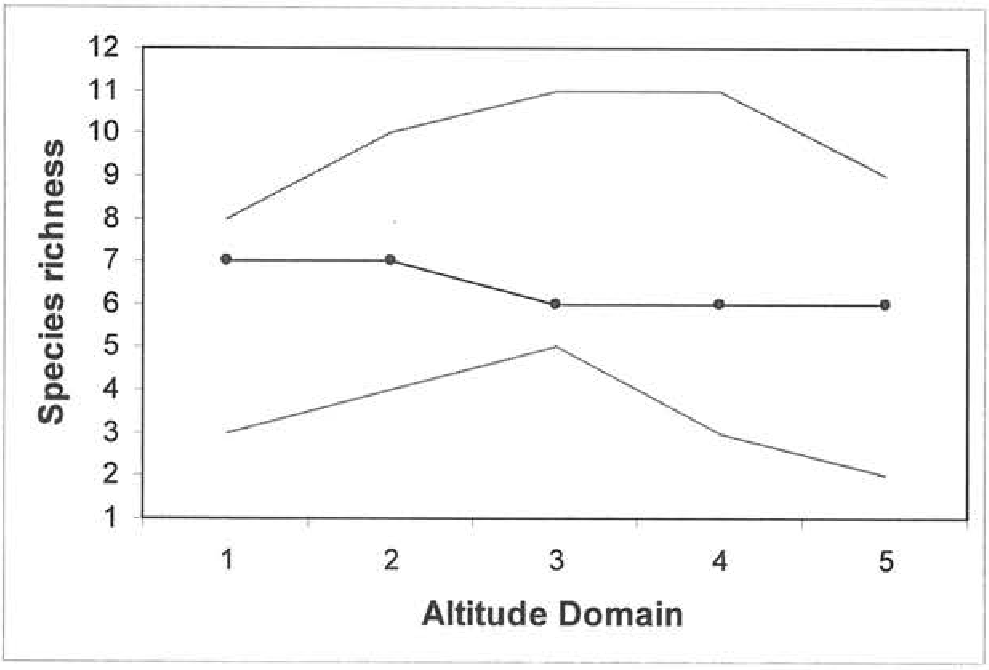


Figure 4.5: A comparison of the empirical species richness with 95% confidence intervals obtained from null model based on mid domain effect. The altitudinal domains ranges from 280 m to 3700 m.

4.3.4 Composition and abundance

Murid rodents comprised of 13 taxa with 11 species and shrews consisted of five species of ground shrews and one species of tree shrew (Table 4.1). The most dominant species were *Rattus sikkimensis* (56.76% of all captures) in Zone I, *Soriculus nigrescens* (68.52% of all captures) in Zone II, and *Niviventer eha* in Zones III and IV (36.47% and 47.52% of all captures, respectively). Among the widespread species were *Niviventer fulvescens* occurring in Zones I, II and III, and *Soriculus nigrescens* and *S. caudatus* occurring in zones II, III and IV (Fig. 4.4). In order to examine the compositional changes among small mammals with altitude, the relative capture rate of shrews were plotted with increasing altitude classes. The results failed to show clear pattern for the shrews (Fig. 4.6a) and the same was true for murids considering the relative capture rate. The species equitability varied from 0.28 in Zone II to 0.41 in Zone III. Zones I and IV had species equitability of 0.30 to 0.29 respectively. The capture rate was highly variable among the 28 trap lines, ranging from 0% to as high as 19.49% with an overall mean of 5.09% (± 0.97, Table 4.3).

The total capture rate differed significantly among the four altitudinal zones (Kruskal-Wallis Test; $\chi^2 = 8.437$, df = 3, P = 0.038), and increased with altitude (Fig. 4.6b). This increase in capture rate with altitude was evident in murids as well as shrews (Fig. 4.6c and d), the former showing a marked difference between the lower two zones and higher two zones.

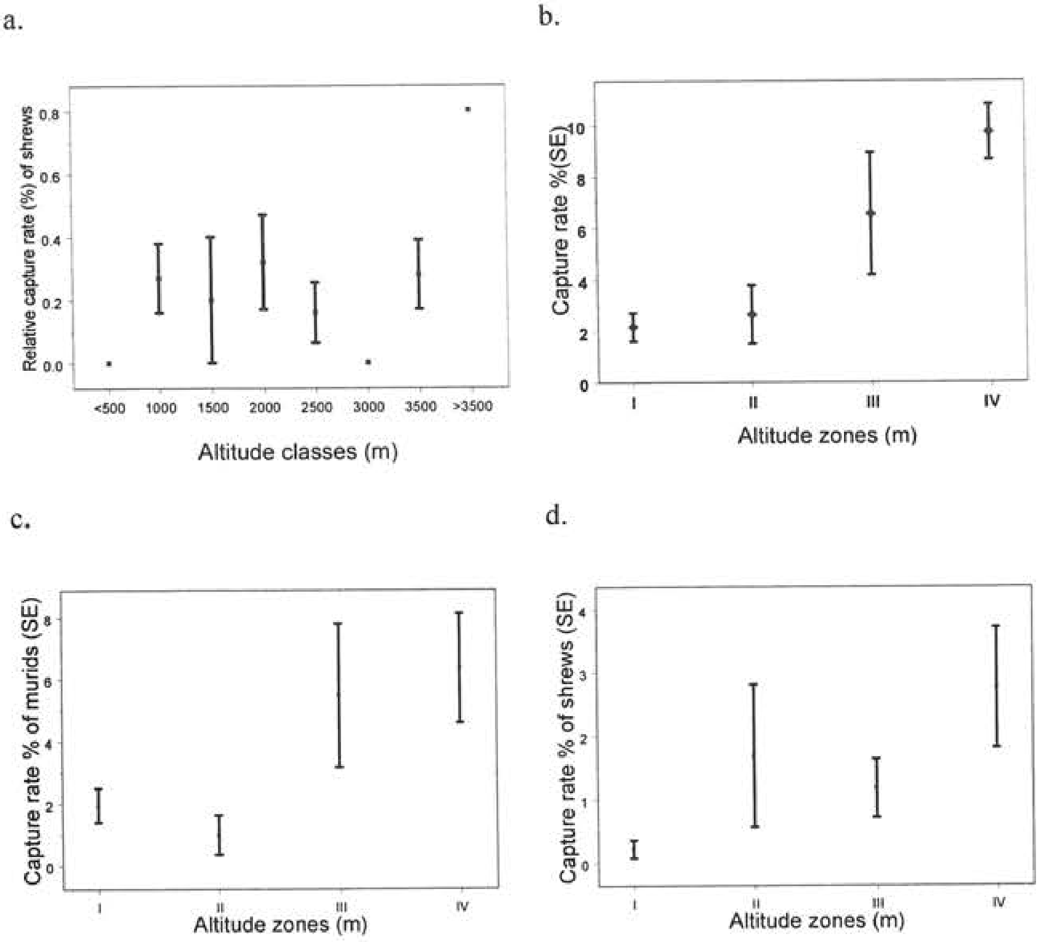


Figure 4.6: (a) Relative capture rate of shrews in eight altitude classes with 500 m interval, capture rates of small mammals (b) murids and shrews, (c) murids and (d) shrews in four altitude zones (I <900 , II >900 to <1800, III >1800 to <2800 and IV >2800 to <3800).

4.3.5 Species overlap and turnover

Species overlap among trap lines was highest in Zone IV followed by Zones I and III (Fig. 4.7a). Trap lines in these zones showed relatively low species overlap with trap lines in the other zones. Thus, the small mammal communities within these zones had different species assemblages. Species overlap in the trap lines within Zone II was the lowest whereas that of Zone IV was the highest (Fig. 4.7b).

Table 4.3 Capture rate and taxa of murid rodents and shrews captured in 28 trap lines.

Alt. (m)	Trap line	Trap night	Capture rate (%)	No. of spp	Species
280	14	197	4.06	2	*Rattus sikkimensis* and *Mus musculus castaneus*
370	16	397	0.5	2	*Rattus sikkimensis* and *Mus musculus. castaneus*
480	13	200	1.0	2	*Rattus nitidus* and *Mus musculus castaneus*
600	17	399	1.5	1	*Rattus sikkimensis*
620	18	392	3.83	3	*Rattus sikkimensis, Mus musculus castaneus* and *Tupaia belangeri*
810	15	188	2.13	2	*Niviventer fulvescens* and *Crocidura sp.*
960	19	192	5.73	4	*Rattus sikkimensis, Niviventer fulvescens, Mus musculus homourus* and *Suncus murinus*
1000	27	158	2.43	2	*Rattus sikkimensis* and *Soriculus nigrescens*
1010	28	120	4.17	2	*Mus musculus. castaneus* and *Soriculus.nigrescens*
1190	22	198	0	0	
1200	20	200	0	0	
1250	21	200	0	0	
1330	23	197	0	0	
1500	24	376	9.04	2	*Soriculus nigrescens* and *S. caudatus*
1820	6	299	1.36	2	*Rattus rattus tistae* and *Soriculus nigrescens*
1920	2	118	6.78	3	*Mus pahari, Niviventer fulvescens* and *Soriculus nigrescens*
1950	4	250	0.4	1	*Soriculus nigrescens*
2100	5	316	0.95	2	*Soriculus nigrescens*
2210	3	341	0.88	1	*Soriculus nigrescens*
2400	1	118	19.49	4	*Rattus rattus brunneusculus, Niviventer fulvescens, Niviventer niviventer* and *Soriculus nigrescens,*
2520	25	225	14.2	4	*Niviventer fulvescens, Niviventer eha, Soriculus nigrescens* and *Soriculus caudatus*
2630	26	119	9.24	3	*Niviventer eha, Soriculus nigrescens* and *Soriculus caudatus*
3340	9	116	12.07	3	*Rattus blanfordi, Niviventer eha* and *S. caudatus*
3460	10	119	11.76	1	*Niviventer eha*
3480	8	199	11.56	5	*Rattus blanfordi, Niviventer eha, Pitymys sikkimensis, Soriculus nigrescens* and *Soriculus caudatus*
3480	12	234	8.55	4	*Rattus blanfordi, Niviventer eha, Pitymys sikkimensis* and *Soriculus nigrescens*
3520	7	350	5.72	5	*Rattus blanfordi, Niviventer eha, Soriculus nigrescens, Soriculus caudatus* and *Sorex* sp.
3700	11	199	5.03	4	*Niviventer eha, Pitymys sikkimensis, Soriculus. nigrescens* and *Soriculus caudatus*

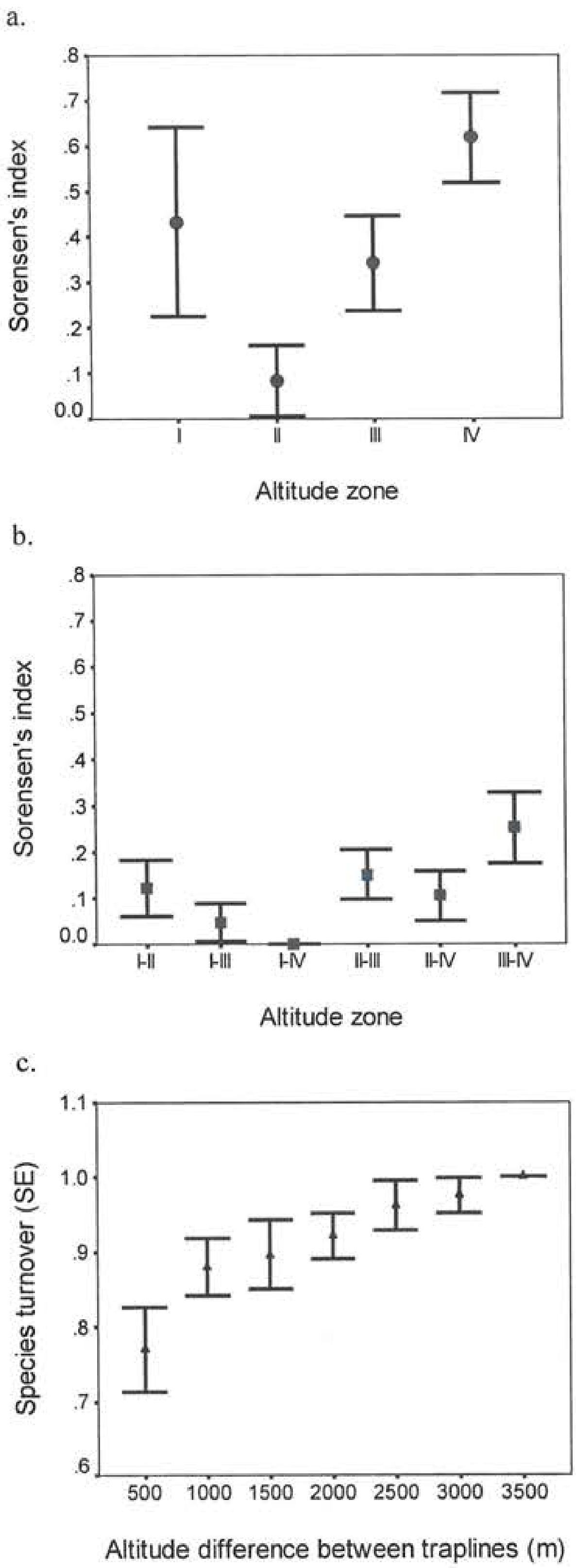


Figure 4.7: (a) Sorensen's index showing species overlap within (zones I to IV) and (b) between four altitude zones (Zones I <900, II >900 to <1800, III >1800 to <2800 and IV >2800 to <3800. (c) Species turnover across altitudinal in 28 trap lines.

4.4 Discussion

4.4.1 Species richness

The mid-domain effect cannot be ignored as it occurs due to hard boundaries on the range sizes of the species and thus, the empirical species richness should always be compared with the null model (Colwell *et al.* 2004, McCain 2004). In this study, the mid domain model showed the empirical species richness within the upper and lower confidence interval limits though it did not show a distinct mid altitude peak. The probable reason for the absence of any peak in the empirical species richness in the mid domain analysis could be insufficient data. Species richness distribution from both empirical data, based on observed altitudinal range of species, and from the MDE null model are both less likely to show mid-elevation peak when species have short distribution ranges (Dunn *et al.* 2006). In this study, up to ten species were captured only from one trap line, and only few from many trap lines. Thus insufficient data on altitudinal distribution of species could be one reason for the lack of a mid-elevation peak in the empirical data and in the MDE null model. Secondary data could not be used due to the absence of any other study from Teesta basin.

In contrast, both the observed and estimated species richness showed a mid altitude peak similar to several other studies in Phillippines (Heaney *et al.* 1989), China (Li *et al.* 2003), Costa Rica (McCain 2004) and compiled data from many areas (McCain 2005, 2006, 2007). The peak diversity of plants, and a high rainfall and humidity in the mid altitudes have been the basis for the productivity hypothesis on the mid altitude peaks in species richness (Rahbek 1997; Brown 2001; Lomolino 2001). It would be difficult for any species to tolerate extreme range of climatic variation along an altitudinal gradient, thus species are distributed with specific altitudinal range with few overlaps in a gradient (Brown 2001). High productivity in the overlapping ranges will lead to higher species richness in these transition zones, and has been observed in an intermediate altitude between two adjacent species-rich small mammal communities (Md. Nor 2001). However, McCain (2004) found lower species richness at the transition of lower montane forest and premontane rain forest compared to the middle of premontane rain forest where she recorded the highest species richness. However, in this study, the highest species richness was recorded at the transition areas, from the tropical broadleaf forest to temperate broad leaf forest, in Zones II and III. The estimated species richness was also higher in the Zones II and III, between 900 m and 2800 m. Therefore, the middle peak of observed and estimated species richness in altitudes could be due to the transition of two vegetation types which occur due to the steep altitude gradient causing a drastic change in vegetation.

