Distribution and Resource Use Patterns of Reptiles along the Teesta Valley, Eastern Himalayas, Sikkim, India

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DEGREE OF DOCTOR OF PHILOSOPHY

in
ZOOLOGY

by
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CERTIFICATE

This is to certify that the thesis entitled, **"Distribution and resource use patterns of reptiles along the Teesta Valley, Eastern Himalayas, Sikkim, India"** is a record of original work done by Ms. Basundhara Chettri in the Division of Conservation Ecology, Sálim Ali Centre for Ornithology and Natural History, as a full time Research Scholar during August 2002 – November 2007 under my guidance and supervision for the award of the Degree of Doctor of Philosophy in ZOOLOGY. I further certify that this research work has not previously formed the basis for the award of any other Degree or Diploma or Associateship or Fellowship or other similar title to this or any other candidate in any University.

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DECLARATION

I, DO HERBY DECLARE THAT THE THESIS ENTITLED **"Distribution and resource use patterns of reptiles along the Teesta Valley, Eastern Himalayas, Sikkim, India"** submitted to the Bharathiar University, Coimbatore, for the award of the Degree of Doctor of Philosophy in ZOOLOGY, is a record of original and independent research work done by me from August 2002 to December 2007 under the guidance and supervision of Dr. S. Bhupathy, Senior Scientist, Division of Conservation Ecology, Sálim Ali Centre for Ornithology and Natural History, Coimbatore and it has not previously formed the basis for the award of any other Degree or Diploma or Associateship or Fellowship or other similar title to this or any other University.

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Signature of the Candidate

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Acknowledgement

It was an important turning point in my life when I was selected as a Research Fellow of the project, “Ecology of mammals, birds, herpetofauna and butterflies in Sikkim” by Sálim Ali Centre for Ornithology and Natural History (SACON), funded by the Ministry of Environment and Forests, Govt. of India through Centre for Interdisciplinary Studies of Hill and Mountain Environment, University of Delhi. The project work had to be undertaken in the difficult mountainous terrain of Teesta valley starting from 300 to 4800 m altitude above the sea level. From the beginning of the project till this date, I have received help, support, encouragement, guidance and suggestions from various institutes and personnel. Here I'm expressing my gratitude to all those who have helped me in various ways.

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SUMMARY

Understanding factors governing the geographical distribution pattern of species remains the central focus in community ecology (Pianka, 1966a; MacArthur, 1972). Irrespective of taxa and region, higher diversity of species is found in tropics compared to temperate conditions (Rohde, 1992). The study on species distribution along the altitude, although initiated long back (Grinnell and Storer, 1924), has got due attention only in recent years. Although many studies especially on birds and mammals have documented the relationship between species richness and altitude, generalized patterns are lacking (Brown, 2001).

Compared to other taxa, studies on the distribution patterns of reptiles along the altitudinal gradient are scanty despite their importance in proposing conservation strategies. Considering the lacuna, the present study was initiated with the following objectives: (1) to understand aspects of reptile populations (2) to document reptile distribution patterns along the altitude gradient and the factors governing the same, and (3) to understand the resource utilization patterns of reptiles along the Teesta valley, Sikkim, India.

Sikkim (27° 5′ - 28° 10′ N and 88° 4′ - 88° 58′ E), located in the Eastern Himalayas has an area of 7096 km². The present study was carried out along the Teesta valley from June 2003 to March 2006. Teesta River is the major physical feature of Sikkim, and within 85 km, it descends from its source Chholahmu Lake (4800 m) to Rangpoo (300 m), bordering West Bengal state, India. Due to the wide variations of altitude (300-4800 m) and climate (tropical-arctic), Sikkim becomes an ideal area for study on distribution pattern of biota. In the present study, the entire altitude range was divided into seven zones with 500 m interval; zone I (<500 m), II (500-1000 m), III (1000-1500 m), IV (1500-2000 m), V (2000-2500 m), VI (2500-3000 m) and zone VII (>3000 m). Since reptile species were not observed above 3000 m during this study, the same was considered as single zone.

Considering the topography and altitude of the study area and logistics available, time constrained visual encounter survey (Heyer *et al.*, 1994) was used for sampling reptiles. Sampling was restricted largely to day hours (0900/1000 hrs to 1200/1300 hrs). This method involved searching for reptiles, examining all possible microhabitats such as boulders, fallen logs and decayed roots by two personnel throughout the study. Other sampling methods such as transect, road cruising and night survey along the stream were done initially. As the encounter rate of reptiles was low in these methods, they were discontinued and data were excluded from higher analyses, barring estimation of total species richness and morphometric analyses. Data were analyzed using various statistical tools and computer softwares / programmes such as Microsoft Excel, SPSS, EstimateS and Mid-Domain Null Model.

Visual encounter survey for 2494 man-hours resulted in 1596 reptiles, which included 663 snakes and 933 lizards. In all, 42 species (14 lizards and 28 snakes) belonging to 32 genera comprising of five families each of lizards and snakes have been observed. No chelonians were observed during this study.

Shannon-Weiner (H′), Hill's diversity ($e^{H'}$) and Evenness (E) were high for lizards compared to snakes, whereas snakes had high species richness. Among snakes, the family Colubridae contributed the highest of 18 (64.3 %) species and the least by Boidae with only one species. Among lizards, Gekkonidae with five species (35.7 %) was the most contributing family with respect to species. Of the ten families of reptiles, three were represented by single genera and species (Lacertidae, Varanidae and Boidae). In terms of abundance, lizards contributed 58.5% of the total abundance of reptiles and the rest by snakes (41.5%). Members of Scincidae were most abundant (596 individuals) followed by Colubridae (551 individuals). Among lizards, *Asymblepharus sikimmensis* had maximum relative abundance (36.55%) and minimum by *Cosymbotus platyurus*, *Calotes jerdoni*, *Oriotaris tricarinata* and *Varanus bengalensis* (each contributing only 0.11%). Among snakes, maximum relative abundance was shown by *Trachischium guentheri* (68.02%) and minimum (0.15% each) by *Oligodon albocinctus*, *Python molurus*, *Rhabdophis subminiatus*, *Bungarus bungaroides* and *Ophiophagus hannah*.

Among lizards, *Varanus bengalensis* and *Hemidactylus bowringii* were the largest and smallest species encountered and in snakes it is *Python molurus* and *Typhlops* sp. respectively. Size structure obtained for overall reptile species, and separately for lizards and snakes showed that the highest proportion of species were small bodied. Of the nine species considered for morphometric analysis, all high altitude species showed unimodal right skewed pattern, whereas the lower altitude species showed both unimodal (typical bell shaped) and bimodal patterns.

Six species of reptiles were considered for testing the applicability of Bergmann's rule. Body length (maximum SVL) showed positive relation with altitude. Two widely distributed and common species, *Japalura variegata* (800 - 2200 m) and *Amphiesma platyceps* (700-2600 m) were considered for detailed analysis. *J. variegata* showed positive correlation between SVL and altitude (Pearson correlation $r = 0.41$, $P = 0.000$). Although, *A. platyceps* showed increase in size with altitude, the relationship was not statistically significant.

Variation in species richness among different altitude zones studied was significant. Maximum of 21 species was observed in zone II (500-1000 m) and minimum of three species in zone VI (2500-3000 m) and none above 3000 m. The species richness decreased linearly with altitude ($R^2 = 0.93$, $P < 0.000$). The decline was abrupt in high altitude zones. Species diversity also showed linear decrease with altitude ($R^2 = 0.96$, $P < 0.005$). Equitability though showed declining trend with altitude, the relationship was not significant. Species abundance showed maximum at zone VI (2500-3000 m) and minimum at zone IV (1500-2000 m). Maximum number of exclusive species (restricted to single zone) was found in zone I followed by zones III, II and none beyond 2000 m (zones V and VI) indicating the wide altitudinal distribution of high altitude species.

Non-parametric estimators such as Chao2, Jackknife1 and Jackknife2 were used for estimating species richness (EstimateS, Colwell, 2005). This study revealed that Jackknife2 as an appropriate estimator to assess the biodiversity along the Teesta valley. Species accumulation curve did not reach an asymptote except in zone IV and VI.

Observed species and Jackknife2 estimator when plotted against altitude controlling for individuals (50, 100, 150 and 200) showed closer value between observed species richness and estimated richness when the sample size was 50 individuals. However, the estimated richness increased as the sample size becomes larger indicating the probability of obtaining more species with higher effort, especially in lower altitudes.