4.4.2 Species composition and abundance

In the mid-altitudes (Zone II and Zone III), species overlap was lower than the higher zones (Zones III and IV). However, species turnover increased steadily with the increasing altitudinal difference. Community turnover rates have been observed to significantly increase with altitudinal difference even among bird communities from the tropics (Rahbek 1997; Raman *et al.* 2005). Both the studies found a distinct community composition between the lowest and the highest altitudes. In this study also, the community composition were distinctly different in the lowest and the highest altitude, with lowest species overlap between altitudinal zones I and IV and highest between zones III and IV.

Historical events like dispersal, extinction and speciation can influence the composition of a community, as well as past environmental changes that are responsible for generation of patterns in a community (Brown 2001). Structural vegetation such as, tree species composition has also been found to be correlated to community of birds in northeast India (Raman *et al.* 1998). In an altitude gradient, environment variables closely related to altitude, such as temperature and other factors, can vary and influence the composition as well as abundance of the community (Brown 2001). Therefore, it would be difficult to single out one factor responsible for various patterns.

The relative abundance of small mammals, estimated as capture rates, was evaluated in different altitude zones. This measure of relative abundance can provide patterns proportional to those derived from estimates of absolute abundance (Hopkins and Kennedy 2004). In this study, the relative abundance of small mammals increased significantly with the increasing altitude with largest capture occurring in the highest altitude zone sampled. This pattern of higher relative abundance at the higher altitudes was consistent with previous studies on small mammals (Rickart *et al.* 1991; Heaney 2001). But Li *et al.* (2003) found more captures in the low altitude compared to the high altitudes, similar to that of Zhang *et al.* (1964; in Li *et al.* 2003), an older study from the same area. Further, Li *et al.* (2003) also reported that both species richness and species abundance decrease from east to west due to the higher diversity of vegetation in the east resulting from higher rainfall. This could not be confirmed in this study due to the random placement of the spatial trap lines as well as the study being focussed in north to south plane in the Teesta River Basin. The abundance of small mammals has also been found to be higher in the middle altitudinal ranges in Costa Rica (McCain 2006).

The abundances of shrews when examined as the proportions or relative capture rate was expected to increased with altitude since, as temperate species (Churchfield 1990), they are more likely to be abundant in the higher altitudes. The mean proportions showed a slight increase with the altitude class but the overall pattern was not very clear in shrews as well as murids.

4.5 Summary

Altitude gradient studies have gained more attention recently especially with reference to a different pattern of species richness, also called the mid domain effect. I examined the mid domain peak in an altitudinal gradient along with its effect on estimated species richness, abundance and composition of murid rodent and shrew community in Sikkim. I sampled 28 trap lines in four altitude and vegetation zones and found that from the captured 19 taxa of small mammals, both the observed and estimated species richness were higher in the middle altitudes. The mid domain effect was tested to examine whether the higher species richness in the middle altitudes are purely due to geometric or geographic constraints. A sum of factors including, the mid domain effect, biological and historical, influences the species richness in an altitudinal gradient. The abundance of murids and shrews showed wide variation in the trap lines (0 to 19.49%). However, the total small mammal abundance measured as its capture rate (5.09% overall) increased with the increasing altitude. Species turnover increased sharply with increasing altitudinal difference between the trap lines. *Rattus sikkimensis* (Zone I), *Soriculus nigrescens* (Zone II) and *Niviventer eha* (Zones III and IV) were the numerically dominant species in the four altitude zones.

Plate III

Few small mammals from the North and South Districts of Sikkim

Tupaia belangeri

Suncus murinus

Rattus nitidus

Niviventer niviventer

CHAPTER 5

MICROHABITAT USE

5.1 Introduction

Habitat complexity has been known to increase species diversity (MacArthur *et al.* 1966; Terborgh 1977; August 1983; Kerr and Packer 1997; Tews *et al.* 2004). Complex habitats enable animals to choose from a variety of microhabitats that are available, and this partitioning of habitat into microhabitats allows many sympatric species to coexist (Rosenzweig and Winakar 1969; M'Closkey and Fieldwick 1975; Dueser and Shugart 1978; Marsh and Harris 2000).

The concept of partitioning of a habitat into microhabitats was introduced by Rosenzweig and Winakar (1969) without using the term microhabitat. The term itself was first used by Schoener (1974) followed by M'Closkey (1976). When it finally came into regular use, with Price's (1978) experimental study on competition based models on four species of desert rodents in Arizona, the term referred to one or a combination of specific features within the home range of an individual animal that influences its behaviour, especially features of the structural vegetation (Morris 1987).

Their small body size and relatively high local species richness make small mammals an ideal taxon among mammals to examine the concept of microhabitat selection. Research on microhabitat partitioning and selection in small mammals has produced mixed results. Price (1978) estimated the capture frequency of four heteromyid rodent species in different microhabitats and found each species maintaining a distinct capture distribution. This finding was in support of the earlier findings that the distribution of heteromyid rodents was correlated with vegetation (Rosenzweig *et al.* 1975) and that microhabitat partitioning existed among sympatric species (Brown and Lieberman 1973).

In Tennessee, three rodent species (*Peromyscus leucopus, Ochrotomys nutalli* and *Tamias striatus*) showed significant differences in 18 out of 29 habitat variables measured from six strata (overstory, understory, shrub level, herbaceous level, forest floor and litter-soil level), including a combination of vertical foliage profile, ground cover and soil characteristics (Dueser and Shugart 1978). Microhabitats such as log cover, tree with larger buttresses, slope and vines showed significant differences among two morphologically similar tropical forest rodent species (*Proechimys semispinosus* and *Hoplomys gymnurus*) in Panama (Tombline and Adler 1988). Similarly, Bellows *et al.* (2001) found significant differences in the microhabitat characteristics among one rodent and three shrew species (*Microtus pinetorum, Blarina brevicauda, Sorex hoyi* and *Sorex longirostris*) with reference to variables such as diameter of dead wood debris, shrub presence and canopy closure. Higher tree density, canopy height, canopy cover and ground cover separated microhabitat selection in two murid rodents and one shrew species (*Rattus rattus, Mus famulus* and *Suncus montanus)* in the Western Ghats, India (Shanker 2001). The Malabar spiny dormouse (*Platacanthomys lasiurus*), also in the Western Ghats, was reported to be associated with liana laden trees (Mudappa *et al.* 2001). In Anaimalai hills of the Western Ghats, habitat heterogeneity (measured as spatial variation in structural properties of vegetation such as occurrence of rattans, presence of buttressed trees and greater shrub density) was found to be a major factor, that increased the capture rate of *Rattus rattus wroughtoni* (Prabhakar 1998). Higher herb cover and litter cover increased the capture rate of *Suncus niger*, while *Mus booduga* responded to medium values of shrub density and herb cover, and *M. musculus* responded to lower values of most of these variables (Prabhakar 1998).

In contrast, several studies have found little support for differences among small mammals in microhabitat characteristics that they prefer. Chandrasekar-Rao and Sunquist (1996) did not find any distinct microhabitat preferences among five species of rodents (*Rattus rattus, Mus platythrix, Funambulus tristriatus, Cremnomys blanfordi* and *Golunda ellioti*). Wells *et al.* (2004) found that 20 species of small mammals (families Muridae, Sciuridae, Tuapiidae, Hystricidae, Viverridae and Lorisidae) did not restrict themselves to any microhabitats, as they relied on resources from different microhabitats. Jorgensen *et al.* (1995) found that desert rodent species, presumed to be open-microhabitat specialists, were captured more frequently in patch types characterized by thick vegetation.

Consistency in the selection of microhabitats by the same species in different but adjoining vegetations has rarely been examined, primarily because most studies are of small spatial scales (Jorgensen 2004). Thus, results from different studies should be generalized with caution even if same species have been studied (Jorgensen 2004). Microhabitat selection is known to vary between study sites (Bowers 1986). However, it may be possible to predict the occurrence of rodents or shrews based on a combination of microhabitat parameters. Moreover, although most studies have reported the microhabitats of rodents and shrews, very few have compared the results between the two groups.

In this Chapter, I examine and compare the selection of microhabitats, measured as local structural characteristics of the vegetation, in murid rodents and ground shrews. More specifically, I test the hypothesis that the occurrence and capture rate of rodents and shrews can be predicted from a combination of structural vegetation characteristics. Among murids, microhabitat selection of the most dominant species in the higher altitudes, *Niviventer eha*, compared with that of other rodent species. Furthermore, in order to test the hypothesis that microhabitat selection is consistent across vegetation types, I compare microhabitat selection by this species in adjoining tropical and temperate forests.

5.2 Methods

5.2.1 Live trapping of small mammals

The data on microhabitat selection was collected from live trapping of small mammals between June 2003 and April 2004 (in tropical semi-deciduous, temperate broadleaf and coniferous forests), and between May 2005 to December 2005 (in tropical semi-deciduous, tropical broadleaf and temperate broadleaf forests) (Section 2.3 for details). The traps were placed at intervals of 5 m on alternate side of the trap lines, each 200 m to 300 m in length. I laid 6 to 8 trap lines each in the tropical semi-deciduous, tropical broadleaf, temperate broadleaf and coniferous forests in a total of 28 trap lines.

5.2.2 Measurement of microhabitat variables

Structural characteristics of vegetation were measured along all 28 trap lines. Quadrats of 5 m × 5 m were laid at 50 m to 100 m intervals depending on the length of the trap line. In each quadrat, 15 variables were measured consisting of altitude, tree species number, gbh (girth breast height) of trees, total basal area, number of shrub species, canopy height, canopy cover, slope, ground cover percentage consisting of herb, leaf litter, rock, soil, fern, *Ageratum* and others (Table 5.1). Small mammals captured in the quadrats were recorded separately.

5.2.3 Data analysis

In order to meet sample size requirements, the data from four vegetation types were pooled in two groups; tropical (semi-deciduous and broadleaf forests) and temperate forests (broadleaf and coniferous forests). I also pooled all murid species into one group and all ground shrews into another. The differences in microhabitat selection between murids and shrews were then examined separately for tropical and temperate forests.

Microhabitat variables measured in quadrats from which murids and shrews were captured were compared using box and whiskers plots to identify those showing major differences between murids and shrews in the tropical as well as temperate forests. These variables were used in discriminant function analyses to further identify those that contributed most to the separation of murids and shrews in each forest type. Wilks' λ was used to test the differences between murids and shrews in group means of the selected microhabitat variable. The function at group centroids, depending on the combination of microhabitat variables, was used to assess the separation of murids and shrews. The same analysis was used to compare microhabitat selection of *Niviventer eha,* the most abundant murid in the temperate forests, with all other murids together.

Table 5.1 The microhabitat variables measured in 5 m × 5 m quadrats, placed at 50 m to 100 m intervals along trap lines used to capture small mammals.

Habitat Variable	Method of measurement
Altitude	In metres using an altimeter (Barigo).
Number of trees and tree species	Number of trees and tree species >30 cm in GBH within the plot.
GBH of trees (cm)	Of trees >30 cm in GBH, measured with a measuring tape.
Number of shrubs and species	Number of shrubs of each species within the plot.
Canopy height (m)	Tree height, from base of the tree in the group to its tip, estimated visually at 5 m from the tree.
Canopy cover (%)	A round rear view mirror of a motorcycle (10.20 cm diameter) was divided into 20 square grids. This mirror was held at waist height and the number of grids with canopy was counted, and converted into percentage out of 20.
Slope (°)	Visual estimation of the general slope.
Ground cover (%).	The type of ground cover (leaf litter, rock, soil, fern, *Ageratum* and others) was recorded at every two step along the diagonal of plot. (in 20 steps). This was converted into percentage cover for each type.

In addition, I also examined whether the species richness and capture rates of murids and shrews along trap lines were correlated with different microhabitat variables, measured as the mean of all quadrats along the trap line. Since altitude was correlated with capture rate (Section 4.3.4), partial correlation controlling for altitude was used to examine the relationship of species richness and capture rate of murids and shrews with the microhabitat variables. Given the very low capture rates, I made no comparison between sites with and without captures.

5.3 Results

A total of 277 individuals from 19 taxa and 17 species of small mammals were captured from 6417 trap nights in 28 trap lines from four vegetation types. Murid rodents consisted of 13 taxa, with 11 species from five genera and ground shrew consisted of five species from four genera (Table 4.1). One species of tree shrew (*Tupaia belangeri*) was also captured, which has been excluded from analysis. Microhabitat variables were measured in a total of 181 quadrats (Table 5.2). Since only a small fraction (17.68%) of the capture sites fell within the vegetation quadrats, sample sizes for comparison of microhabitat selection were low, even for comparison between murids and shrews (Table 5.2).

Table 5.2 Sample sizes for comparison of microhabitat selection in murids and shrews.

Forest type	**Trap lines**	**Total animals (species) captured**		**Animals (species) captured in veg. quadrats**		**Quadrats sampled**
		Murids	**Shrews**	**Murids**	**Shrews**	
Tropical forest	14	47 (5)	44 (5)	5 (3)	7 (3)	96
Temperate forest	14	132 (10)	54 (3)	19 (5)	7 (2)	85

5.3.1 Differences between murids and shrews

Among the 15 microhabitat variables measured (Appendix II), those that showed large differences between murids and shrews in the tropical forest were the number of trees

(Mann-Whitney, U = 4.0, P = 0.01), total basal area of trees (U = 10.0, P = 0.19), canopy height (U = 10.0, P = 0.02), herb cover (U = 0.0, P = 0.01) and litter cover (U = 5.0, P = 0.03). Compared to ground shrews, murid capture sites in the tropical forest had a greater tree density, total basal area and litter cover, and lower herb cover (Fig. 5.1). In the temperate forest, the microhabitat variables showing large differences between the murids and shrews were number of trees (U = 42.5, P = 0.12), total basal area (U = 27.0, P = 0.02), herb cover (U = 42.0, P = 0.12), litter cover (U = 43.0, P = 0.13), slope (U = 26.5, P = 0.11), and canopy cover (U = 31.5, P = 0.22). In this forest, compared to shrews, murid captures were associated with higher litter cover, and lower herb cover, tree density and total basal area (Fig. 5.1). Although the same four variables showed the largest differences between murids and shrews in both forest types, the direction of difference was the same in herb and litter cover, and opposite in tree density and basal area (Fig. 5.1).

Based on the box and whiskers plots, I selected the number of trees, total basal area, herb and litter cover as the predictor variables in discriminant function analysis. In the tropical forest, the Wilks' λ was highly significant with a distinct separation between the group means for murids and shrews. Therefore, a combination of the above four vegetation variables gave a good separation of the sites from where murids and shrews were trapped (Table 5.3). While herb cover had the greatest influence on the function (coefficient = 1.12), other three variables also had lower, but similar, influence. Number of trees and herb cover were the best determinants, as indicated by their high correlation with the canonical coefficients. The discriminant function successfully classified all 12 cases which were used in the analysis.

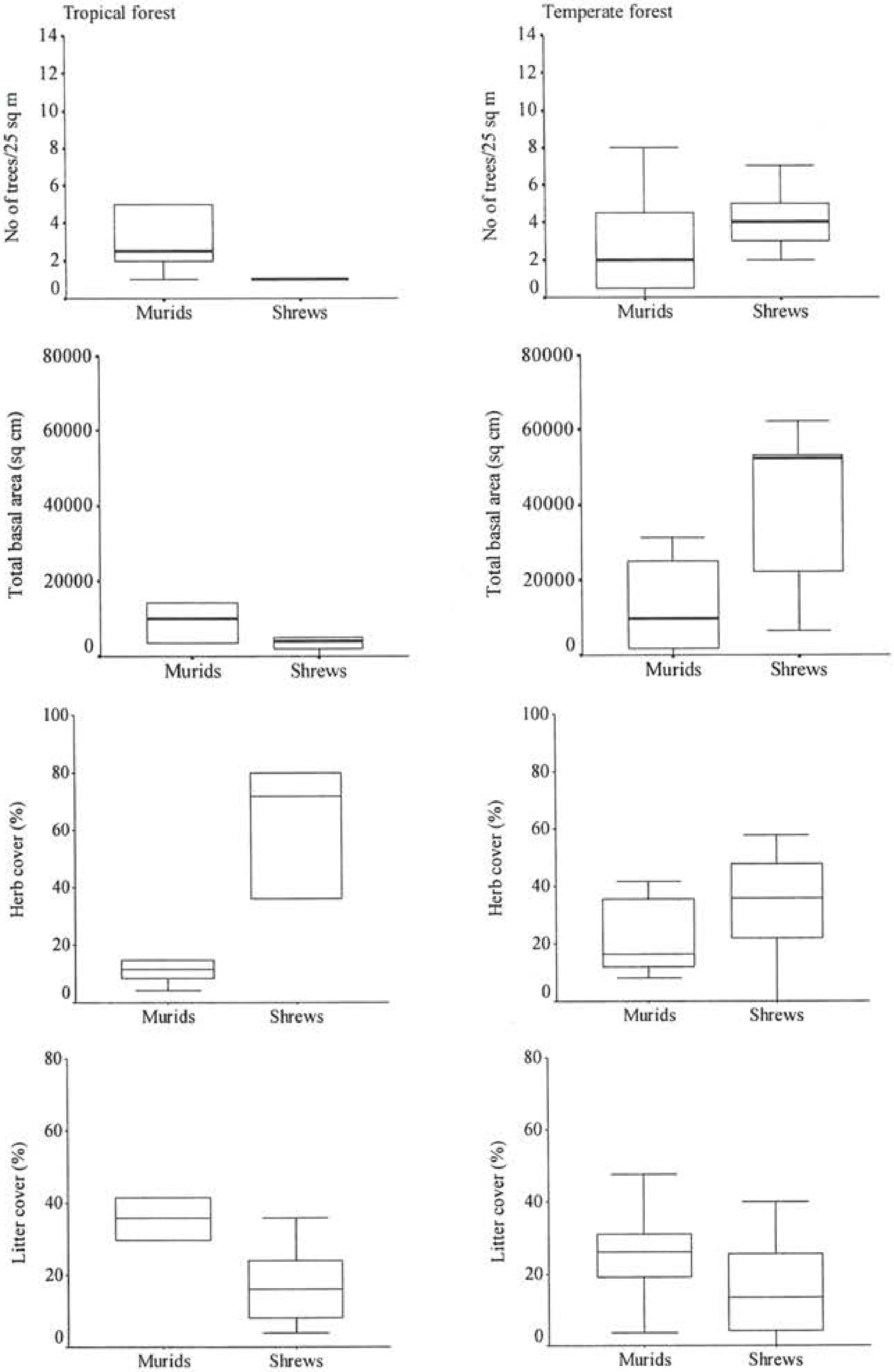


Figure 5.1: Differences in four microhabitat variables between sites, from where murids and shrews were trapped, in tropical and temperate forests. The measurements were made from quadrats of 25 sq m, centred on the capture site.

Table 5.3 Results of discriminant function analysis of quadrats from where murids and shrews were captured using four vegetation variables. DFA was done separately for tropical and temperate forests. The last row gives results of DFA of temperate forest where *N. eha* and other murids were captured.

Group	N	Wilks λ (P)	Standardised canonical function coefficients				Structure matrix				Functions at group centroids		Cases classified (%)
			nt	ba	hc	lc	nt	ba	hc	lc	Mur	Shr	
Tropical forest	6, 6	.20 (.01)	-.31	-.32	1.12	.36	-.43	-.22	.81	-.31	-1.84	1.84	100.0
Temperate forest	20, 7	.73 (.13)	.04	.84	.05	-.52	.30	.84	.55	-.50	-.34	.98	81.5
Temperate forest	15, 5	.28 (.01)	.46 (sh)	.89 (ch)	--	.56	.32 (sh)	.79 (ch)	--	.27	-.88 (*N. eha)*	2.65 (Om)	95.0

(nt = number of trees, ba = total basal area, hc = herb cover, lc = litter cover, sh = number of shrub species, ch = canopy height, Om = Other murid species, Structure matrix = correlations between discriminant variables and standardized canonical discriminant function).

In the temperate forests, however, total basal area of trees and litter cover had the greatest influence on the discriminant function (with coefficients of 0.84 and -0.52, respectively), while the other two variables had low coefficients. Basal area and litter cover also showed high correlations with the canonical coefficients. The separation of group centroids and the percentage of cases correctly classified were lower in this forest. The difference between the murids and shrews in group means (of the four variables), though significant in tropical forest (Wilks' λ = 0.20, P = 0.01), was not significant in temperate forest (Wilks' λ = 0.73, P = 0.13).

5.3.2 Differences among murids

I examined microhabitat use within murids by comparing *Niviventer eha* (n=15) with other murid species combined (five individuals of four species- *Niviventer fulvescens, Mus pahari*, *Rattus turkestanicus* and *Rattus blanfordi*) in the temperate forests, as this was the only comparison that was possible given the sample sizes. An examination of the box and whiskers plot showed that number of shrub species, canopy height and litter cover had the greatest differences between these two taxa (Fig. 5.2).

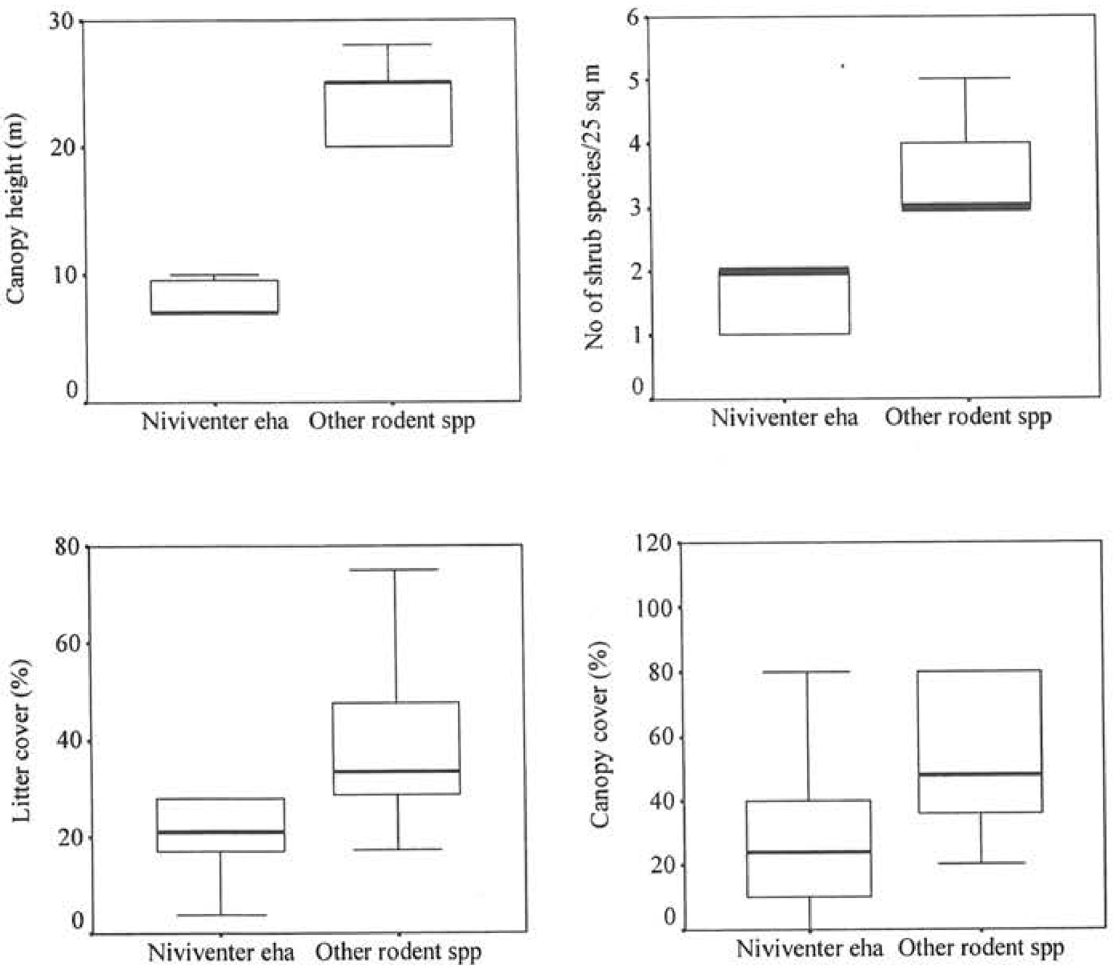


Figure 5.2: A comparison of canopy height, canopy cover, number of shrub species and litter cover in quadrats from where *Niviventer eha* (n = 11 quadrats) and the other murid rodents (n = 4) were trapped in the temperate forest.

Compared with other murids, *N. eha* used areas with lower canopy height, canopy cover, number of shrub species and litter cover. Canopy height was the best determinant of the separation of these two taxa, as indicated by the canonical coefficient and the structure matrix, which is the correlation of discriminant variables with the canonical coefficients. The function successfully classified 95% of the 20 cases used in the analysis and the group means were significantly different between these two taxa (Wilks' $\lambda = 0.28$, $P = 0.01$).

5.3.3 Capture rate and species richness

I examined whether the capture rate and the number of species caught in a trap line were related to vegetation characteristics of the trap line. Since the capture rate and species richness showed a clear relation with altitude (Section 4.3), I used partial correlation while examining the relationship with vegetation variables. The analysis was done separately for tropical and temperate forests.

Results from partial correlation in the tropical forest, when the influence of altitude was controlled for, showed species richness in murids to be negatively correlated to canopy height and canopy cover (Table 5.4). In the temperate forest, species richness of murids was not significantly related to any of the microhabitat variables, however, the capture rate showed a negative correlation to herb cover. Among shrews the best positive correlation was shown by increasing herb cover with respect to both the species richness and capture rate in the tropical forest (Table 5.4). Shrews from the temperate forest did not show any positive correlation with the microhabitat variables.

I also compared correlates of capture rates of *N. eha* with those of other murids in 14 trap lines in the temperate forests, after controlling for altitude through partial correlation. None of the measured vegetation variables was significantly correlated with the capture rate of *N. eha* (Table 5.5). The capture rate of other four murid species showed a positive correlation with litter cover and a negative correlation with herb cover (Table 5.5).

Table 5.4: Partial correlation coefficients (controlling for altitude) of species richness and capture rates of small mammals with habitat variables in tropical (14 trap lines) and temperate forests (14 trap lines).

	Species richness		**Capture rate**	
Tropical forests	**Murids (P)**	**Shrews (P)**	**Murids (P)**	**Shrews (P)**
Mean no of trees	-.07 (.84)	-.25 (.43)	.06 (.85)	-.10 (.75)
Mean GBH of trees	-.06 (.85)	.03 (.93)	-.37 (.24)	.07 (.83)
Mean total basal area of trees	-.06 (.85)	-.16 (.61)	-.29 (.37)	-.09 (.79)
Mean herb cover	-.32 (.32)	**.44 (.15)**	-.22 (.49)	**.47 (.12)**
Mean litter cover	.02 (.95)	-.06 (.85)	.01 (.97)	.25 (.47)
Mean rock cover	-.34 (.29)	-.28 (.38)	-.24 (.45)	-.04 (.91)
Mean soil cover	-.26 (.42)	-.37 (.24)	-.32 (.31)	-.18 (.58)
Mean canopy height	**-.70 (.01)**	-.27 (.39)	**-.74 (.01)**	-.04 (.91)
Mean canopy cover	**-.61 (.04)**	.09 (.78)	**-.47 (.12)**	**.44 (.15)**
Temperate forests				
Mean no of trees	.03 (.94)	-.08 (.79)	-.33 (.27)	-.09 (.77)
Mean GBH of trees	.05 (.86)	-.04 (.88)	-.09 (.78)	.01 (.96)
Mean total basal area of trees	.12 (.73)	-.14 (.64)	-.14 (.64)	-.19 (.54)
Mean herb cover	**-.45 (.13)**	-.05 (.87)	**-.55 (.05)**	-.36 (.23)
Mean litter cover	.33 (.29)	-.23 (.45)	**.44 (.13)**	.17 (.60)
Mean rock cover	.03 (.92)	-.04 (.89)	-.12 (.69)	-.12 (.69)
Mean soil cover	.09 (.78)	-.34 (.26)	-.05 (.88)	.15 (.61)
Mean canopy height	.03 (.93)	**.42 (.15)**	-.22 (.46)	.14 (.66)
Mean canopy cover	.04 (.91)	-.05 (.88)	-.09 (.76)	.09 (.76)

*The numbers in bold indicate significant as well as nearly significant correlations.

5.4 Discussion

5.4.1 Murids and shrews differ in microhabitat use

A major constraint in this study was the limited sample sizes, due to low capture rates, with an overall mean of 5.11% (see Section 4.3.4). Moreover, only a few of these captures fell within the quadrats from which I made microhabitat measurements (Table

5.1). Box and whiskers plot revealed differences between murids and shrews in 4 out of 15 variables, in both tropical and temperate forests, and the DFA gave further results on these four variables.

Table 5.5: Partial correlation coefficients (controlling for altitude) of the capture rate of *Niviventer eha* and other murid species with the habitat variables in 14 trap lines of the temperate forest.

Habitat variables	***Niviventer eha* (P)**	**Other murid spp (P)**
Mean no of trees	**-.41 (.17)**	.02 (.96)
Mean GBH of trees	-.17 (.58)	-.02 (.94)
Mean total basal area of trees	-.24 (.44)	-.06 (.84)
Mean herb cover	-.33 (.27)	**-.49 (.09)**
Mean litter cover	-.02 (.95)	**.54 (.06)**
Mean rock cover	-.16 (.61)	.01 (.97)
Mean soil cover	-.26 (.39)	.25 (.41)
Mean canopy height	-.37 (.21)	.10 (.75)
Mean canopy cover	-.34 (.25)	.28 (.36)
Mean slope	.28 (.35)	.32 (.28)

*The numbers in bold indicate significant as well as nearly significant correlations.