Most reptile species of Teesta valley had narrow distribution range along the altitude. Of the 42 species observed, 13 were restricted to one altitude zone, and 17 to two zones. Range profile showed that most of the high altitude species extended their range towards lower altitude. Similarity of species between altitude zones showed two clusters, (in high and low altitude) with 1000 m as a transition zone. Species turnover rate was lower than 50% indicating the low overlap of species between consecutive zones. Comparatively higher turnover was observed between zone II (500-1000 m) and zone III (1000-1500 m) among adjacent zones.

Mid-Domain Null Model simulation (McCain, 2004a) showed deviation at 500-1000 m, where the empirical species richness was higher than the predicted curve. Low value of regression between empirical and simulated richness indicates that the distribution of reptiles along the Teesta valley was not fully governed by geographical hard boundaries. Data showed that temperature played major role in determining distribution of reptiles along the altitudinal gradients of Teesta valley.

Data on microhabitat, vertical position (from ground) and temporal dimensions were clumped into eleven, nine and twelve categories respectively. Maximum species (16.1%) as well as abundance (37.32%) of reptiles were using under-boulder microhabitat. Minimum of 2.54% reptile species utilized shrubs. Similarly in vertical strata, maximum species (45.83%) as well as abundance (90.67%) used ground (0 cm). Maximum species (86%) and abundance (90%) of reptiles were observed from March to October, with peak during July. Only 14% of species and 10% of abundance were observed from November to February, the colder months of Teesta valley.

Usage of resources (microhabitat, vertical strata and time) by reptiles showed significant variations along the altitude gradient. Percentage of species found on logs and ground covered microhabitat showed positive correlation with altitude, whereas species on artificial structures showed negative correlation. With the increase of altitude, the use of various vertical strata decreased. Reptiles using maximum vertical strata were found in the lowermost (<500 m) and middle (1000-2000 m) altitudes. Percentage of species on ground (0 cm) increased with altitude, whereas usage of higher vertical strata (>210 cm) decreased with altitude. Number of months with reptile observation decreased significantly with increasing altitude ($P < 0.001$). No reptiles were sighted above 1500 m from November to January.

Principal component analyses showed that tree related factors such as tree number, litter and canopy cover positively influenced factor loadings in the lower two zones (<500 and 500-1000 m). In three higher zones (1000-1500, 1500-2000 and 2000-2500 m) boulders and other microhabitats (gravel, moss, fern, sand) positively influenced the distribution of reptile species. In 2500-3000 m, herb cover had positive influence on PC I.

For niche analysis, 38 resource categories belonging to 26 spatial (6-habitat, 11-microhabitat, 9-vertical position) and 12 temporal (month) were considered. Overall niche breadth was low in vertical position compared to habitat, microhabitat and temporal dimensions. Both lizards as well as snakes were specialists, as all species fell <50% of niche breadth. Snakes were relatively more specialists compared to lizards in Teesta valley.

Among 45 pairs of lizard species, none of them showed complete overlap in microhabitat and temporal dimensions, whereas three pairs showed complete overlap in macrohabitat and 11 pairs in vertical dimensions. Among 78 pairs of species, six pairs in macrohabitat and 45 pairs in vertical dimension showed complete overlap, whereas in microhabitat and temporal dimension none of the pairs showed complete overlap.

According to MacArthur's latitude-niche breadth theory (MacArthur, 1972), average niche breadth of the community becomes narrower towards tropics due to stable climatic condition. Since, altitude is reported to mirror the latitude, similar result is expected along the altitude. In the present study, the average niche breadth of overall reptiles (average of three resources) showed declining trend with increasing altitude, though the relation was not significant. Result of the present study is not consistent with the latitude-niche breadth theory.

Most reptiles of the Teesta valley are highly specialized to specific habitats and altitude zones as 60% showed narrow (<1000 m) altitude ranges and none of the species occurred in all the six altitude zones. The species richness was higher in lower altitude forests with more number of species exclusive to particular altitude zones. Hence, the present study suggests for conserving the forests and maintaining its contiguity along the altitude gradients of the Teesta valley. The study recommends to extend the protected areas to the remaining forest patches of lower altitudes (<1000 m) which is fast depleting with the unsustainable developmental activities.

CHAPTER 1

INTRODUCTION

"*Sikhim Himalaya, probably no other country of equal or large extent on the globe can present so many features of interest or so many problems for the solution to the thoughtful naturalist.*"

George A. Gammie (1928)

INTRODUCTION

1.1. BACKGROUND

The patterns and diversity of nature bewildered human being since time immemorial. Distributional patterns of species in latitude as well as altitude got considerable attention from many ecologists and biologists across the globe (Grinnell and Storer, 1924; Terborgh, 1971, 1977; Rahbek, 1995, 1997; Brown, 2001; Lomolino, 2001; McCain, 2003, 2004b, 2005). In this regard, several questions were put forth by the researchers; "why some species are restricted to tropics while others in poles and similarly why some species are found at the summit of the mountain while others at sea level? What is the relationship between species richness and altitude?" These questions were addressed by many scientists working on various taxa, and attempted to formulate patterns, but the generality of such pattern is yet to emerge.

Grinnell and Storer (1924) conducted pioneering study on the distribution pattern of species richness and reported a humped shaped pattern along the altitude gradient. Since then many studies were attempted on this subject covering taxa such as mammals (Patterson *et al.*, 1996, 1998; Brown, 2001; Heaney, 2001; Md. Nor, 2001a; Rickart, 2001; Sanchez-Cordero, 2001; Li *et al.*, 2003; McCain, 2004b, 2005, 2006) and birds (Terborgh, 1977; Navarro, 1992; Blake and Loiselle, 2000; Kessler *et al.*, 2001; Latta *et al.*, 2003; Kattan and Franco, 2004; Raman *et al.*, 2005). Relatively a few studies are available on this aspect in herpetofauna (Scott, 1976; Daniels, 1992; Raxworthy *et al.*, 1997; Hofer *et al.*, 1999; Vasudevan *et al.*, 2006; Naniwadekar and Vasudevan, 2007).

The eastern Himalayas, that includes Sikkim, is one of the biodiversity hotspots of the world (Mittermeier *et al.*, 2005). Jayaram (1974) highlighted the rich herpetofaunal diversity of Eastern Himalayas. Northeast India harbors diverse reptile fauna with high proportion of endemics (39.1% of the 522 known species) and considerable numbers of them are threatened species even though, exact figure is not available (Conservation International, 2006). A few new species of reptiles have been reported from northeast India (e.g. *Cnemaspis* - Das and Sengupta, 2000; *Lycodon* - Slowinski *et al.*, 2001; *Trimeresurus medoensis* - David *et al.*, 2001) in recent years. Prioritization of area for biodiversity conservation in India and elsewhere is largely based on mammals and birds (Conservation International, 2006). Pawar *et al.* (2007) used herpetofauna to evaluate the conservation status of the Himalayas.

Sikkim is included in Himalayan Biogeographic Zone by Rodgers and Panwar (1988). The state has hilly terrain without considerable flat land and forms catchment of the river Teesta. River Teesta is one of the major physical features of the state, which originates from the snow fed Chholhamu Lake at about 4800 m above sea level and within a short course of about 85 km it traverses a variety of climate (Arctic-Tropical), vegetation (Alpine meadows-Tropical forest) types, and altitude (4800-300 m) prior to entering West Bengal state at Rangpoo. Teesta valley with wide altitude range representing various bioclimatic zones and associated forest types provides ideal setting for studying altitude distribution pattern of biota. Barring distributional records and occasional explorations (Gammie, 1928; Waltner, 1973; Swan, 1993;Ganguli-Lachungpa, 1998; Shaw *et al.*, 1999; Jha and Thapa, 2002), data on general ecology of reptiles of Sikkim are scanty. Besides, no studies are available on the distribution pattern of herpetofauna on large landscape level in Himalayas including Sikkim. Hence, the present study was initiated with the following objectives.

1.2. OBJECTIVES

1. Assess the population status of reptiles with respect to species richness and diversity along the Teesta valley,
2. Determine distribution pattern of reptiles with respect to altitude and factors governing the same, and
3. Study the resource utilization patterns at spatial and temporal dimensions along the altitude gradient.

Ecological communities evolved as a consequence of interactions of component (species) populations. According to Crump (1982), in a nature, two types of interactions between animals are usually considered; predation (between trophic levels) and competition (within a trophic level). Population ecology deals with number, density, age structure, reproduction, sex ratio, natality and mortality (Parker and Plummer, 1987). Relative or absolute number of species (richness) of an area is important in prioritization for conservation (Myers *et al.*, 2000). Efforts to study the population attributes of reptiles are few compared to birds and mammals (Begon *et al.*, 1996a, b; Odum, 1996). Reptiles form important component of many ecosystems serving both as prey and predators (Winne *et al.*, 2005). Body size of a species is considered to be one of the most important life history characteristics reflecting age, size at maturity, sexual dimorphism and habitat utilization (Vitt, 1987; Roff, 1992).

It is reported that in the mountain system, species richness reaches high at the base and low at the summit. This pattern is due to changing climate and vegetation types (Yu, 1994). Many ecologists attempted to investigate the patterns of species distribution along the altitude gradient across various habitats, taxa and the factors governing the same (Rahbek, 1995, 1997; Patterson *et al.*, 1996, 1998; Brown, 2001; Heaney, 2001; Lomolino, 2001; Vetaas and Grytnes, 2002; Li *et al.*, 2003; Sanders *et al.*, 2003; McCain, 2004b, 2005, 2006, Naniwadekar and Vasudevan, 2007). Understanding the factors governing species distribution along the altitude gradient may provide insights on the biodiversity and their conservation (Vetaas and Grytnes, 2002).

Distribution of species along the altitude gradient shows three general patterns: (i) a monotonic decline in species richness from low to high altitude (Heatwole, 1982; Graham, 1990; Patterson *et al.*, 1996; Md. Nor, 2001b) (ii) a hump-shaped pattern with a peak at mid altitude (Graham, 1990; Rahbek, 1995, 1997; Patterson *et al.*, 1998; Heaney, 2001; Li *et al.*, 2003; McCain, 2003, 2004a) and (iii) increase in number of species with increase in altitude (Sanders *et al.*, 2003; Naniwadekar and Vasudevan, 2007). Lomolino (2001) reported that latitudinal and altitudinal gradient behave in similar way, and hence monotonic decrease of species richness with increasing altitude is expected as the general pattern, similar to the decline of species from equator to poles (Rahbek, 1997).

Any component of an ecosystem either at spatial, trophic or temporal levels that is used by organisms may be considered as resource. Study on resource utilization pattern provides insights on the requirements/use of resources by an organism or community. Data on habitat use of rare and endemic species are useful in formulating conservation and management plans (Bright and Morris, 1990; Buhlmann, 1995; Beauchamp *et al.*, 1998). Niche and resource utilization is considered as central theme for explaining species coexistence and diversity (Tokeshi, 1999). Pianka (2000) summarized the ecological niche as the "sum total of the adaptations of an organismic unit". The unit of resource utilization in a particular niche dimension is niche breadth and the extent of co-utilization of the same resources by two organismic units (species) in one or more dimensions is niche overlap (Noon, 1981).

Based on studies in three continents, Pianka (1975) reported that average summation overlap (sum of different niche dimensions) negatively correlated with species density (a measure of species richness). According to "latitude-niche breadth hypothesis" (MacArthur, 1972) niche breadth decreases with decreasing latitude i.e. niche breadth becomes narrower towards the tropics. This is in consistence with Rapoport rule (Tokeshi, 1999). Taxa occurring in lower latitude have a narrower or more specialized niche compared to high latitude counterparts, as a consequence, higher numbers of species are found in tropics. Whether a narrow niche is a cause or an effect of high species richness is debatable (Tokeshi, 1999). Altitude is considered as proxy for latitude

(Brown, 2001). It is assumed that narrow niche breadth of species in tropics or lower altitude reduces competition leading to coexistence of many species. According to Tokeshi (1999) narrow niche breadth might not have given rise to high species diversity, but it may be an adaptation for coexistence in species rich regions.

1.3. STUDIES IN INDIA

The difficulties in observation, extended period of inactivity, low density and secretive nature of most species of reptiles have resulted in limited studies, especially in the tropical region (Parker and Plummer, 1987). Available information on the reptiles of India are largely based on surveys. The compilation by Smith (1931, 1935, 1943) is the single most authoritative data bank on reptiles of the Indian subcontinent. Daniel (2002) provided data on natural history of Indian reptiles along with key identification characters. Photographic plates of Indian reptiles with brief natural history information are available in Das (2002). The book on snakes by Whitaker and Captain (2004) provides information on 157 out of 270 Indian species with colorful photographs.

A few ecological studies available in India are mostly confined to Western Ghats. Inger *et al.* (1987) provided information on the habitat use and resource utilization in microhabitat dimension of herpetofauna dwelling in Ponmudi Hills, Western Ghats, Kerala. Brown (1992a, b) analyzed microhabitat use of reptiles in South India. The distribution, habitat and microhabitat use by Agamid lizards in Western Ghats was reported by Bhupathy and Kannan (1997). Ishwar *et al.* (2001) documented the distribution of reptiles in the rainforest of Western Ghats, South India. Nixon (2005) and Mukherjee (2007) provided the resource utilization patterns of reptiles in wet montane shola of Nilgiris and mixed dry deciduous forest of Anaikatty Hills, Western Ghats respectively.

In-depth ecological studies on reptiles of Northeast India have been initiated only during recent years. Waltner (1973) documented the distribution pattern of reptiles inhabiting Himalayas. Pawar (1999) studied the effect of habitat alteration on herpetofaunal assemblages in Mizoram. Shrestha (2001) compiled the information on the distribution pattern of reptiles of Nepal including Eastern Himalayas. Prioritization of area based on reptiles and amphibians and their role in conservation assessment of the Northeast India on the whole was provided by Pawar *et al.* (2007). Other studies are mainly surveys and related to taxonomy (Das and Sengupta, 2000; David *et al.*, 2001; Slowinski *et al.*, 2001). Massive destruction of habitat in Himalayas and the impact on fauna including herpetofauna has been discussed by Pandit *et al.* (2007).

In India, little efforts were made to study the altitude patterns of species. Most of the available studies were done in the hill ranges of Southern India. Ishwar *et al.* (2001) documented altitude pattern of lizards and snakes in Southern Western Ghats. Vasudevan *et al.* (2006) compared turnover of amphibians in two hill ranges of Western Ghats, India. Naniwadekar and Vasudevan (2007) and Raman *et al.* (2005) documented diversity patterns of anuran distribution and bird species richness respectively, along the altitude gradient of Western Ghats.

Few studies are available on the altitude distribution of reptiles in Himalayas. Waltner (1973) provided some data on the altitude distribution of reptiles along the entire Himalayas including Sikkim and Darjeeling. Waltner (1991) documented altitude distribution of Agamid (*Agama tuberculata*) in Western Himalayas. Swan (1993) reported the reptile fauna of the Darjeeling-Sikkim Hills and Khasi Hills and interrelations among them at species level.

Information on the distribution of reptiles of Eastern Himalayas, which includes Sikkim, is scanty (Smith, 1931, 1935, 1943; Shaw *et al.*, 1999; Shrestha, 2001; Daniel, 2002; Whitaker and Captain, 2004). The information specific to reptiles of Sikkim is meager. Gammie (1928) provided a checklist of reptiles of Sikkim with some data on location and altitude. Ganguli-Lachungpa (1998) listed 26 species of reptiles from Sikkim. Jha and Thapa (2002) listed 61 species from Sikkim, which is largely based on literatures such as Smith (1935, 1943) and Ganguli-Lachungpa (1998).

Studies on the altitude pattern of various biota in neighbouring countries are few. Bhattarai and Vetaas (2003) documented plant species richness along a subtropical altitude gradient in the Himalayas, east Nepal. Altitudinal distribution of ferns was studied in Central Himalaya, Nepal by Bhattarai *et al.* (2004). Carpenter (2005) reported the role of environmental parameters on plant species density on altitude gradient of Himalayas. Studies on altitude distribution pattern of plants (Yu and Saprunoff, 2005) and mammals (Li *et al.*, 2003) are also available from China.

Considering the rich diversity of reptiles in India, the current knowledge on the Indian reptiles is meager. Relatively few studies are available on herpetofauna of Eastern Himalayas. The present study deals with the distribution pattern of reptiles along the altitude gradient of Teesta valley, Eastern Himalayas, Sikkim, India.

1.4. ORGANIZATION OF THE THESIS

This dissertation is organized in six chapters:
Chapter 1 provides general introduction to the subject with major objectives and briefly reviews studies conducted in India. Chapter 2 describes various biotic and abiotic features of the study area. Aspects of reptile population of Teesta valley are discussed in Chapter 3. Chapter 4 analyzes the distribution pattern of reptiles along the altitude gradient of Teesta valley and the factors governing the same. Chapter 5 and 6 deals with use and partitioning of resources by reptile community at spatio-temporal dimensions. An attempt is also made to test biological concepts and hypotheses such as (1) Bergmann's rule in selected species, (2) MacArthur hypothesis (decrease of niche breadth with decreasing latitude) and (3) Pianka hypothesis (positive relation between niche breadth and species diversity). Last two sections provide the list of literatures cited in the dissertation and supportive data in the form of Appendices.