In tropical forests, tree density and herb cover distinctly separated murids and shrews. In the temperate forests, the separation was not so distinct. Differences in microhabitat selection between murids and ground shrews have been examined by other studies. A clear separation was found between three shrew species (*Sorex longirostris, S. hoyi* and *Blarina brevicauda*) and one murid (*Microtus pinetorum)* in the Upper Coastal Plain of Virginia (Bellows *et al.* 2001). Shrews responded to shrub occurrence and canopy closure, whereas murids responded to mean dead wood debris diameter. *Blarina brevicauda* showed some similarity with *M. pinetorum*, but differed when examined in combination of two habitat parameters (i.e. presence of shrub and mean dead wood debri diameter). In the evergreen forests in the Western Ghats, Shanker (2001) found no clear separation between a shrew (*S. montanus)* and a murid (*Mus famulus)*; both preferred higher tree density, greater ground cover and lower canopy height. In Assateague Island, murids preferred sites with higher tree density, whereas shrews preferred heavier canopy cover (Dueser and Porter 1986). The microhabitat requirements for murids and shrews differed especially in the tropical forest. Shrews preferred areas with low tree density and high herb cover. Shrews probably benefit in such areas that makes detection by its predator difficult. An area with greater herb cover traps moisture and has higher humidity, which helps shrews as they are sensitive to water loss due to their high metabolic rate (Glennon and Porter 2007). The microhabitat use by shrews for areas with higher herb cover and low litter cover seems consistent across vegetation types; this was shown in both the vegetation types. Though the population size of both rodents and shrews in both the tropical and temperate forest seem to be small and are mainly due to the lower capture rates. However, rodents and shrews would differ in their microhabitat use as both their ecological requirements are different. For example, rodents are primarily herbivorous, whereas shrews are insectivorous and they are unlikely to compete against each other for resource requirements.

***5.4.2 Microhabitat use in* Niviventer eha**

There was a significant difference between *N. eha* and other rodent species in the selection of microhabitats in the temperate forest. Several studies have also found differences in microhabitat selection among sympatric murids. Canopy cover was the main factor, which along with ground cover, separated two groups of taxonomic assemblages of eight rodent species in Oklahoma (Stancampiano and Schnell 2004). Dueser and Porter (1986) found that the four most abundant rodent species in Assateague Island, Virginia, showed significant differences in their utilization of the five vegetation types; *Mus musculus* in mixed grass/shrub habitat, *Microtus pennsylvanicus* in salt marshes, *Zapus hudsonius* in shrubland and *Peromyscus leucopus* in the forest. Dueser and Shugart (1978) found that the golden mouse, *Ochrotomys nutalli,* responded to thickness of woody vegetation, shrub cover, woody stem density, herb characteristics (stem, foliage and density) and litter. *Ochrotomys* was encountered more frequently at locations with dense ground cover and undergrowth denser than average (Linzey 1968). As found in this study, murids seem to use higher tree density in other areas also. In the Western Ghats, *Rattus rattus* used higher tree density areas with lower canopy cover (Shanker 2001). Similarly, *R. r. wroughtoni* also showed significant response to the presence of buttressed trees in Anamalai hills (Prabhakar 1998).

Lack of studies does not allow a comparison of *N. eha* from Sikkim to other regions nearby. Studies on *Niviventer* spp. in China (Wu *et al.* 1996) and Malaysia (Wells *et al.* 2006) do not specifically address microhabitat selection. *Niviventer cremoriventer* is found in both arboreal and terrestrial habitats in Malaysia but do not show any significant preferences (Wells *et al.* 2004).

One problem that makes comparisons difficult is that the studies on microhabitat selection have covered relatively few species. Jorgensen (2004), in a review, found a total of 61 small mammal species which had been studied with respect to microhabitat selection. However, only eight rodent species in five genera (*Dipodomys, Peromyscus,* *Chaetodipus, Perognathus* and *Reithrodontomys*) accounted for about 50% of the published research.

5.4.3 Does microhabitat predict abundance at a larger scale?

Studies in the neotropics have found small mammal densities responding positively to secondary habitats or to disturbed areas due to availability of more microhabitats (Adler and Levins 1994; Lambert *et al.* 2003, 2006). Although microhabitat is an important factor influencing the density of small mammals (Adler 1988), they have been found to respond to macrohabitat without any correlation with microhabitats in temperate forests (Morris 1987). In contrast, no significant differences were found in the total small mammal abundance among different macrohabitat types in coastal plain of Virginia (Bellows *et al.* 2001). Microhabitats within a macrohabitat used by small mammals can be similar to the unused microhabitats within an unused macrohabitat and hence, density may not be determined by the microhabitats available (Jorgensen and Demarais 1999). Thus, the interaction between the macrohabitat and microhabitat that may determine small abundance, are not clearly known (Jorgensen and Demarais 1999). In this study, the species richness and capture rate over a large spatial scale within the tropical forest were negatively correlated with canopy height and canopy cover (Table 5.5), and not with tree density and herb cover, which were the major predictors of capture sites (Table 5.3). In South India also, the density of small mammals, except for *Rattus rattus*, were found to be correlated with canopy height (Shanker and Sukumar 1998). However, the species richness and capture rates of shrews were best correlated, though not significantly, with herb cover which was also the best predictor of capture sites. Thus, at least in the case of shrews in the tropical forests, there seems to be some relationship between microhabitat availability and abundance as well species richness supporting Yahner's (1986) study. In the temperate forest, where there was poor separation between capture sites of murids and shrews, there was no consistent relationship between microhabitat availability and abundance and species richness in both murids and shrews.

5.4.4 Consistency in microhabitat selection

Jorgensen (2004) reported that 50% of the studies on microhabitat selection in small mammals had used fewer than 5000 trap nights and most studies were at small spatial scales. In addition, most of the studies conducted on microhabitat partitioning by small mammal species have included only one macrohabitat. Therefore, Jorgensen (2004) recommended that studies should include measurement of the habitat structure at a finer spatial scale and in more vegetation types, with focus on populations rather than individuals. I used more than 5000 trap nights and included two vegetation types, though due to low capture and abundance of small mammals I had to pool the four vegetation types into two.

Compared to murids, shrews were found in lower tree density areas in the tropical forest, whereas in the higher altitudes of temperate forest they used higher tree density areas. However, in both forests, shrews seem to prefer high herb and low litter areas. Shrews (*Sorex cinereus, S. monticolus, S. merriami, S. nanus* and *S. pleblei*) from different habitats (grassland/short-shrub habitat, tall shrub habitats, or ecotonal boundaries) have shown a lack of microhabitat preference within the shrub-steppe ecosystem of Wyoming (Kirkland *et al.* 1997). Shrews also responded to canopy cover and canopy height in the temperate forest. Another factor that should be taken into consideration is the high metabolic rate of shrews (Miller and Getz 1977), due to which they may prefer microhabitats which will cause a minimum loss of water from their body through evaporation. Microhabitat features like the canopy cover and herb cover traps moisture and thus increases local humidity (Tallmon and Mills 1994; Bellows *et al.* 2001).

5.4.5 Constraints

There are at least two major constraints of this study which should be considered. One is the low sample size which constrained the kinds of analysis that could be used. The second constraint, resulting from small sample sizes, is the pooling of species, all murids into one group and shrews into another. Since small mammal species are known to differ in their selection of microhabitats (Price and Kramer 1984), the pooling of such species with different microhabitat preferences could hide patterns that could exist. Moreover, the results would be influenced by the numerically dominant species, which are often also generalists. Generalist species are most likely to use a wide range of microhabitats making it difficult to correlate their abundance with any microhabitat variable (Adler 1985). In this study, *Rattus sikkimensis* was the most numerically dominant murid in the tropical forests forming 27.47% of all captures, and *Niviventer eh*a was the most dominant in the temperate forests, forming 42.47% of all captures. *Soriculus nigrescens* was the dominant shrew in both the tropical (40.66%) and temperate forests (23.66%). Thus the pooling of species could be a major reason for the lack of clear differences in microhabitat use.

5.5 Summary

Microhabitats generally refer to the structural attributes of the vegetation in the home range of an animal which may serve as substrate for food, cover from predators and sites for roosting. Generalizations about microhabitat selection by species are difficult due to various reasons. For instance, microhabitat selection of a species may vary between different areas or with time. Furthermore, most of the studies on microhabitat selection are conducted at small spatial scales. In this Chapter, I hypothesize that the occurrence of murids and shrews can be predicted from the structural attributes of the vegetation or microhabitats. I also examine whether the abundance and species richness in small mammals can be related to attributes of the vegetation. In tropical and temperate broadleaf forests, I measured 15 microhabitat variables from 181 plots (5 × 5 sq m) in 28 trap lines, where 6417 trap nights of Sherman live traps were set to capture small mammals. I used discriminant function analysis to identify the variables that separated the microhabitats of murids and shrews. I also used partial correlation controlling for altitude, to examine the correlation of vegetation variables with small mammal species richness and capture rate. I found the separation between murids and shrews to be significantly distinct in tropical forest with respect to lower tree density and higher herb cover, but not in temperate forest. Murids used areas with higher tree density, total basal area, litter cover and lower herb cover in the tropical forest. Species richness and capture rate of murids in tropical forest were negatively correlated to canopy height and canopy cover, where as for shrews only herb cover was significant. In the temperate forest, lower herb cover and higher litter cover were significantly correlated to murid species richness and capture rate. *N. eha* also showed a significant difference in its microhabitat use with

respect to higher total basal area and litter cover in the temperate forest. Therefore, the occurrence of murids and shrews can be predicted with microhabitat variables especially in the tropical forest.

CHAPTER 6

SMALL CARNIVORES

6.1 Introduction

Intra- and inter-species interactions of competition and predation are known to regulate species-specific population sizes and the composition and structure of communities (Menge and Sutherland 1987). Communities can comprise of species that have wide as well as narrow distributional ranges (Brown *et al.* 1996). Thus, the ability of a species to distribute itself across space also has a strong influence in determining community compositions (Hadly and Maurer 2001).

Small carnivore communities comprising of families Herpestidae, Viverridae, Mustelidae, Felidae (smaller sized species) and Canidae, can vary from landscape to landscape. These communities include solitary as well as group living species with nocturnal and diurnal habits, which feed on small mammals, invertebrates, fruits and a variety of other food resources. Species of the order Carnivora exhibit a wide range of dietary and habitat preferences and fill many different niches across ecosystems, ranging from omnivory to carnivory (Ewer 1973). Presence of a particular small carnivore species in a community also affects the space use by the other carnivores, for e.g. Iberian lynx kills mongooses, genet, and foxes and hence most of the latter were found to avoid areas used by the former (Palomares *et al.* 1996). Among mammalian carnivores, inter-specific killings are known to be common (Palomares and Caro 1999). All these processes lead to variation among small carnivore communities with respect to their composition and abundance.

An increase in human activities resulting in poaching and habitat fragmentation threatens the small carnivore community. An understanding of the dynamics and structure of the small carnivore community followed by conservation and forest management based on this understanding is therefore of utmost importance (Rabinowitz and Walker 1991).

It is often observed that a number of small carnivores coexist in the same landscape and overlap in terms of their food resources as well as home range. Ray and Sunquist (2001) found ecological separation among sympatric carnivores in an African rainforest to be influenced by size diversity and abundance of mammalian prey as well as spatial (habitat) and temporal (activity) separation. But what happens to the small carnivore communities in different vegetation types that are contiguous? To what extent does altitude affect the abundance and distribution of small carnivore communities?

The state of Sikkim in India forms an ideal area to study factors related to ecological separation of the small carnivore community, since it is located at the junction of three biogeographic realms and exhibits a very sharp altitudinal gradient (about 200 m to 8000 m; Section 2.1). Owing to this altitude gradient, a wide range of habitats are found within small areas. These two factors allow Sikkim to accommodate a variety of small carnivore species originating from three different biogeographic realms, such as the Paleoarctic martens and weasels, the Afrotropic mongooses and the Indo-Malayan civets and small cats.

In this Chapter, I examine the small carnivore community in Sikkim with respect to the distribution and abundance of Viverridae, Mustelidae, Felidae (smaller sized species) and Canidae in an altitude gradient and in different vegetation types. Furthermore, I investigate changes in the diet of the small carnivore community across altitude and vegetation types.

6.2 Methods

6.2.1 Estimation of abundance

Since sightings of small carnivores were expected to be infrequent, I used the encounter rates of their scats as an index of relative abundance. Encounter rates were estimated from belt transects, within 2 m on either side of an existing forest trail, which varied in length from 200 m to 1 km depending on the slope of the area. The same belt transects were used as trap lines to sample rodents and shrews and estimate its capture rate (Section 2.3). Transects were distributed in the four major vegetation types (tropical semi-deciduous forest, tropical broadleaf forest, temperate broadleaf forest and coniferous forest) in the North and South Districts of Sikkim. The number of transects in the four vegetation types were 6, 7, 8 and 6 respectively. Each transect was temporally replicated 4 to 6 times between June 2003 and November 2005. In each transect, all droppings were recorded. The droppings were also recorded from opportunistic belt transects, especially along trails leading to the above-mentioned regular transects. These trails were not replicated.

In order to record the photographic presence of small carnivores, two camera traps (Wildlife Pro) were also used in the trap lines. The area was baited for two days with dry fish and banana, then on the third day the cameras were placed on a tree stump in the evening and removed in the morning.

Scats of small carnivores located along the belt transects were photographed and collected in paper envelopes. The location, content, surrounding vegetation type and altitudinal location of each scat were recorded, as were physical attributes of each scat like its length and diameter. The identification of species from scats was difficult *in situ*. Therefore, each dropping was identified as belonging to one amongst three groups, namely viverrids, mustelids or canids and felids grouped as one. The identification of scats was based on its physical appearance, shape and size.

6.2.2 Diet analysis

In the laboratory, each scat was soaked and washed with water in a sieve. The contents were then sun-dried. The contents of the scats were analysed to assess the diet of the small carnivores. Rodent hair in the scats could easily be identified as distinct from that of other mammals due its short length and large quantity. Besides rodent hair, the scats contained jaws, teeth, feathers, seeds and at times hair of other mammals, especially small carnivores. Prey items in the scats were characterized into seven types- rodents, other mammals, birds, reptiles, invertebrates, seeds and other plant parts. The prey item categorized as other mammals constituted of any other evidence of mammals other than small mammals for example, small carnivore hair.

6.2.3 Species identification using fecal DNA

A small number of unwashed scat samples (n = 28) were used to identify the species of small carnivore using fecal DNA extracted using the Qiagen stool kit. The Qiagen multiplex kit was used for the Polymerase Chain Reaction (PCR). A primer designed by Mukherjee *et al.* (in prep) for the NADH5 region was used to identify the scats of leopard cat and jungle cat. The sequencing of DNA was carried out at the National Centre for Biological Sciences, Bangalore. The identification of all scats to the species level was constrained by the unavailability of primers for most species.