CHAPTER 2

STUDY AREA

STUDY AREA

The present study was conducted along the Teesta river valley in Sikkim, Eastern Himalayas, India.

2.1. HIMALAYAS

The Himalayas is one of the youngest mountain ranges of the world extending about 3000 km from west to east with profound climatic difference between them (Mani, 1974). Eastern Himalayas is humid and densely forested compared to Western Himalayas and hence their flora and fauna also differ remarkably (Waltner, 1973).

2.2. EASTERN HIMALAYAS

Rodgers and Panwar (1988) categorized India into ten principal Biogeographic zones, and Sikkim was included in the central Himalayas. However, a few considered Sikkim as a part of eastern Himalayas (Ali, 1962; Mani, 1974). Himalayan upliftment is the most determining features of Indian Biogeography (Delhi University, 2006). India is divided into several phyto and zoogeographical zones based on distribution of flora and fauna (Günther, 1858; Jerdon, 1862; Wallace, 1876; Blanford, 1888-1891; Smith, 1931, 1935, 1943). However, none of these classifications are complete as all of them ignored gradual changes in distributional pattern leading to geomorphological evolution (Mani, 1974).

The Eastern Himalayas is located at the crossroad of Indian, Indo-Malayan and Indo-Chinese bio-geographic regions. Hence, it is also considered as the gateway of Indian flora and fauna (Ramakantha *et al.*, 2003). The Eastern Himalayas, including both tropical and temperate forest elements, is most humid and rugged mountain system lying between 26° 30′ to 28° N and 87° to 97° 30′ E encircling an area of 2,62,379 km^2 (Chettri, 2000) which stretches from the Singalila Ridge of Sikkim and West Bengal in the west to Arunachal Pradesh in the east (Fig. 2.1).

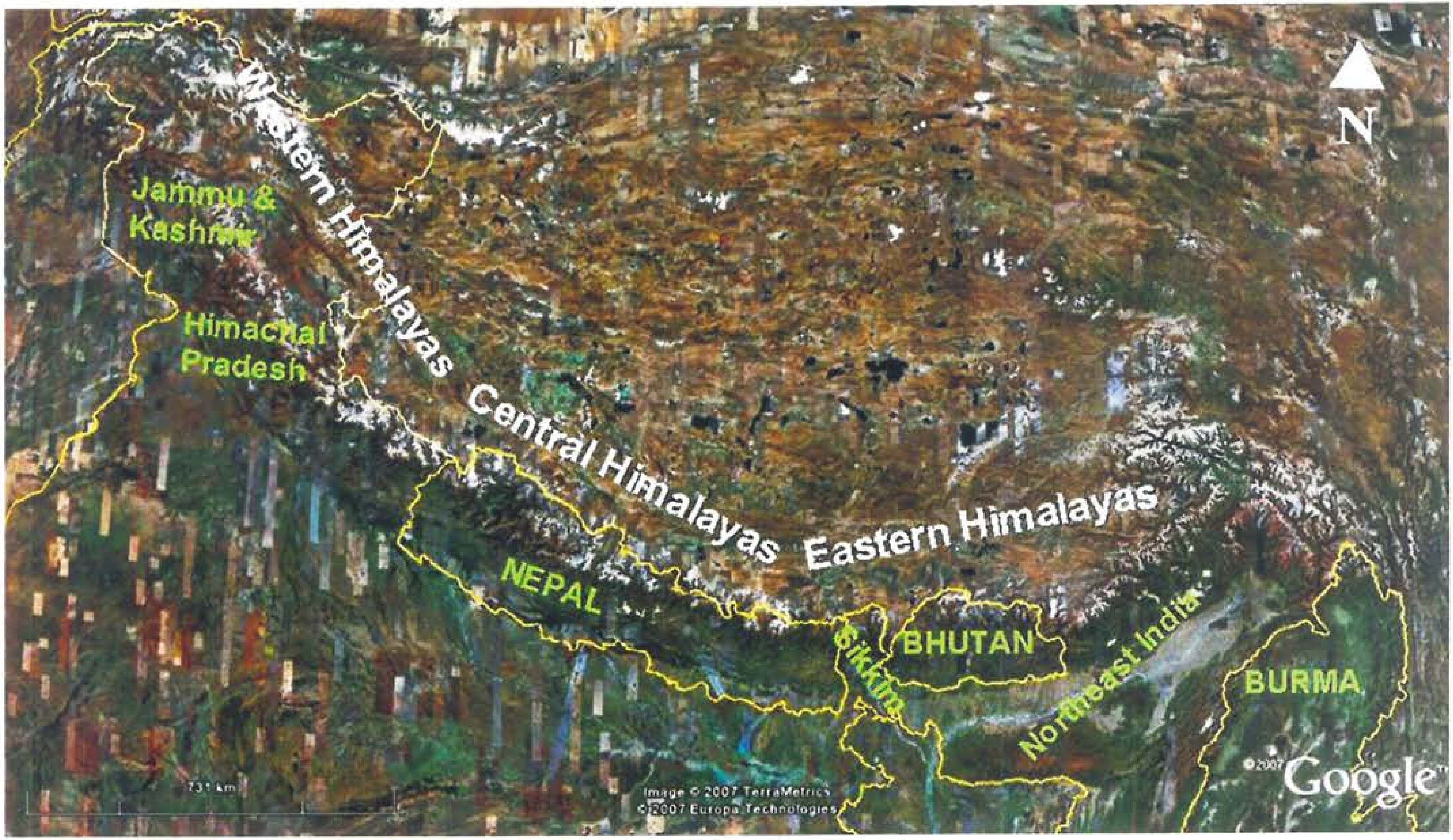


Figure 2.1 The Himalayan range showing Sikkim and neighboring countries

2.3. SIKKIM

Sikkim, one of the smallest states of India (27° 5′ - 28° 10′ N and 87° 4′ - 88° 58′ E) is situated at the western most boundary of eastern Himalayas, which encompasses an area of 7096 km^2. It is bounded on the north and northeast by Tibetan Autonomous Republic Council (TARC), China, southeast by Bhutan, west by Nepal and south by Darjeeling district of West Bengal, India. Himalayas on the northern side, Singalila and Kanchanjunga on the west and Rishipangola on the east encircle Sikkim giving horse-shoe shaped structure (Bose, 1928). Entire Sikkim is considered as the catchment of River Teesta. Sikkim has 180 perennial lakes among them Khechiperi, Gurudongmar, Chho-Lhamo, Changu and Men Moi Tso are a few high altitude lakes to mention, which are not only of scenic and religious importance, but have immense ecological value.

Although Sikkim is only one twentieth of the Western Ghats in geographical area, diversity of flora with 4,500 species of flowering plants, 450 orchids, 36 rhododendrons (Jha and Thapa, 2002) and fauna with 158 mammals (Avasthe and Jha, 1999), 550 birds (Ali, 1962; Chettri, 2000), 78 reptiles (Chettri and Bhupathy, 2007), 20 amphibians (Jha and Thapa, 2002), 48 fishes (Tamang, 1993) and 689 butterflies (Haribal, 1992) is remarkable. This high diversity is attributed to its geographical location on the borderland between Oriental and Palearctic regions, an altitude range extending from 300 m to over 8598 m and climatic regime from tropical to cold desert. Hence, both floral and faunal representative of these regions are found in Sikkim (Gammie, 1928).

2.4. TEESTA RIVER VALLEY

This study was carried along the Teesta river valley. Important biotic and abiotic features of Teesta river valley are briefly discussed below.

2.4.1. Physical Geography

Sikkim is essentially a rugged, mountainous state with an average steepness of 45° with almost no considerable flat lands (Plate 1; Bose, 1928). The altitudinal rise of mountain is towards north finally leading into a plateau of cold desert (Tibetan plateau). The valley formed by the Teesta river is extremely deep towards north giving steep rise to mountains, whereas less steep southern portion open towards the plains of West Bengal (Bose, 1928). The summits of most mountains are generally covered by ice and glaciers. Huge boulders eroded by glaciers are common above 3000 m.

Teesta river originates from Chholhamo Lake (about 4800 m above sea level) and descends to about 300 m altitude within 85 km at Rangpoo (Ali, 1962). Several tributaries, torrential streams and rivulets (khola) such as Lachen, Lachung, Muyong, Manual, Dikchu, Rani Khola and Rangpoo add to the flow of this river (Fig. 2.2). The combined flow of these tributaries and streams makes the normally placid Teesta river transform as a thundering and devastating river during monsoon.

2.4.2. Geomorphology

The horseshoe shaped catchment area of Teesta River valley is due to east-west and north-south folds, which are subjected to major tectonic movements (Ray, 2000). The Daling rock constitutes a large portion of Teesta valley, which underlies the Darjeeling Gneiss. Northern portion of the area is largely constituted by gneiss rocks, capable of resisting considerable denudation (Bose, 1928). The southern region consists of chiefly soft, thin, slaty rocks, which are prone to denudations. Seismotectonic records show that Sikkim is traversed by MCT (Main Central Thrust) and MBT (Main Boundary Thrust) placing it at High Damage Risk Zone (Zone IV; Narula *et al.*, 2000). Soil is largely sandy and clayey mixed with pebbles brought down by rain from higher altitude.

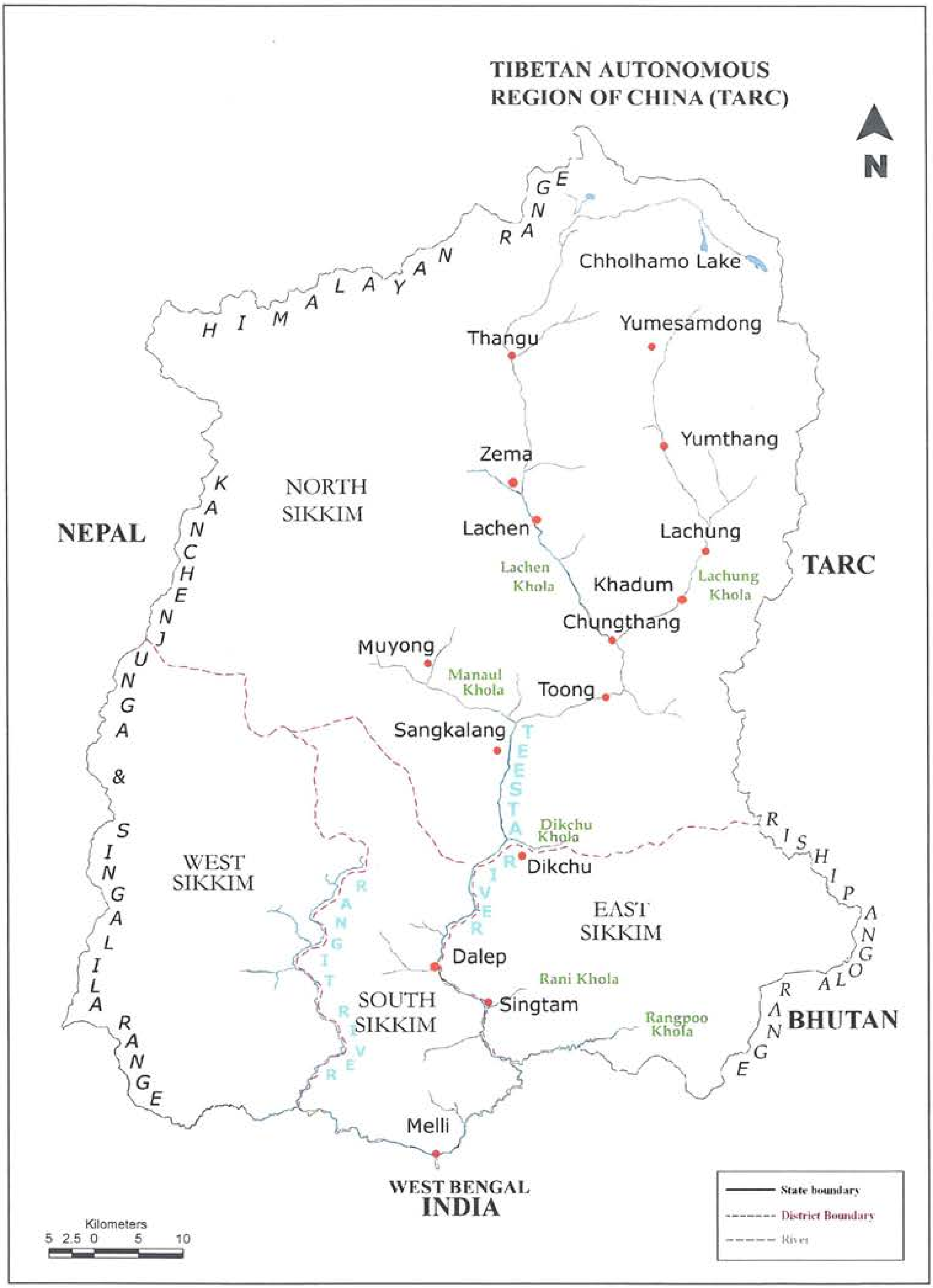


Figure 2.2 Study area with prominent locations and river system of Teesta valley, Sikkim, Eastern Himalayas, India.