6.2.4 Sampling small mammals and vegetation

Murid rodents and shrews were sampled using Sherman live traps placed on the belt transects (Section 2.3), from which the abundance of scats was sampled. Structural features of vegetation along the belt transects were assured by measuring 15 vegetation parameters in quadrats sized 5 m × 5 m each (Section 5.2). The four major forest types sampled were tropical semi-deciduous forests, tropical moist broadleaf forests, temperate broadleaf forests and coniferous forests (Section 2.2).

6.2.5 Data analysis

The encounter rate of the small carnivores scats were estimated for each transect as *(n/L)* where *n* is the number of scats encountered along the transect and *L* is the length of the transect in km. The encounter rates for all transects were used to examine the effect of vegetation and altitude, so as to maximize samples. However, only the encounter rates from transects along trap lines were used while examining the correlation between encounter rate of small carnivores and the small mammal abundance and vegetation parameters. The correlation of encounter rates with altitude group and vegetation types was evaluated with Spearman's correlation coefficient (r).

The diet of each prey type was estimated as the frequency of its occurrence in the scats, using the formula, $(N_i/\Sigma N_i) \times 100$, where, N_i is the N number of occurrence of the prey item i and ΣN_i is the total number of occurrences of i items.

In order to examine the correlation of small carnivore and small mammals, data from 27 trap lines corresponding to the 27 transects for small carnivores were used. Abundance of small mammals for each trap line were estimated as $(n/Nd) \times 100$, where n is the number of the animals trapped in a total number of N trap nights in d number of days in one trapping session (Section 4.2). For the purpose of analysis the altitudinal location of the scats were categorized into eight classes; 1 <500 m, 2 >500 - <1000 m, 3 >1000 - <1500 m, 4 >1500 - <2000 m, 5 >2000 - <2500 m, 6 >2500 - <3000 m, 7 >3000 – <3500 m and 8 >3500 m.

6.3 Results

6.3.1 Altitudinal variation

A total of 280 scats were collected from 162.04 km of belt transects with an overall encounter rate of 1.73 scats/km (Table 6.1). The encounter rate of viverrid scats was the highest (2.69/km) in the lowest altitude class (<500 m; Fig. 6.1a). The highest encounter rate for mustelid scats (1.37/km) was found in altitude class of >3000 m (Fig. 6.1b).

Table 6.1 The number of viverrid, mustelid, and canid and felid scats encountered in belt transects in four vegetation types.

Vegetation type	Transect length (km)	Number of scats		
		Viverrids	Mustelids	Canids & Felids
Tropical semi deciduous forest	29.67	12	0	18
Tropical broadleaf forest	30.35	6	1	16
Temperate broadleaf forest	81.41	78	29	46
Coniferous forest	20.61	3	31	9

Canid and felid scat encounter rate (1.95/km) was higher in the 4th and 7th altitude classes (>2000 m to <2500 m and >3000 to <3500 m; Fig. 6.1c). No mustelid scats was encountered in the first three altitude classes and the lowest encounter rate was found in between altitude class of >2500 m and <3000 m ($r = 0.77$, $P = 0.03$). No altitudinal gradient pattern was seen in the scat encounter rate of viverrids, canids and felids.

6.3.2 Variation among vegetation types

The overall encounter rate of scats differed among tropical semi-deciduous forests, tropical broadleaf forests, temperate broadleaf forests and coniferous forests (Kruskal Wallis test, $\chi^2 = 9.43$, df = 3, $P = 0.02$). The scat encounter rate in tropical broadleaf forest was considerably lower than in the other three vegetation types (Fig. 6.2a). The highest encounter rate (2.13/km) was in the coniferous forest. The encounter rate for viverrid scats (1.99/km) was highest in temperate broadleaf, for canid and felid scats (0.61/km) in tropical semi deciduous and for mustelid scats (1.5/km) in coniferous forest. Mustelid scat encounter rate increased from tropical forest to coniferous forest and showed a significant difference among vegetation types (Kruskal-Wallis test, χ^2=21.8, df = 2, P = 0.001; Fig. 6.2b).

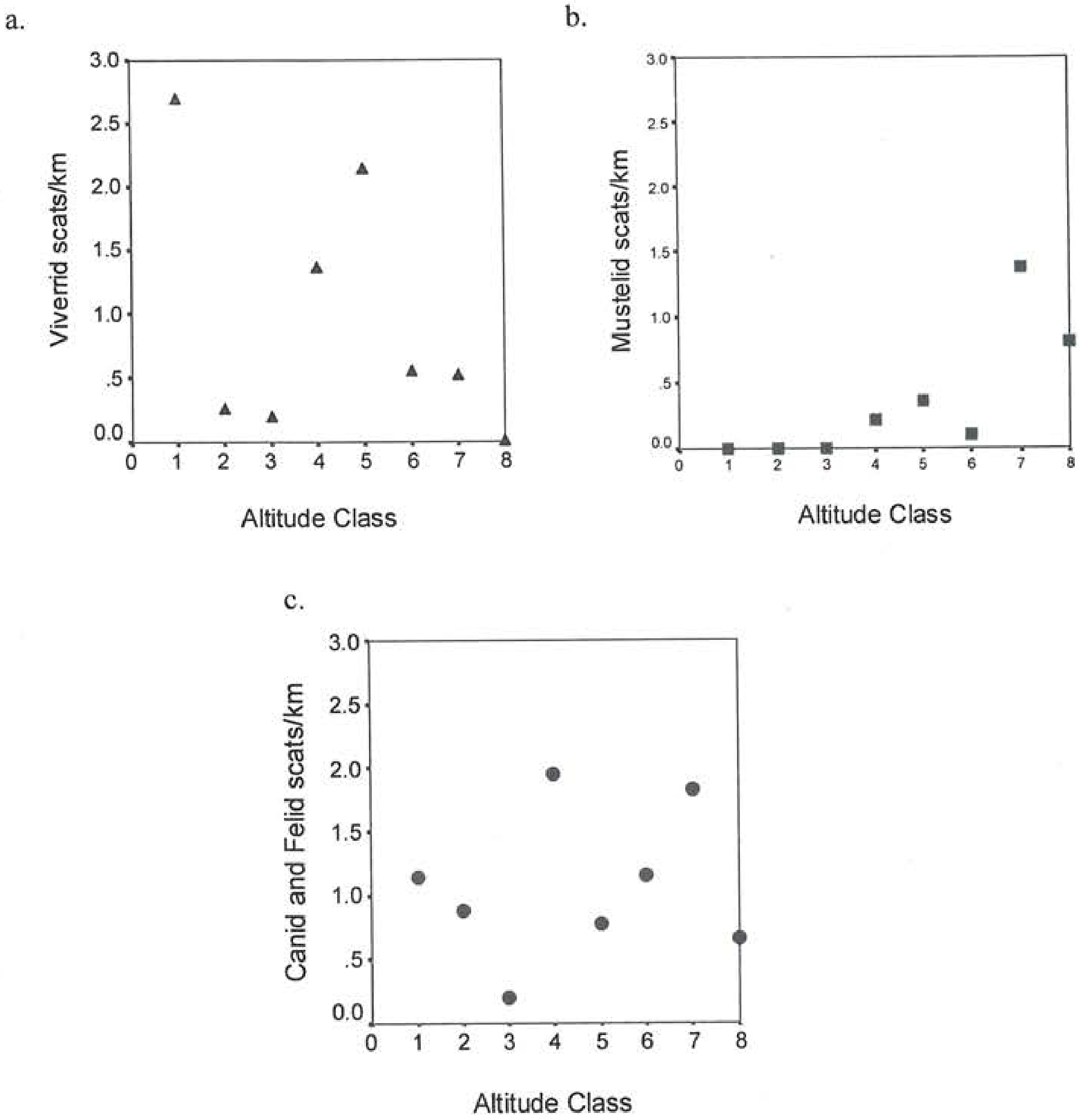


Figure 6.1: Mean encounter rates of (a) viverrid, (b) mustelid and (c) canid and felid scats in the eight altitude classes (1 <500 m, 2 >500 - <1000 m, 3 >1000 - <1500 m, 4 >1500 - <2000 m, 5 >2000 - <2500 m, 6 >2500 - <3000 m, 7 >3000 – <3500 m, 8 >3500 m)

Viverrid scat encounter rates also showed a significant difference among vegetation types ($\chi^2 = 11.19$, df = 3, P = 0.01; Fig. 6.2c) with a decline in the temperate broadleaf and coniferous forests. The canid and felid scat encounter rates also differed amongst vegetation types ($\chi^2 = 8.85$, df = 3, P = 0.03; Fig. 6.2d), primarily due to lower encounter rate in tropical broadleaf forest.

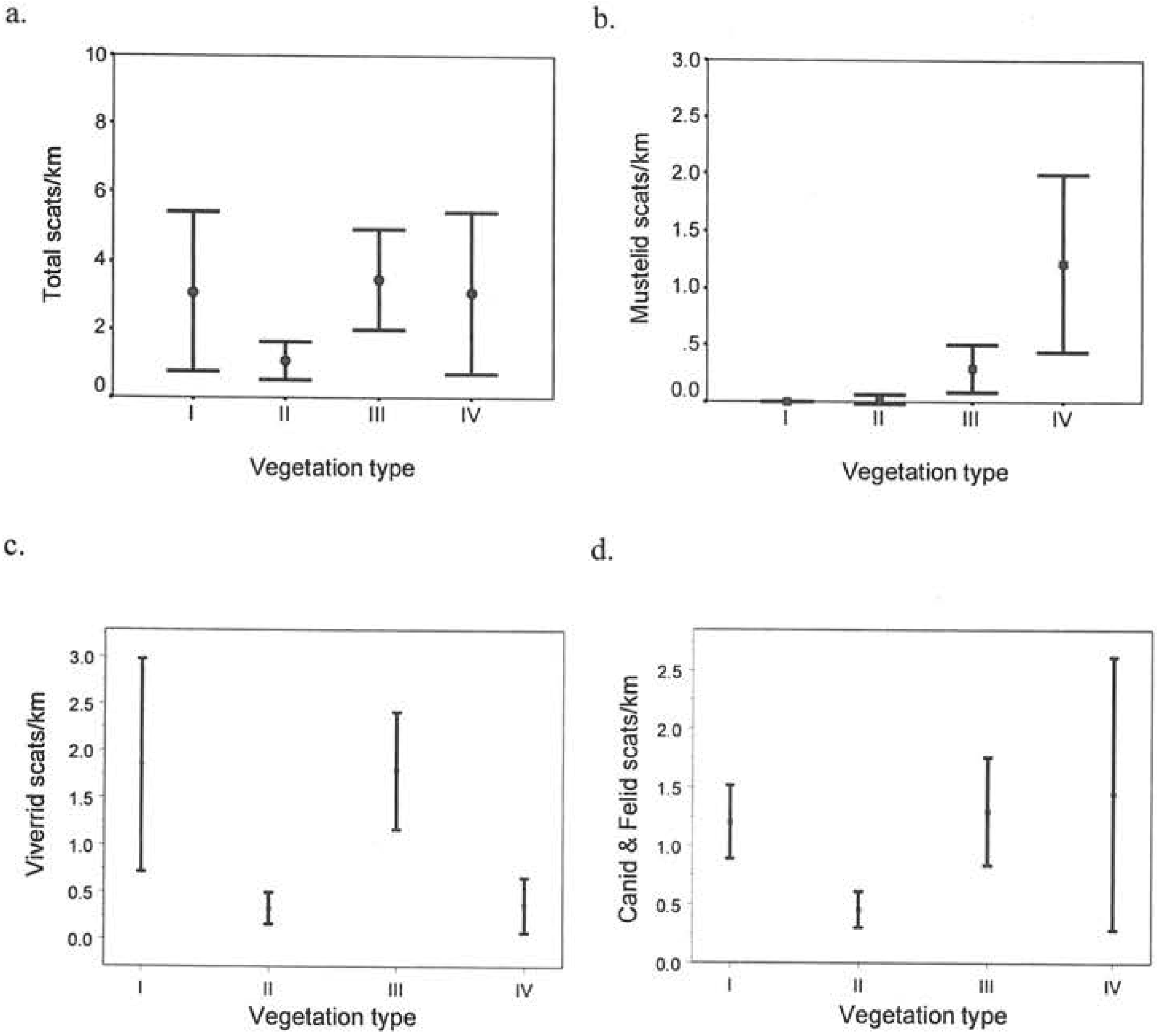


Figure 6.2: Encounter rate of small carnivore scats (a) total, (b) mustelids (c) viverrids and (d) canids & felids in the four major vegetation types, tropical semi-deciduous forest (I), tropical broadleaf forest (II), temperate broadleaf forest (III) and coniferous forest (IV).

The overall scat encounter rate of all three groups in the 27 transects showed a significant increase with an increase in the number of trees (r = 0.49, P = 0.10; Fig. 6.3a). The overall encounter rate did not respond to other vegetation parameters such as girth at breast height of trees, total basal area, canopy height, canopy cover, slope and percentage ground cover, with 'r' values ranging from -0.36 to 0.22 and 'P' from 0.07 to 0.89 (Appendix III).

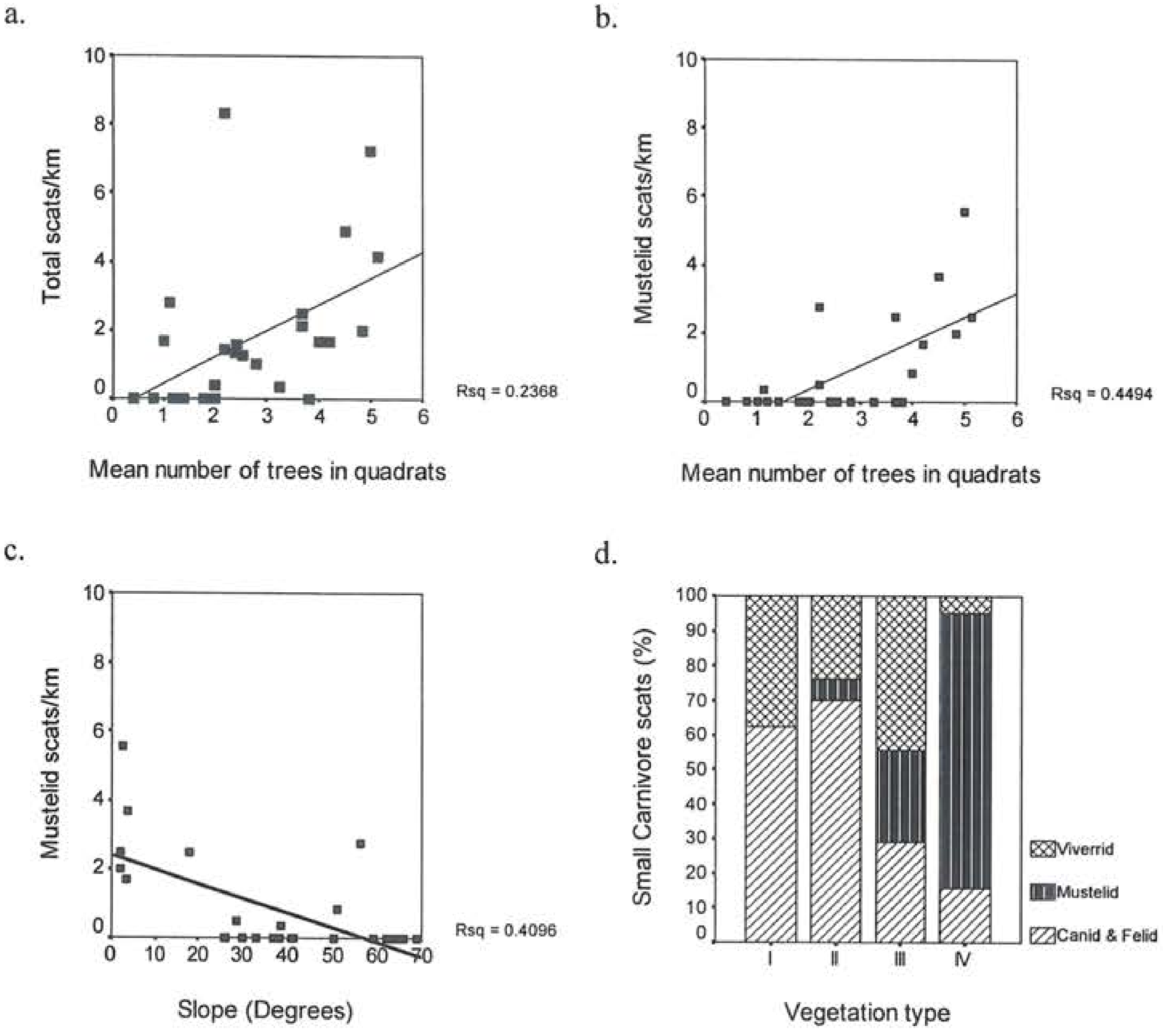


Figure 6.3: (a) Encounter rate of scats of small carnivores against tree density (per 25 m^2) in 27 belt transects. Encounter rate of mustelid scats with (b) tree density and (c) degrees of slope in 27 belt transects. (d) Relative percentages of scats of viverrids, mustelids, canids and felids in four vegetation types (I = Tropical semi-deciduous forest, II = Tropical broadleaf forest, III = Temperate broadleaf forest, IV = Coniferous forest).