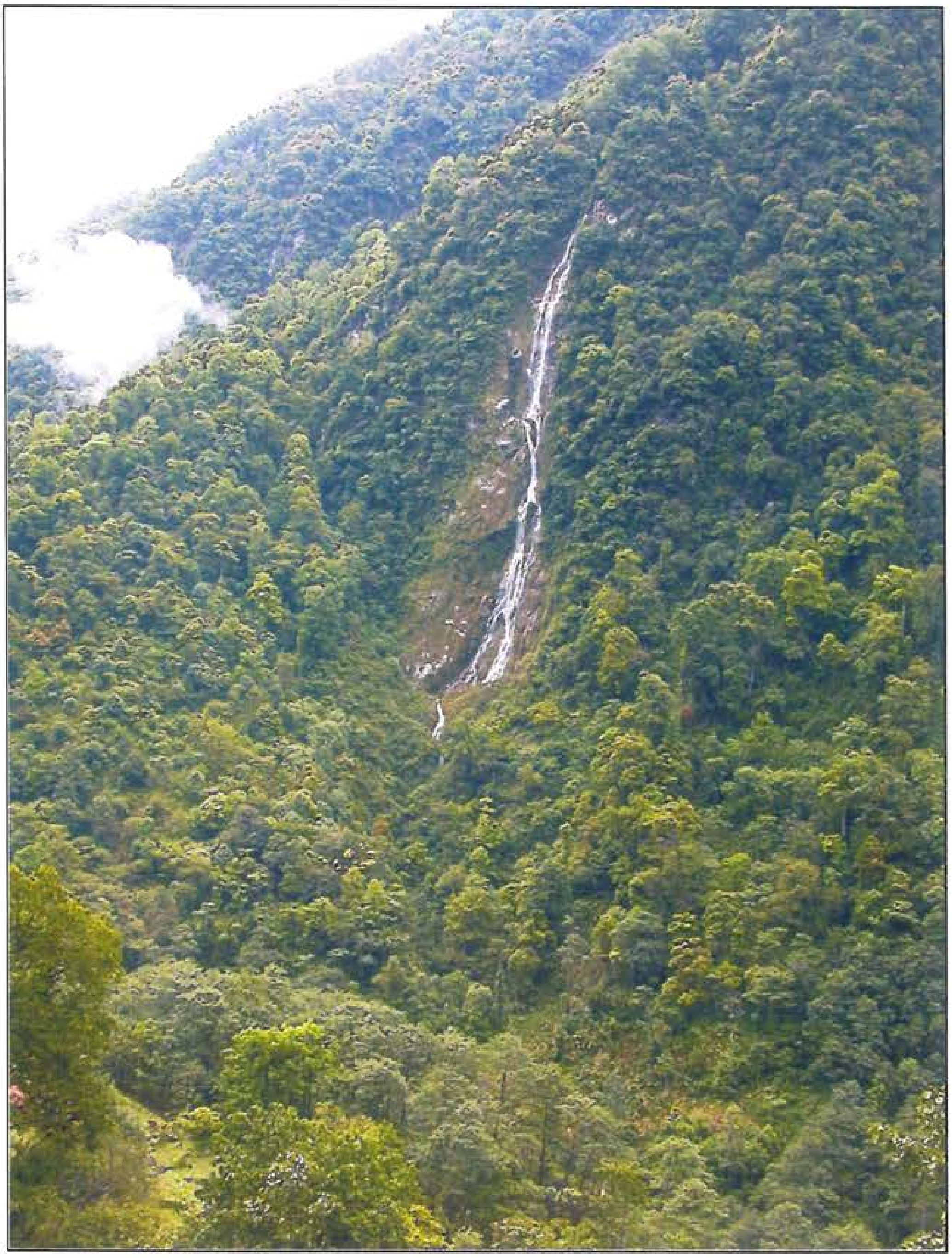


Plate 1. View of Teesta valley, Sikkim: Average steepness of the terrain is 45°

2.4.3. Climate

The abrupt increase in altitude as well as its proximity to the glaciers, diverse climatic condition prevails in Teesta valley starting from tropic in lower altitude to arctic in higher reaches. Most places in Teesta valley are humid with 70-80% relative humidity throughout the year. In lower altitude, summer and monsoon is hot and humid, winter being pleasant, whereas it is severe cold in higher altitude. Permanent snow line appears at about 5000 m. In the past, glaciers were reportedly found at much lower altitude than today (Bose, 1928). At higher altitudes precipitation is mainly in the form of snow, while in the lower regions it is rainfall. Thunder and hail storms occur during April and May. Most of the areas above Yumthang (3500 m) and Thangu (3700 m) experience snowfall from November to March. Rainfall is heavy from May to September with maximum in July. The rainfall varies from 2,000 mm to 5,000 mm in most of the inner valleys. Due to unavailability of data at regular altitudinal interval, temperature and relative humidity data was taken from Hooker (1854). Temperature and relative humidity at various altitudes is shown in Fig. 2.3.

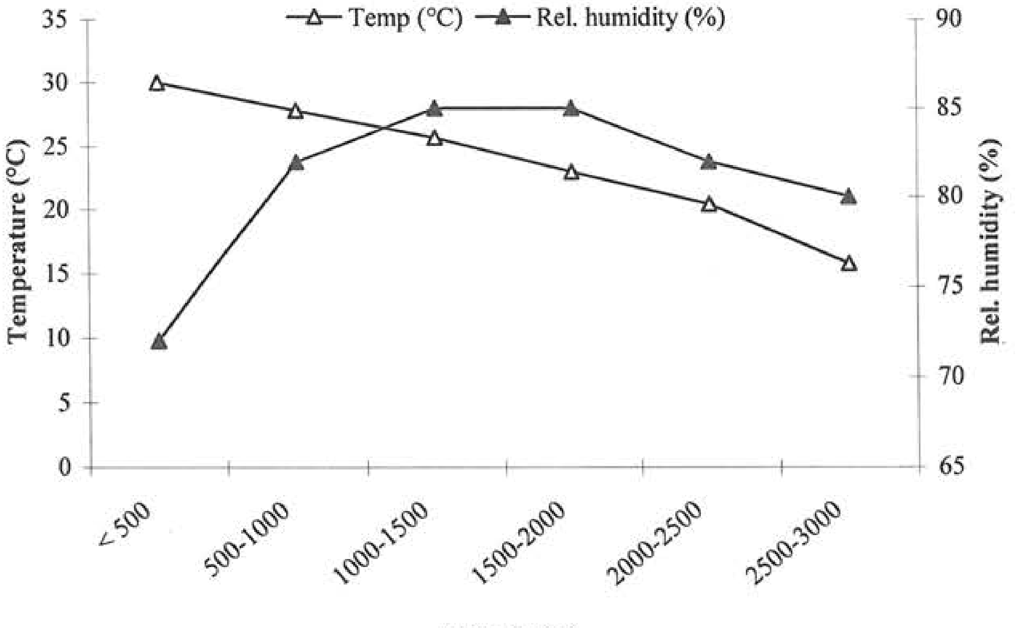


Figure 2.3. Mean annual temperature and relative humidity recorded in various altitudes along the Teesta valley (modified from Hooker, 1854).

2.4.4. Vegetation

Varied climatic and ecological conditions prevailing in Sikkim Himalayas has favored many align floristic elements to invade (Gammie, 1928; Mani, 1974; Srivastava, 1996). The complex orogeny of the Himalayas, coupled with the ensuing climatic and edaphic changes facilitated its colonization by flora and fauna from the neighboring regions (Pandit *et al.*, 2000). However, Sikkim being a land locked country, bounded by high mountains on all sides has led to the isolation of population occurring in Sikkim (Haribal, 1992).

Sir J.D. Hooker explored the entire Sikkim Himalaya and divided into three main zones- Tropical, Temperate and Alpine (Hooker, 1854). In the present study, Teesta valley was classified into five major zones on the basis of altitude and composition of vegetation following Haribal (1992).

Tropical Semi-deciduous and Tropical wet forest (Below 900 m) – It includes lower valley from Rangpoo to Sangkalang in Dzongu. It is represented by mainly deciduous species such as *Shorea robusta, Schima wallichi, Bauhinia purpurea, Cedrela toona, Bombax ceiba, Terminalia myriocarpa* and *Albizzia* spp. Secondary growth consists of *Bauhinia* sp., *Strobilanthus* sp., *Eupatorium* sp., *Tridax* sp., *Polygonum* sp. and varieties of bamboo. Forests are occasionally interspersed by *Pandanus* sp., *Caryota urens* and tree ferns. As in most tropical regions, ferns and orchids are abundant in these forests.

Tropical moist forest or Broad-leaved forest (900-1800 m) – This zone includes area between Sangkalang and Chungthang and surroundings. Tree trunks draped by climbers such as *Rhapidophora* are common. Tropical broadleaved forest is represented by *Engelhardtia spicata, Spondias lutea, Saurauia nepalaensis, Alnus nepalensis* and *Macaranga* sp. Secondary growth comprises of species of *Girardinia, Maesa, Melastoma, Edgeworthia, Mussendra, Rubus* and *Pavetta*.

Temperate broad-leaved forest (1800-2800 m) – Chungthang, the convergence of Lachen and Lachung rivers from where it flows down as Teesta, marks the entry of this zone and continues up to Lachen and Lachung valley on either side. Mosses and other epiphytes cover trees. Dominant trees are *Quercus lamellosa*, *Machilus edulis*, *Michelia excelsa*, *Betula* sp., *Symplocus theaefolia* and *Andromeda elliptica* associated with *Vibernum* sp., *Mahonia* sp. *Alnus nepalensis* colonize in landslide area along the water course. *Rhododendron arboratum* occurred in the form of trees and stunted shrub. Forests are interspersed with marshy grassy patches especially in Khedum and Bitchu (Lachung valley) and Rabum and Bansoi (Lachen valley).

Temperate coniferous and broad-leaved forest (2800-3800 m) – Lachen to Thangu and Lachung to South Yumesamdong falls under this zone. Mainly conifers and rhododendrons characterize these evergreen forests. Lower range of this zone is represented mainly by Himalayan hemlock mixed with variety of *Rhododendron* spp., *Betula* sp. and *Acer* sp. which are replaced by stunted shrubs of *Rhododendron campanulatum*, *Rhododendron grande*, *Rhododendron wightii*, *Rhododendron thomsonii*, *Rhododendron cinnabarium* in higher range of this zone. *Arisaema* spp. occurred in great variety and abundance in moss covered floor. Beyond Thangu (3700 m) and Yumesamdong South (4000 m), where tree line ceases, thickets of stunted rhododendrons interspersed by *Salix* sp. is the dominant vegetation. The ground of the upper ranges of this zone is covered by herbaceous plants such as *Aconites, Senecio, Saxifraga, Primula, Potentilla, Polygonum, Fragaria, Astragalus, Impatiens* and various species of *Meconopsis, Gentians* that burst into multi-coloured blossoms during spring (April-May).

Sub-alpine and Alpine vegetation (3800 m and above) - This zone is represented by the area above Thangu and South Yumesamdong up to Tibetan plateau. It is characterized by alpine meadow with pockets of stunted rhododendrons such as *Rhododendron nivale*. The area is relatively dry and the ground will be covered with snow till the mid June. The Alpine flora resembles much with that of the western Himalayas at least in generic level (Gammie, 1928).

Above 3800 m, the valley is wider giving rise to plateau. As one goes further above, vegetation becomes scanty with only patches of grasses, sedges and bright blue flowering Gentians dominating the Alpine meadow. The most conspicuous and unique rhubarb of alpine meadow is a yard high *Rheum nobile*. It is found at the base of the rocky mountains of Yumesamdong and Thangu, which from a distance, looks like prayer flag of Sikkim.

The Teesta valley represents tropical forest to alpine meadow, which has an altitude range from 300 m to 4800 m. The study area depending on altitude was categorized into different zones by dividing the gradient at 500 m interval (Plate 2 & 3). Data on the altitude zones and their vegetation types are given in the Table 2.1.