Mustelid scat encounter rate increased with an increase in the mean number of trees in the quadrats accounting for 45% of the variation (Fig. 6.3b) and decreased with an increase in slope accounting for 41% variation (Fig. 6.3c).

The canid and felid scat encounter rates had no significant association with any of the vegetation parameters. The percentage of scats of the small carnivores differed among the four vegetation types (Fig. 6.3d). In the tropical semi-deciduous forest, the percentages of canid and felid scats (60%) were higher than that of viverrids (40%). Same pattern was observed in the tropical broadleaf forest. But in the temperate broadleaf forest, higher percentage of viverrid scats (51%) was found than that of canids and felids (30.1%). In the coniferous forest, the percentage of viverrid scat was very low as compared to canid, felid and mustelid scats. Mustelid scat was not found in tropical semi deciduous forest, while its relative percentage increased from 4.3% in tropical broadleaf forest to 72.1% in coniferous forest

6.3.3 Variation in diet

Small mammal abundance (estimated as capture rate along trap lines) accounted for 37% of the variation in encounter rate of small carnivore scats (r = 0.61, P = 0.001; Fig. 6.4a). However, the only small carnivore group that responded to small mammal abundance were the mustelids (r = 0.58, P = 0.001; Fig. 6.4b). The other two groups, viverrids and canids and felids did not show any significant change.

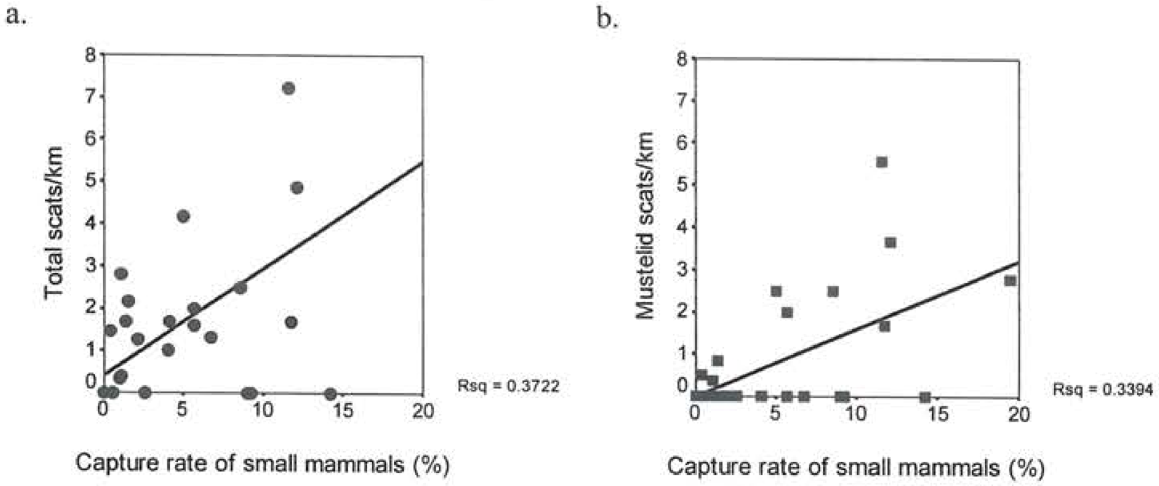


Figure 6.4: Scat encounter rates of (a) small carnivore community and (b) mustelids against the total capture rate of rodents and shrews.

The frequency of occurrence of prey items in scats differed among the four vegetation types (Fig. 6.5). The rodents constituted the largest amount in small carnivore scats from tropical broadleaf to coniferous forest. Percentage of seeds was highest in the temperate broadleaf forest and lowest in the coniferous forest. The occurrence of other mammals in scats was almost the same in all vegetation types. The occurrence of bird and reptile parts in scats was very low where presence of bird in the scats was found in all four vegetation type but reptile was found only in the temperate broadleaf forest. Invertebrates showed an increased occurrence in scats with the highest percentage in the coniferous forest.

Among eight altitude classes, the occurrence of mammals in scats increased with altitude, but not significantly (P = 0.13; Fig. 6.6a). Altitude had almost the same effect on the occurrence of rodents in scats, accounting for about 37% variation (Fig. 6.6b), whereas other mammals accounting for 34% of the variation. The occurrence of invertebrates in scats increased with altitude (r = 0.76, P = 0.03; Fig. 6.6c) with the highest variation of about 59%, while that of seeds decreased but not significantly (r = -0.45, P = 0.26; Fig. 6.6d).

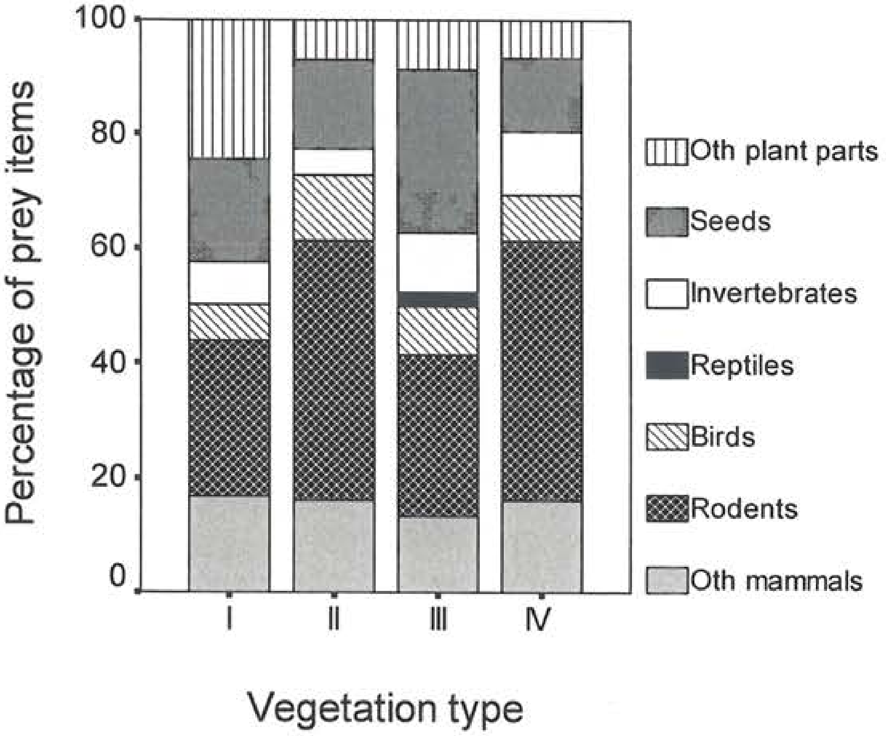


Figure 6.5: The percentage frequency of occurrence of different groups of prey in scats of small carnivores in four vegetation types (I = Tropical semi-deciduous forest, II = Tropical broadleaf forest, III = Temperate broadleaf forest, IV = Coniferous forest).
(See Table 6.1 for sample size or the total number of scats)

6.3.4 Species identification using fecal DNA

Fecal DNA was extracted from 28 scats classified in the field as belonging to cats. Since the primer had been specifically designed (Mukherjee *et al.* in prep) to identify the scats of leopard cat and jungle cat, scats from other groups could not be identified. Out of the 28 scats, six were confirmed as belonging to the leopard cat (*Prionailurus bengalensis*). These scats were collected from an altitudinal range of 340 m to 2690 m indicating that the leopard cat could be the most widespread small carnivore species in terms of altitudinal range. The species identity of other scats could not be established, as the others scats did not give any clear results. The two camera traps captured photographs of two species (Himalayan palm civet, *Paguma larvata* and Jackal, *Canis aureus*) of small carnivores in the lower altitudes.

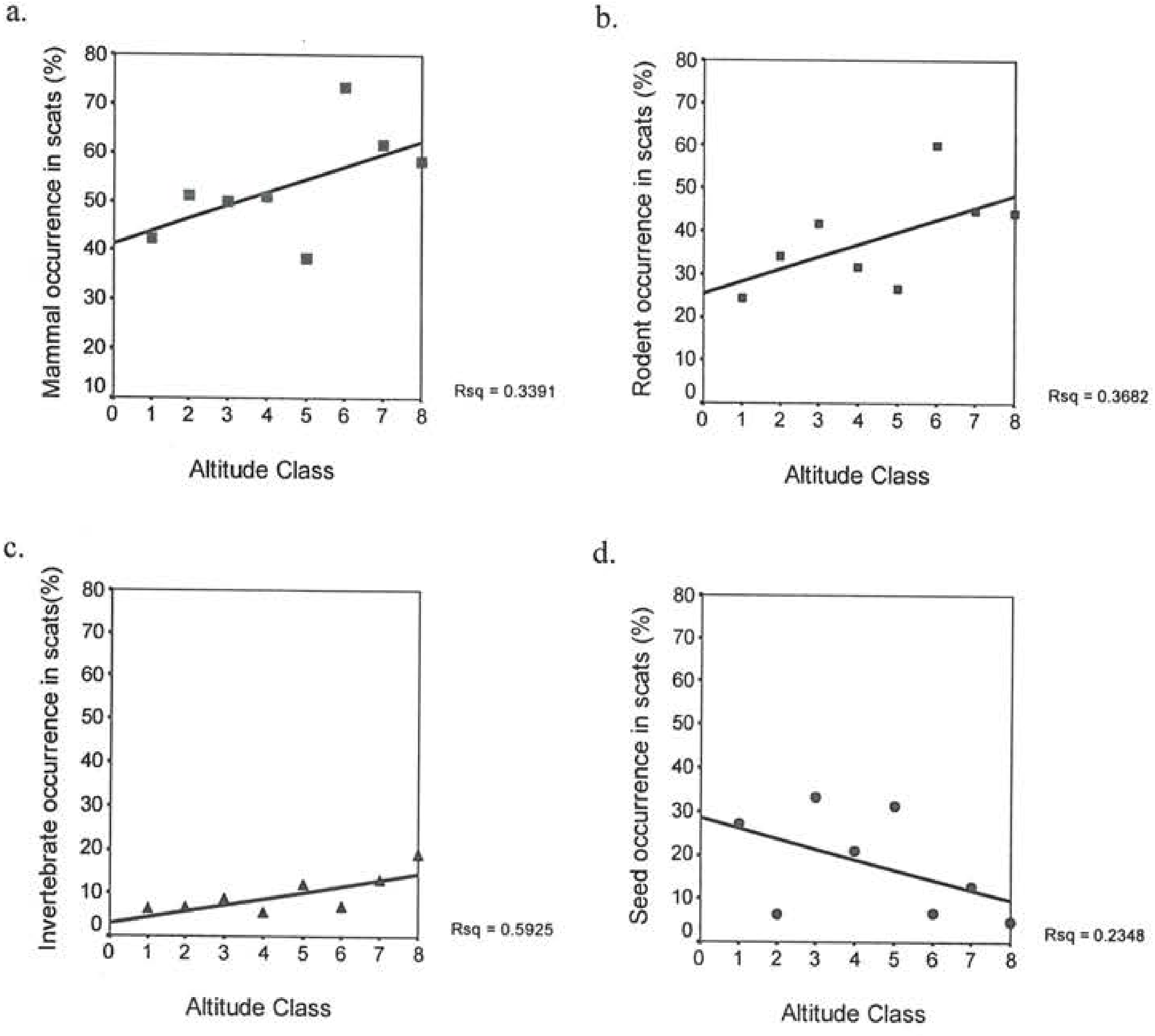


Figure 6.6: Percentage occurrence of (a) all mammals, (b) rodents, (c) invertebrates and (d) seeds in eight altitude classes (1 = <500 m, 2 = 501 - 1000 m, 3 = 1001 - 1500 m, 4 = 1501 - 2000 m, 5 = 2001 - 2500 m, 6 = 2501 - 3000 m, 7 = 3001 – 3500 m, 8 = >3500 m).

6.4 Discussion

6.4.1 Encounter rate as an indicator of abundance

Most of the small carnivores are nocturnal and occur at low densities and therefore an estimation of their abundance based on direct sightings was not possible. Estimation of abundance based on photographic capture-recapture was also not possible, given the steep and inaccessible terrain. Sign surveys have been found to be an appropriate way to measure small carnivore abundance (Bonesi and MacDonald 2004). Therefore, I used encounter rates of scats as an index of abundance (Sutherland 1996).

However, there are several limitations to the use of scats as an indicator of abundance.

a. A comparison of encounter rates of sympatric viverrids, mustelids, felids and canids, is not possible since they have different defecation rates. For example, fruits form a major part of the diet of viverrids particularly palm civets (Mudappa 1999; Chiang 2007). Viverrids are therefore most likely to have a higher defecation rate, and thus show a higher scat encounter rate, than canids, felids, and mustelids. Felids, the most carnivorous, probably have the lowest defecation rate (e.g. 1 scat/day for house cats, Liberg 1984). Thus, encounter rates of sympatric small carnivores would be greatly influenced by their feeding ecology. In addition, some small carnivores are known to have different diets across large spatial scales. For example, Kaneko *et al.* (2006) summarised the diet of *Meles meles* from her study and other sources and found that the badgers were eating wheat in agricultural England, olives in coastal Italy, berries and beetles in southern Italy, plums and grapes in Spain, olives, fruits and insects in cork oak woodlands in Portugal, rodents in Switzerland, rabbits in the Mediterranean shrublands of Spain and earthworms in Japan. However, the diet of the same taxon in adjoining habitats can be expected to be more similar, hence defecation rates also may be similar.

b. Scat decay rate or its removal also varies among taxa. Seeds, which form a major part of viverrid scats, are likely to be removed by rodents (Livingston *et al.* 2005). On the other hand, hair from scats of felids, canids and mustelids are likely to persist for a longer time. Such differences in the decay rates would affect scat encounter rate.