Table 2.1. Categorization of the study area (Teesta valley) based on vegetation types

Altitudinal zone	Altitude (m)	Forest type
Zone I	< 500	Tropical Semi Deciduous Forest (TrSDF)
Zone II	500-1000	Tropical Semi Deciduous Forest (TrSDF)
Zone III	1000-1500	Tropical Broad Leaved Forest (TrBLF)
Zone IV	1500-2000	Tropical + Temperate Broad-Leaved Forest (TrBLF+TmBLF)
Zone V	2000-2500	Temperate Broad-Leaved Forest (TmBLF)
Zone VI	2500-3000	Temperate Broad-Leaved + Coniferous Forest (TmBLF+CnF)
Zone VII	>3000	Coniferous Forest + Sub-alpine + Alpine (CnF+SAl+Al)

2.4.5. Wildlife

Wide altitudinal range, climatic conditions, diverse vegetation types found along the Teesta valley support rich faunal diversity as well. Common mammalian fauna of the area include Barking deer, Indian porcupine, Wild boar, Jackal, Flying squirrel, Hoary-bellied squirrel, Orange-bellied squirrel, Civets, Leopard cat, Ghoral, Blue sheep, Marten, Mouse hare or Pika, Himalayan marmot, Red fox, Common and Himalayan langur.

Birds of Sikkim are well documented (Ali, 1962; Ganguli-Lachungpa, 1998; Chettri, 2000). The state bird of Sikkim 'blood pheasant' was sighted often in the coniferous forests. Few species common in lower altitude includes Kaleej pheasant, Jungle fowl and Cormorant. Brahminy duck, Ibis bill, Snow pigeon, Dipper and Cough were relatively common above 3000 m.

An updated checklist of reptiles of Sikkim is available in Chettri and Bhupathy (2007). No consolidated work is available on amphibians. Jha and Thapa (2002) reported 20 species of amphibians based on compilation from literatures. Forty-eight species of fishes have been reported from the hill streams of Sikkim including four new species and two new subspecies from river Teesta and Rangeet (Tamang, 1993). About half of the total number of butterflies species found in Indian subcontinent is recorded in Sikkim. Haribal (1992) provided a checklist of 689 species of butterflies of Sikkim.

The above information clearly indicates that ecological studies or even presence of species found along the Teesta valley is poorly understood.

Plate 2. (a) <500 m and (b) 500-1000 m representing tropical semi-deciduous forests and (c) 1000-1500 m representing tropical broad-leaved forest

Plate 3. (a) Tropical broad-leaved forest (1500-2000 m),
(b) Temperate broad-leaved forest (2000-2500 m),
(c) Coniferous forest (2500-3000 m) and
(d) Alpine meadow (>3000 m)

CHAPTER 3

POPULATION ASSESSMENT

POPULATION ASSESSMENT

3.1. INTRODUCTION

Population is defined as a group of individuals of the same species, which live together in one geographical area at the same time (Begon *et al.*, 1996a, b; Odum, 1996). Population is considered as the smallest unit of evolution (Yablokov, 1986), which deals with species abundance or density, sex ratio, size structure, reproduction, natality and mortality. The study on population provides information on distribution and abundance of species and population structure, which help in framing species conservation and management plans (Southwood and Henderson, 2000).

Species richness (number of species) is the simplest expression of species diversity (Magurran, 1988; Pough *et al.*, 1998). Species diversity provides information regarding diversity of habitat or area and changes over a period of time (MacArthur, 1965). Accurate estimation of species richness of a habitat/area is important for proposing strategies for biodiversity conservation (Raxworthy and Nussbaum, 1994; Southwood and Henderson, 2000). However, accurate measure of species richness, especially for 'hyperdiverse' terrestrial groups in tropics is seldom possible (Colwell and Coddington, 1994). Hence, samples can be taken as representative and various estimators could be used to assess total number of species present in an area. Several non-parametric estimators also help to figure out the completeness of the sampling.

Relationship of species morphometry with life history traits is demonstrated in many species of lizards and snakes (Perez-Mellado and De la Riva, 1993; Keogh *et al.*, 2000; Shine *et al.*, 2000; Lobo *et al.*, 2004). The size structure of population is a result of numerous biotic (age, growth, maturity, competition, predation) and abiotic factors (climate, resource availability). In many species of reptiles, it is reported that size determines their reproductive maturity and fecundity (Andrews, 1982). Body size of an organism also provides some information on habitat utilization, activity pattern (Vitt, 1987; Shine, 1994), diet, vulnerability to predators, age at maturity and reproductive success (Shine *et al.*, 2000). Variation in morphology of an animal plays significant role in food selection and resource partitioning, thus reflect its overall ecology (Pianka, 1975; Dixon *et al.*, 1995). It is reported that difference in body size may allow coexistence of species due to difference in prey handling and food selection (Farlow and Pianka, 2002). Hutchinson and MacArthur (1959) reported that in nature, higher number of smaller bodied animals and only few large bodied occur due to various ecological reasons.

It is reported that according to Bergmann's rule body size of a species increase with increasing latitude or decreasing environmental temperature (Ashton and Fieldman, 2003). The applicability of Bergmann's rule was largely studied in endothermic vertebrates such as mammals (Ashton *et al.*, 2000), birds (James, 1970; Ashton, 2002) and also in invertebrates such as insects (Arnett and Gotelli, 1999). However, studies in this regard are scanty pertaining to ectothermic vertebrates such as herpetofauna (Ashton, 2002; Ashton and Feldman, 2003). Body size of various taxa showed diverse patterns with latitude and altitude. Ashton and Feldman (2003) reported different patterns for different groups among reptiles: turtles follow Bergmann's rule, whereas lizards and snakes show the reverse trend. Laugen *et al.* (2005) reported that mean adult body size increased from south to mid-latitudes and then decreased in case of *Rana temporaria*. McNab (1971) concluded that Bergmann's rule is valid at higher and the reverse trend in lower latitudes.

As mentioned earlier, studies on reptiles are scanty in oriental region. The compilation by Smith (1931, 1935, and 1943) is the single most authoritative data bank on reptiles of Indian subcontinent. Most of the researches on the herpetofauna of India were conducted in South India, especially in the Western Ghats. Data on herpetofaunal diversity of Ponmudi Hills are available in Inger *et al.* (1987). Population aspects of agamid lizards in the Western Ghats were studied by Bhupathy and Kannan (1997). Ishwar *et al.* (2001, 2003) studied aspects of population of rainforest reptiles in Kalakad-Mundanthurai Tiger Reserve, Western Ghats. Nixon (2005) provided data on population ecology of reptiles dwelling Shola forests and grasslands of Upper Nilgiris. Mukherjee (2007) conducted similar study in the dry deciduous forest of Anaikatty Hills. Lakshmi and Rao (2004) documented the abundance and diversity of reptiles in parts of Eastern Ghats and provided recommendations for conserving them.

Studies pertaining to the herpetofauna of Sikkim are meager. Barring anecdotal notes by British explorers and Zoological Survey of India surveyors, no information is available on aspects of population ecology of herpetofauna inhabiting Sikkim Himalayas (Jha and Thapa, 2002). Jha and Thapa (2002) provided a checklist of herpetofauna of Sikkim based on literatures. No systematic sampling was available until this study to assess the reptile populations in Sikkim, especially Teesta valley.

This Chapter deals with aspects of population such as species richness, diversity, relative abundance, composition and morphometry of reptiles inhabiting the Teesta valley. An attempt is also made to explore the applicability of Bergmann's rule in selected species of reptiles distributed along this valley.

3.2. METHODS

3.2.1. Sampling Methods

Important reptile sampling methods include pitfall traps, quadrat, transect, road cruising and visual encounter survey (Heyer *et al.*, 1994). Heyer *et al.* (1994) and Doan (2003) pointed out the importance of more than one method in herpetofaunal sampling. It is reported that the above methods were seldom tested in tropics (Pearman *et al.*, 1995).

Quadrat – Sampling using Quadrat, though reported to be one of the quantitative methods for herpetofaunal assessment (Jaeger and Inger, 1994), loses effectiveness in habitats with dense ground cover and steep terrain. Since the present study was conducted along the steep valley of Teesta river (steepness is over 45° in most parts, Plate 1), this method was discarded after preliminary testing. Quadrats provided very low success rate in Western Ghats (i.e. 71/1,700; 4.1% quadrats with species; Mukherjee, 2007).