Due to these reasons, in this study, I have only compared scat encounter rates of the same taxon in different habitats or altitude classes. This comparison assumes that defecation rates in adjoining habitats are similar. The relative percentages of scats of different taxa were also compared among different vegetation types, without comparing taxa with each other.

6.4.2 Altitudinal gradient

Species identification from scats could not be established; although a small number was identified using fecal DNA. Therefore, altitudinal variation in species richness in small carnivores could not be examined except for the leopard cat which showed its presence in a wide altitudinal range. The overall encounter rate of small carnivore scat did not show any change with altitude. However, between 500 m and 1500 m, scat encounter rate in all three groups were lower than in the other altitude classes. The effect of altitude was only significant on the scat encounter rate of mustelids. This was not surprising because mustelids are basically a Palearctic taxa with greater species richness in the higher altitudes of Sikkim (hog badger - *Arctonyx collaris*, Burmese ferret badger - *Melogale personata*, beech or stone martin - *Martes foina,* Siberian weasel - *Mustela sibirica*, yellow-bellied weasel – *M. kathiah*, stripe-backed weasel – *M. strigidorsa*, pale weasel - *M altaica*; Avasthe and Jha 1999), only one species (yellow-throated marten - *Martes flavigula*) also occurs in the lower altitudes (Grassman *et al.* 2005). In contrast, viverrid scat encounter rate decreased with increasing altitude, but for the low encounter rate in tropical broadleaf forest. The scat encounter rates of canids and felids did not show a clear pattern. However, the scat analysis results showed that the leopard cat (*Prionailurus bengalensis)* is widely distributed from the low to the higher altitudes.

Thus, altitude has a strong influence in structuring the small carnivore community in Sikkim. The lower altitudes are dominated by viverrids (common palm civet - *Paradoxurus hermaphroditus,* masked palm civet - *Paguma larvata,* small Indian civet - *Viverricula indica,* spotted linsang - *Prionodon pardicolor*), few canids (Indian fox - *Vulpes bengalensis,* jackal - *Canis aureus*), and small cats (jungle cat - *Felis chaus,* leopard cat - *Prionailurus bengalensis*). The higher altitude community consists dominantly of mustelids and high altitude species of canids and felids (Tibetan wolf - *Canis lupus chanko,* red fox - *Vulpes vulpes,* Tibetan fox - *Vulpes ferrilatus,* and Tibetan lynx - *Felis lynx*). A few species (binturong – *Arctictis binturong*, masked palm civet, large Indian civet, spotted linsang and leopard cat) also have been reported in the middle altitudes from 1800 m to 2800 m (Avasthe and Jha 1999). Small carnivore communities in the other areas also seem to follow altitudinal structures, although a dearth of altitudinal gradient studies on small carnivores restricts any comparison with other areas.

In the Western Ghats, where the altitudinal range is only from 400 m to 1200 m, the small carnivore community changed from a civet dominated one in the lower altitudes to Nilgiri marten (*Martes gwatkinsi*) dominated community in the higher altitudes (Kumar and Yoganand 1999). In Taiwan, altitude was found to be the strongest factor influencing the change in carnivore community composition with two distinct groups in low-mid altitude (comprising of Formosan ferret badger - *Melogale moschata*, masked palm civet, smaller Indian civet, crab-eating mongoose - *Herpestes urva*, leopard cats and feral cats - *Felis catus*) and mid-high altitude (comprising of yellow-throated marten and Siberian weasels; Chiang 2007).

6.4.3 Variation among vegetation types

In Sikkim, vegetation shows a sharp transition with altitude due to the steep gradients in the latter. Therefore, there is considerable overlap between the altitude gradient in small carnivores and their variation among vegetation types. One major difference among the four vegetation types was a higher encounter rate for mustelids in the two high altitude vegetation types (temperate broadleaf forest and coniferous forest). Although the other two groups did not show differences among vegetation types, both showed a decline in relative abundance in the higher altitude vegetation types. Felids and canids, however, occurred in all four vegetation types.

Overall encounter rates of viverrids, mustelids, canids and felids showed a significant difference in among vegetation types. The tropical broadleaf forest showed a lower encounter rate than the other forest typed for all the groups. This could be attributed to the land use pattern. Most of the forests in this vegetation type have been converted to cardamom plantations. In most areas only *Alnus nepalensis* is found, used as a shade tree for cardamom. This seems to have affected the abundance of small carnivore community in the tropical broadleaf vegetation, showing lower encounter rates for all groups of small carnivores.

The abundance of small carnivore did not show any overall relationship with the habitat parameters. However, mustelids used areas with higher tree density and greater small mammal abundance. The overall abundance of small carnivores, as expected, was also correlated to small mammal abundance, as rodents are an important prey for the group (Carvalho and Gomes 2004; Mukherjee *et al.* 2004). Small carnivore diet was more carnivorous at higher altitudes with the occurrence of small mammal and invertebrate remains in the scats increasing significantly and that of seeds decreasing in the higher altitudes. Besides small mammals, invertebrates are also known to be eaten by species like ferret badgers and oriental civets (Chiang 2007). Although mustelids (*Mustela nivalis* and *M. erminea*) have been found to feed on wild fruits (23.3% of scat volume), small mammals (41.5% of scat volume) still form a large part of their diet in the Alpine prairie in Italy (Remonti *et al.* 2007).

6.5 Summary

Small carnivores are one of the least studied mammal groups since most species are nocturnal in habit and are rarely sighted. I examined the influence of altitude and vegetation types on the composition and relative abundance of the small carnivore community. I also examined the variation in the diet of small carnivores in different vegetation types. I used scat encounter rate as an indicator of their abundance and sampled 27 belt transects in eight altitude classes between 230 m to 3700 m. Identification of scats of each species was difficult due to high species richness of small carnivore community in Sikkim, so they were divided into three groups: Mustelidae (martens and weasels), Viverridae (civets), and smaller species of Felidae (small cats) with Canidae (jackal and fox). 280 scats of small carnivores were recorded in a total transect length of 169.29 km, with an overall encounter rate of 1.65 scats/km. The encounter rate of scats varied among the four vegetation types and was highest in the coniferous forest (2.13 scats/km). Viverrid scats dominated the lower altitudes, whereas mostly Mustelid scat were encountered in the higher altitudes. The Canid and Felid scats were encountered through out all altitude classes. The over all encounter rate of scats increased with higher tree density along transects. Mustelid scats showed higher correlation with increasing altitude and decreasing slope. Small mammal abundance accounted for 37% of the variation in encounter rate of small carnivore scats. Frequency of occurrence of prey items such as plants, seeds, invertebrates, reptiles, birds, rodents and other mammals varied from tropical semi deciduous to coniferous forests. The occurrence of rodents was highest in scats from tropical broadleaf and coniferous forest, and seeds in temperate broadleaf forest.

Plate IV

Evidence of small carnivores in Sikkim


Mustelid scat


Vivverrid scat


Felid scat


Small mammal hairs in scat


Rodent dentition in scat


Camera trap picture of *Paguma larvata*

CHAPTER 7

CONSERVATION IMPLICATIONS

7.1 Introduction

Altitudinal gradients in body weight and species richness have been the subject of considerable debate in recent decades. Similarly, the influence of vegetation type and microhabitat preferences in shaping the community structure of small mammals has also been a subject of considerable research. In this study on small mammals and small carnivores along a steep altitudinal gradient and in different vegetation types in the Sikkim Himalaya, I have attempted to address some of the critical issues in the above debate. The results of this study have important implications for conservation of biodiversity in Sikkim.

7.2 Altitudinal gradient in body weight

Results of this study show that body weight of murid species declined with increasing altitude, whereas that of shrews increased. Body sizes relates to central processes responsible for functioning of an individual or species such as metabolism, life history as well as ecology. Long term data on body sizes from an altitudinal gradient can also be a basis to predict altitudinal migration of animals. Higher altitudes are directly related to lower temperatures, so in case of climate change effects, the lower altitude small mammals would gradually shift and compete with the higher altitude community.

Therefore, the high altitude small sized mammalian communities are more vulnerable to any changes in the temperature.

When pooled with data from published literature, the pattern in altitudinal gradient in body weights of murids seems to have a strong taxonomic basis, where the temperate genera increased in their body weights with an increase in the altitude (Bergmann's rule), whereas tropical genera showed a decrease. This can be further investigated to find the differences in the behaviour of small mammals such as burrowing habits and torpor from the tropical and temperate areas. Lack of such data from the tropical areas makes the responses of small mammals to altitude incomplete. However, more studies would provide an understanding of the differences in the response of tropical and temperate small mammals to altitude. This would also help and predict the altitudinal migration of animals following climate change.

7.3 Altitudinal gradient in species richness and composition

Small mammals are an interesting taxon to examine altitudinal gradient in species richness because of its high species richness and its sensitivity to environmental and habitat features due to its small size. The steep slope and sharp altitudinal gradient within only about 7000 sq km makes Sikkim an ideal area where the animal community consists of same regional species pool with no other confounding factors acting on them. The observed species richness pattern of small mammals was higher in the middle altitudes. It is expected that combination of this data and secondary data on non-volant mammals of Sikkim would show a higher species richness in the mid-altitudes. However, the application of MDE as a null model to examine altitudinal gradient in species richness, in a study like this, is constrained by two major factors. Firstly MDE requires a complete record of altitudinal ranges of species which is not possible to obtain by a single study like this where no information is available from literature or museum records. Secondly, MDE has been found to be ineffective where the altitude ranges of species are small. It is highly possible that most species in Sikkim would have smaller altitudinal ranges due to the sharp gradient. The absence of any secondary data on the species richness of this area and the low capture rates during this study did not provide adequate data for an analysis of the mid-domain effect. However, the observed and estimated species richness did show a mid altitudinal peak.

If this mid-altitudinal peak in species richness of small mammals in Sikkim is compared to the available secondary data on mammals of Sikkim (excluding the small mammals and bats; Fig. 1.1), a completely different picture on the species richness pattern would emerge. Secondary data on other mammals showed high species richness in the low as well as high altitudes. It is highly possible that, if all the species of small mammals and bats were included in the secondary data then the species richness curve of mammals would peak in low, mid and high altitudes in Sikkim, with small mammals responsible for the peak in the middle altitudes.. It should also be noted that this mid-peak may only be applicable to the small mammals and probably bats in Sikkim whereas the other mammalian taxa found in Sikkim are specialised for particular habitats, such as high altitude ungulates and mustelids which are only found in the sub-alpine and alpine habitats. Therefore, the applicability of mid-domain effect can only be tested among specific mammalian taxa like small mammals and possibly bats. Thus, there is also an urgent need for conducting more field-based mammalian studies in Sikkim to understand the other processes governing the community and appropriately manage the habitats for conservation. Besides the mid-domain effect, the information on the altitudinal distribution of species cannot be ignored as it would be valuable for conservation of species as well as habitats. This study shows the high conservation value of middle altitudes and at the same time the secondary data showed both the lower and higher altitudes to be important for conservation of other mammalian groups. The capture rates, although low compared to many other study sites, still showed gradient of increasing abundance with altitude, in the case of both murids and shrews. The higher capture rates in the high altitudes were primarily due to the increased capture rate of shrews.

In Sikkim, all the declared protected areas cover the temperate and alpine habitats whereas the tropical habitats are not represented. However, few tropical habitats such as Kitam Wildlife Sanctuary have been proposed as protected areas by the State Forest Department but they are very small areas (6 sq km). Areas with higher species richness including threats associated are an indicator for biodiversity hotspots. Therefore, considering the high species richness in the middle altitudes as well as the tropics, it becomes more important to conserve the tropical as well as temperate areas in Sikkim. Problems related to declaring more protected areas in the lower altitudes would be the high human population as well as conversions to agricultural land. Small carnivores as well as small mammals, which do not require large patches of forest, have been found to occur in the remnant patches of reserve forests in the lower altitude. Thus, adequate protection of these reserve forest are required in the lower altitudes to maintain the high species richness of mammals in Sikkim.

This study has also provided geo-referenced data on the occurrence (Appendix IV) and morphometry of several species of small mammals in Sikkim for the first time. This dataset would be of use in re-examining the distribution of these, and in the analysis of altitude gradients.

7.4 Selection of microhabitats by murids and shrews

Between murids and shrews, a clear and significant separation was seen in microhabitat use in the low altitude tropical forest but the same could not be confirmed in the high altitude temperate forest. Therefore the consistency in selection of microhabitats by murids and shrews could not be assessed. However, vegetation variables such as number of trees, mean GBH (girth breast height), total basal area of trees, canopy height and ground cover of herb and litter, separated the microhabitats of murids and shrews in the tropical forest. Therefore, it would be possible to predict the occurrence or abundance of murids and shrews within tropical habitats from microhabitat variables. In the high altitude temperate forest, *Niviventer eha* differed from other murid species in its use of lower canopy height, and higher number of shrub species and litter cover. The increase in number of trees was correlated to higher abundance among small mammals.

7.5 Small carnivore community

Small carnivore community showed differences in their composition in different altitudes as well as vegetation types, with viverrid species being dominant in the low altitudes and mustelid species in the high altitude. Viverrid scats were absent in the highest altitude class and no mustelid scats were encountered in the lowest altitude class. Among the vegetation types, the highest encounter rates of scat for canids and felids were in the tropical semi-deciduous forests, for viverrids in the temperate broadleaf forest and for mustelids in the coniferous forest. Thus distribution of small carnivores show clear differences among the three taxa- viverrids from the Indo-Malayan realm being in the lower altitude, mustelids from the Palearctic being in the higher altitude, while the canids and felids occurring in all altitudes. A separation of the canids and felids, based on scats was not possible.

Mustelids also have high species richness in Sikkim compared to any other areas in India. Therefore, mustelids should be a major focus of research and conservation efforts. One important factor related to small carnivore studies is that they are mostly nocturnal in habit and also occur in low densities. Therefore, studies based on direct sighting and camera trapping may not be feasible. Identification of small carnivore species from scats using fecal DNA is very important. However, only a few scats were used in this study due to the lack of suitable primer for identifying species so there is an urgent need to develop primers to identify different species of small carnivores. High species richness and distinct community composition of small carnivores in Sikkim are the most important reasons to strengthen conservation efforts and to conduct more field based research on these taxa.

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APPENDIX I

List of small mammal species captured in the North and South Districts of Sikkim with the old and new classification.

Wilson and Reeder 1993		**Wilson and Reeder 2005**	
Order: Family	**Scientific name**	**Order: Family**	**Scientific name**
Rodentia: Muridae	*Rattus blanfordi* (Ellerman 1961), *Cremnomys blanfordi* (Wilson and Reeder 1993)	Rodentia: Muridae	*Madromys blanfordi*
	Rattus sikkimensis		*Rattus andamanensis*
	Rattus turkestanicus		*Rattus pyctoris*
	Rattus rattus		*Rattus rattus*
	Rattus nitidus		*Rattus nitidus*
	Mus pahari		*Mus pahari*
	Mus musculus		*Mus musculus*
	Niviventer fulvescens		*Niviventer fulvescens*
	Niviventer eha		*Niviventer eha*
	Niviventer niviventer		*Niviventer niviventer*
	Pitymys sikimensis	Rodentia: Cricetidae	*Neodon sikimensis*
Insectivora: Soricidae	*Soriculus caudatus*	Soricomorpha : Soricidae	*Episoriculus caudatus*
	Soriculus nigrescens		*Soriculus nigrescens*
	Sorex sp.		*Sorex* sp.
	Crocidura sp.		*Crocidura* sp.
	Suncus murinus		*Suncus murinus*
Scandentia: Tupaiidae	*Tupaia belangeri*	Scandentia: Tupaiidae	*Tupaia belangeri*

APPENDIX II

Mean values of the microhabitat variables in the 28 trap lines from the North and South Districts of Sikkim.

Trap line	Trees			Shrub spp no.	Canopy		Slope (°)	Ground cover (%)							
	No.	GBH (cm)	Tot basal area (sq m)		Height (m)	Cover (%)		Herb	Litter	Rock	Soil	Fern	Grass	Ageratum	Others
1	2.8 (±0.9)	74.8 (±32.1)	2.36 (±1.66)	3.4 (±0.2)	21.0 (±1.9)	63.2 (±7.2)	56.0 (±4.9)	17.5 (±7.9)	43.5 (±5.1)	8.1 (±3.3)	12.4 (±3.3)	9.4 (±5.4)	2.1 (±1.3)	0.0	7.1 (±3.7)
2	3.0 (±1.2)	147.9 (±55.5)	7.34 (±4.28)	2.6 (±0.7)	23.0 (±2.0)	69.6 (±4.5)	38.0 (±4.6)	15.6 (±8.6)	22.3 (±1.7)	35.3 (±4.8)	9.1 (±5.9)	1.8 (±1.8)	0.9 (±0.9)	0.0	15.1 (±4.7)
3	2.5 (±1.1)	33.0 (±13.5)	0.50 (±0.26)	2.1 (±0.3)	8.3 (±2.2)	31.6 (±8.3)	38.3 (±3.5)	25.4 (±5.9)	24.8 (±6.0)	7.0 (±1.3)	21.3 (±4.3)	0.0	12.5 (±6.8)	0.0	14.5 (±4.7)
4	2.4 (±0.4)	143.4 (±32.7)	8.15 (±4.29)	3.1 (±0.4)	27.5 (±2.9)	58.0 (±7.0)	28.5 (±3.2)	35.9 (±5.3)	13.9 (±4.5)	13.1 (±2.5)	12.4 (±5.2)	9.5 (±4.2)	13.8 (±7.3)	0.0	0.0
5	2.4 (±1.2)	73.7 (±26.8)	1.86 (±1.39)	3.5 (±0.8)	16.7 (±3.9)	65.3 (±9.9)	30.0 (±3.4)	31.4 (±8.3)	30.6 (±7.9)	17.8 (±5.9)	7.2 (±3.3)	2.2 (±1.5)	0.0	0.0	10.7 (±3.1)
6	4.0 (±0.5)	69.1 (±6.4)	1.83 (±0.34)	3.2 (±0.4)	26.2 (±1.4)	60.8 (±8.1)	51.0 (±2.9)	35.8 (±2.7)	20.8 (±3.5)	7.9 (±2.9)	6.1 (±2.1)	8.3 (±3.5)	7.4 (±2.1)	0.0	13.6 (±1.7)
7	4.8 (±1.1)	90.3 (±14.1)	4.32 (±1.59)	0.0	25.0 (±2.6)	46.7 (±5.1)	2.0 (±1.0)	44.9 (±6.3)	9.7 (±3.6)	2.1 (±2.1)	0.0	0.0	0.7 (±0.7)	0.0	42.0 (±5.6)
8	5.0 (±1.7)	81.4 (±16.9)	2.48 (±0.70)	1.4 (±0.2)	13.5 (±1.9)	62.7 (±11.5)	2.5 (±1.1)	20.2 (±5.9)	38.5 (±14.5)	0.0	11.2 (±6.9)	1.5 (±0.9)	6.9 (±4.8)	0.0	34.5 (±9.8)
9	4.5 (±0.8)	93.7 (±16.9)	5.27 (±1.92)	1.5 (±0.2)	17.0 (±2.6)	42.0 (±8.1)	3.7 (±0.4)	26.8 (±2.4)	8.4 (±3.2)	11.5 (±3.7)	3.1 (±2.4)	0.0	9.3 (±7.6)	0.0	40.9 (±5.2)
10	4.2 (±0.9)	86.8 (±19.6)	2.42 (±0.71)	1.8 (±0.6)	10.4 (±2.7)	56.8 (±14.6)	3.2 (±0.7)	29.2 (±5.6)	36.7 (±8.1)	5.9 (±4.9)	3.3 (±2.1)	0.0	3.3 (±2.1)	0.0	21.5 (±4.2)
11	5.1 (±0.9)	81.4 (±8.3)	3.79 (±1.06)	2.2 (±0.5)	20.4 (±3.1)	48.6 (±4.4)	17.9 (±4.6)	23.6 (±5.2)	11.2 (±4.2)	22.1 (±6.4)	2.4 (±1.9)	0.5 (±0.5)	0.5 (±0.5)	0.0	39.7 (±7.5)
12	3.7 (±0.8)	123.2 (±31.4)	3.77 (±1.17)	1.8 (±0.3)	15.8 (±2.2)	41.3 (±5.7)	1.8 (±0.4)	33.9 (±4.2)	28.8 (±9.8)	1.3 (±1.3)	2.7 (±2.7)	3.2 (±1.7)	9.1 (±5.5)	0.0	21.1 (±3.1)

Trap line	Trees			Shrub spp no.	Canopy		Slope (°)	Ground cover (%)							
	No.	GBH (cm)	Tot basal area (sq m)		Height (m)	Cover (%)		Herb	Litter	Rock	Soil	Fern	Grass	Ager atum	Others
13	3.3 (±0.6)	100.1 (±13.5)	2.98 (±0.61)	3.0 (±0.4)	20.1 (±1.4)	43.0 (±7.1)	36.9 (±6.8)	12.3 (±2.2)	35.1 (±4.4)	14.9 (±3.3)	29.4 (±4.2)	0.0	6.4 (±3.4)	0.0	1.8 (±1.8)
14	2.8 (±0.6)	55.3 (±5.8)	0.78 (±0.25)	2.4 (±0.6)	16.4 (±1.6)	52.8 (±8.1)	26.0 (±5.3)	9.1 (±1.6)	43.1 (±3.1)	16.1 (±2.5)	14.2 (±6.8)	0.0	6.7 (±4.3)	2.1 (±2.1)	7.1 (±3.5)
15	2.6 (±0.3)	94.9 (±8.4)	1.88 (±0.29)	2.4 (±0.4)	15.8 (±1.1)	38.7 (±5.9)	63.3 (±7.9)	21.1 (±2.6)	18.1 (±3.2)	5.6 (±1.7)	5.6 (±1.7)	29.1 (±3.1)	16.1 (±3.4)	1.4 (±1.4)	3.3 (±2.1)
16	2.0 (±0.6)	118.1 (±17.2)	2.13 (±0.32)	3.2 (±0.6)	19.8 (±1.2)	44.0 (±9.8)	41.0 (±2.9)	8.3 (±2.8)	41.1 (±4.1)	19.9 (±5.7)	15.1 (±5.8)	2.5 (±2.5)	0.0	0.0	13.3 (±3.5)
17	3.7 (±0.6)	81.7 (±16.8)	2.86 (±1.01)	4.0 (±0.5)	17.7 (±2.2)	57.3 (±9.7)	40.8 (±3.5)	27.1 (±2.3)	22.5 (±5.2)	18.1 (±4.7)	16.4 (±5.3)	0.0	4.1 (±1.5)	0.0	10.3 (±1.7)
19	2.9 (±0.6)	77.4 (±18.9)	1.89 (±0.84)	3.0 (±0.3)	13.7 (±1.9)	26.3 (±5.9)	65.7 (±8.8)	16.7 (±3.1)	25.7 (±2.9)	9.8 (±2.4)	7.1 (±3.1)	11.1 (±8.1)	24.4 (±6.8)	0.0	5.3 (±2.9)
20	1.8 (±0.5)	99.1 (±25.5)	1.99 (±0.91)	3.2 (±0.4)	27.6 (±5.1)	56.8 (±11.4)	50.0 (±8.5)	33.9 (±2.6)	6.9 (±2.7)	9.8 (±2.6)	11.4 (±2.7)	18.1 (±3.2)	6.9 (±2.7)	0.0	13.7 (±3.7)
21	3.8 (±0.5)	74.4 (±4.8)	1.77 (±0.26)	2.0 (±0.4)	25.6 (±3.5)	79.2 (±6.1)	66.0 (±4.0)	23.4 (±5.7)	29.5 (±5.2)	7.3 (±5.4)	10.8 (±3.6)	12.9 (±3.9)	5.8 (±3.6)	0.0	10.2 (±3.9)
22	1.8 (±0.4)	116.9 (1±1.5)	2.35 (±0.72)	1.5 (±0.5)	24.4 (±2.4)	52.8 (±12.5)	38.0 (±7.0)	44.1 (±3.7)	19.1 (±4.3)	6.3 (±2.5)	2.9 (±1.7)	15.4 (±3.1)	2.9 (±1.7)	0.0	9.4 (±3.6)
23	1.4 (±0.2)	108.2 (±21.1)	1.44 (±0.41)	1.6 (±0.2)	25.8 (±4.1)	48.8 (±12.2)	33.0 (±12.1)	48.3 (±5.3)	12.4 (±5.6)	9.2 (±3.4)	6.6 (±4.7)	7.5 (±2.4)	8.6 (±2.9)	0.0	7.5 (±3.9)
24	2.0 (±0.3)	80.3 (±6.5)	1.08 (±0.16)	1.5 (±0.2)	23.9 (±1.9)	76.4 (±6.5)	26.3 (±5.5)	61.8 (±3.9)	23.5 (±2.9)	4.6 (±2.2)	1.8 (±0.7)	0.0	0.9 (±0.7)	0.0	7.5 (±1.7)
25	1.0	39.1 (±25.8)	0.34 (±0.25)	2.6 (±0.4)	11.2 (±3.1)	12.0 (±8.0)	59.0 (±5.8)	14.4 (±4.5)	20.0 (±3.3)	5.6 (±3.9)	3.2 (±1.5)	4.8 (±2.9)	32.0 (±42.2)	0.0	20.0 (±3.8)
26	1.0	132.4 (±40.5)	1.89 (±0.69)	3.0 (±0.7)	24.4 (±4.9)	60.0 (±18.2)	69.0 (±3.7)	25.2 (±5.5)	28.0 (±5.1)	2.4 (±1.6)	9.9 (±1.9)	6.7 (±5.1)	11.1 (±3.9)	0.0	16.9 (±2.8)
27	1.5 (±0.5)	85.9 (±27.4)	0.92 (±0.32)	3.0 (±0.4)	22.0 (±4.2)	44.0 (±17.1)	64.0 (±3.3)	50.0 (±7.6)	8.2 (±5.1)	1.6 (±1.6)	2.4 (±2.4)	30.5 (±6.7)	0.8 (±0.8)	0.0	6.5 (±2.1)
28	1.00	190.3 (±42.4)	3.41 (±1.53)	2.0 (±0.4)	28.2 (±2.6)	79.2 (±9.4)	62.0 (±2.6)	47.7 (±7.7)	7.2 (±3.9)	7.8 (±3.2)	1.5 (±1.5)	29.4 (±7.2)	0.0	0.0	6.3 (±1.6)

APPENDIX III

Pearson's correlation matrix for the total encounter rate of small carnivores and the mean vegetation variables in the transects from North and South Districts of Sikkim.

(* ER- Total encounter rate of small carnivore scats, Alt- Altitude, GBH- girth breast height of trees, Cp- Canopy)

	Encounter rate	**Altitude**	**Tree no.**	**GBH**	**Basal area**	**Shrub no.**	**Herb**	**Litter**	**Rock**	**Soil**	**Fern**	**Grass**	**Ageratum**	**Others**	**Canopy height**	**Canopy cover**
Altitude	.533**															
Tree no.	.487**	.464*														
GBH	-.149	-.092	-.151													
Basal area	.221	.288	.333	.602**												
Shrub no.	-.119	-.447*	-.304	-.052	-.045											
Herb cover	-.236	.074	-.149	.257	-.008	-.378										
Litter cover	.222	-.079	.121	-.283	-.265	.193	-.596**									
Rock cover	-.073	-.241	.064	.173	.443*	.389*	-.422*	.072								
Soil cover	.026	-.416*	-.075	-.165	-.053	.463*	-.550**	.487**	.301							
Fern cover	-.221	-.404*	-.426*	.346	-.139	.122	.314	-.438*	-.305	-.283						
Grass cover	-.097	.010	-.270	-.319	-.182	.092	-.329	-.050	-.250	.040	.047					
Ageratum	-.078	-.357	.010	-.198	-.218	-.011	-.312	.244	.067	.096	.114	.118				
Others cover	.449*	.801**	.617**	-.155	.207	-.503**	-.041	-.179	-.079	-.370	-.445*	-.106	-.219			
Canopy height	-.278	-.248	-.131	.582**	.317	.038	.496**	-.437*	.073	-.156	.367	-.421*	-.193	-.210		
Canopy cover	.052	-.066	.125	.420*	.229	-.034	.337	.081	.141	-.056	.084	-.692**	-.095	-.145	.585**	
Slope	-.355	-.600**	-.643**	.044	-.364	.540**	-.105	-.082	-.023	.141	.640**	.294	.040	-.629**	.249	-.007

** Correlation is significant at the 0.01 level.

* Correlation is significant at the 0.05 level.

APPENDIX IV

Coordinates of the transects or the trap lines in the North and South Districts of Sikkim along the Teesta River Basin.

Transect no.	Transect area	Coordinates	
		North	East
1	Dogra	88.571	27.696E
2	Bop	88.667	27.786E
3	Khadum	88.695	27.624E
4	Mentsethang	88.619	27.627E
5	Polay	88.671	27.619E
6	Below Bop	88.735	27.649
7	Yumthang-1	88.710	27.810
8	Yumthang-2	88.711	27.815
9	Singba start	88.702	27.783
10	Singba end	88.729	27.782
11	Above rest hs	88.703	27.798
12	Near hot spring	88.706	27.795
13	Melli	88.458	27.104
14	Rangit valley	88.420	27.088
15	Sankalan	88.30	27.29
16	20th mile	88.486	27.210
17	Pabong	88.461	27.244
18	Dalep	88.474	27.238
20	D-Pakshep	88.538	27.509
21	Pakshep	88.545	27.515
22	Lantay	88.563	27.516
23	Singhik	88.559	27.509
24	Rangma-O	88.636	27.610
25	Lachung-K	88.753	27.683
26	Lachung-H	88.749	27.682
27	Passingthang	88.515	27.525
28	Lingbo	88.517	27.524