Transect –Depending upon the accessibility and terrain, transects of varying length (500-1000 m), were laid. During the survey, two personnel walked slowly along the transect observing the animals without disturbing the microhabitats. As maximum numbers of reptiles were sighted under logs or boulders, walking along transects failed to detect the animals present there. A total of 84 km in seven altitude zones for two years on three monthly intervals (12 km in each altitude zone excluding winter) yielded only 25 reptiles belonging to seven species. The result of this method is biased towards active animals, and hence not continued.

Road Cruising – Road cruising can be done both on vehicle as well as by walk, where the observer scans the road slowly recording the animals (alive/dead) present there. Roads were surveyed both day and night randomly. Due to poor network of roads along the Teesta valley, especially in higher altitudes, comparable data in all altitudinal categories was not possible. Though, species such as vipers were relatively common on roads, it is not an effective method for all species (Heyer *et al.*, 1994).

Visual Encounter Survey (VES) – Visual encounter survey was formalized as a time-constrained technique by Campbell and Christman (1982) and Heyer *et al.* (1994). In this method, field researchers survey an area or habitat for a prescribed time systematically searching for animals in all possible microhabitats (Campbell and Christman, 1982). Total time is expressed as the number of man-hours of searching (Crump and Scott, 1994).

VES is an appropriate method for both inventory and monitoring, and hence suitable for study involving large landscapes. VES is reportedly the best way to sample all species including rare ones and is a suitable method for determining richness, composition and relative abundance of species of an area (Heyer *et al.*, 1994). Doan (2003) compared the suitability of VES and quadrat in the rain forest of southeastern Peru and reported higher number of richness, abundance and high unique species in VES. Major limitations of this method are, all microhabitats cannot be sampled with equal success and density of species cannot be estimated.

Visual encounter survey was used to study the reptiles in Western Ghats (Bhupathy and Kannan, 1997; Giri and Chaturvedi, 2001; Bhupathy and Nixon, 2004; Nixon, 2005; Mukherjee, 2007). Taking into account of landscape, topography and altitude of the study area, time constrained visual encounter survey was used all through this study. Since the main aim of the present study was to find out the pattern along the altitude gradient, VES was considered to be appropriate for maximizing species detection. As the success rate was very low in other methods, data from them were excluded from analyses, except for estimating total species richness.

In the present study (June 2003 to March 2006), sampling was restricted to day hours (0900 hrs – 1300 hrs) and two personnel were involved in searching all through the study. During sampling all possible microhabitats such as boulders, fallen logs and roots were examined. In this method, all individuals sighted during sampling were identified up to species level. Morphometric measurements were done when animals could be caught. After taking close up photographs and recording measurements, reptiles were released in the field.

Snout vent length (SVL) and tail length (TL) of reptiles were measured using metal scale (accuracy ± 0.1 mm) and weighed using *Pesola*® spring balance (accuracy ± 0.5 gm). Length from tip of the snout to the vent and from vent to the tail tip was considered as SVL and TL respectively. McNab (1971) reported that reliable measures of body size would be snout to vent. Based on SVL, reptiles were categorized into various size classes to know the size structure of a species or community. Identification of reptile species was based on Smith (1935, 1943) and Whitaker and Captain (2004), and nomenclature following Das (2003).

3.2.2. Data Analyses

All analyses were done using statistical software SPSS, Version 10.0 and Microsoft excel for windows.

1. Species richness = Number of species observed during the present study.

2. Encounter rate = Number of reptiles (individuals) sighted / total hours surveyed.
3. Species richness was estimated using non-parametric statistical procedures (EstimateS-version 7.5, Colwell, 2005). The sample order was randomized 100 times to eliminate the arbitrariness resulted due to heterogeneity of samples (Colwell and Coddington, 1994). For the data pooled from all altitude zones, a sample-based rarefaction curve (species accumulation as a function of occurrence, with 95% confidence intervals, Colwell *et al.*, 2004) was computed to evaluate the completeness of sampling.
4. Shannon-Wiener Diversity Index (H') = $-\Sigma p_i \ln p_i$

   where, p_i = Proportion of individuals in the i^{th} species with respect to total sample

   ln = Natural logarithm
5. Hill's diversity Index (N_1) = $e^{H'}$

   where, H′ = Shannon-Weiner species diversity
6. Evenness (E) = H′/Hmax,

   where, H′ = Shannon-Weiner species diversity;

   Hmax = ln S (S = Number of species).
7. Relative abundance of a species (%) = $n_i / N \times 100$ (number of observations of a species / total observations of all species) x 100.
8. Pearson correlation was performed between altitude and body size of selected species.

An attempt was made to test the applicability of Bergmann's rule with respect to body size (SVL) and altitude (taken as proxy for latitude; Stevens, 1989, 1992). Altitude range of species was divided into two (upper and lower) categories, to see the variation in body size along the altitude gradient. Due to paucity of sample size and limited distribution range of species, only a few of them were considered for this analysis.

3.3. RESULTS

In the present study, 2494 man-hour searches (VES) were conducted along the Teesta valley. Data using VES was largely considered for in-depth analyses. Out of 42 species, 34 species were observed in VES and eight species in opportunistic observations.

3.3.1. Species Richness

A total of 1596 individuals of reptiles including 663 snakes and 933 lizards were observed during the study. In all, 14 species of lizards and 28 snakes belonging to 32 genera and ten families were observed (Appendix-I). No chelonians were observed during this study.

Teesta valley harboured 42 (53.8%) species of reptiles found in the entire state of Sikkim (78 species), despite the sampling being restricted to 1km on either side of the river. The sampled area is about 170 km^2 (length x width, 85 km x 2 km =170 km^2) only compared to 7096 km^2 of Sikkim. Forty-two species found along the Teesta valley is a subset of the reptilian fauna found in Sikkim. The fauna of Teesta valley also showed similarity with the neighbouring Darjeeling Hills sharing 37 out of 42 species and the remaining five species were exclusive to Teesta valley.

Overall encounter rate of reptiles along the Teesta valley was 0.66/hour. Lizards showed relatively high encounter rate (0.39/hour) compared to snakes (0.27/hour).

As the major objective of this study was to investigate the distribution pattern of reptiles, the species observed during this investigation which were reported before 50 years ago were identified tentatively since type specimens of many of them are not available in India. For instance, among lizards, *Cyrtodactylus* sp. and *Takydromus* sp. were tentatively considered as *Cyrtodactylus khasiensis* and *Takydromus sexlineatus*, and their identity is being worked out (Plate 4). Among snakes, water snakes along the Teesta valley had characters of both *Xenochrophis piscator* and *Xenochrophis sanctijohannis* and they are considered herein as *Xenochrophis* sp. A member of pit viper has the characters similar to that of *Protobothrops kaulbacki* (a Burmese species), pending further taxonomic investigations this species was considered as *Protobothrops* sp. Currently, the identity of this pit viper is being worked out, it could be *Protobothrops kaulbacki* or a new species. Similarly, three species of *Typhlops* (*T. jerdoni*, *T. oligolepis*, *Ramphotyphlops braminus*) were considered as single species in analysis pertaining to habitat use and niche utilization since the identification was extremely difficult in the field at species level.

Species accumulation curve with 95% confidence interval as a function of occurrence (sample based rarefaction curve) for the pooled data from all the altitude zones approached an asymptote but has not reached a plateau (Fig. 3.1a). After initial steep rise (up to 1000 hours) the graph has almost flattened indicating the addition of only few species with additional sampling. Sample based rarefaction curve is not above the observed richness (Fig. 3.1b), which indicates that enough sampling was done to locate most of the species. Sample based (Incidence based) and abundance based (Individual based) rarefaction curves for pooled data from all the altitude zones were plotted and compared to see heterogeneity (Fig. 3.2). The abundance based curve was higher initially than sample based curve subsequently merged in a single line showing the homogeneity of samples (Fig. 3.2). Except few clumped distribution, most species of Teesta valley were homogeneously (sparse and uniform) distributed.

3.3.2. Diversity and Evenness

Species richness and various diversity indices pertaining to the reptiles of Teesta valley are given in Table 3.1. Shannon-Weiner diversity (H'), Hill's diversity ($e^{H'}$) and Shannon evenness was high for lizards compared to snakes, whereas species richness was high in the case of snakes.

Table 3.1. Species diversity indices of reptiles found along the Teesta valley.

Diversity	Lizards	Snakes	Overall
Species richness	14	28	42
Shannon Weiner (H')	1.67	1.52	2.29
Shannon evenness (E)	0.63	0.46	0.61
Hill's diversity ($e^{H'}$)	5.34	4.58	9.86

Plate 4. (a) *Cyrtodactylus khasiensis* and (b) *Takydromus sexlineatus* rediscovered after 50 years from Sikkim

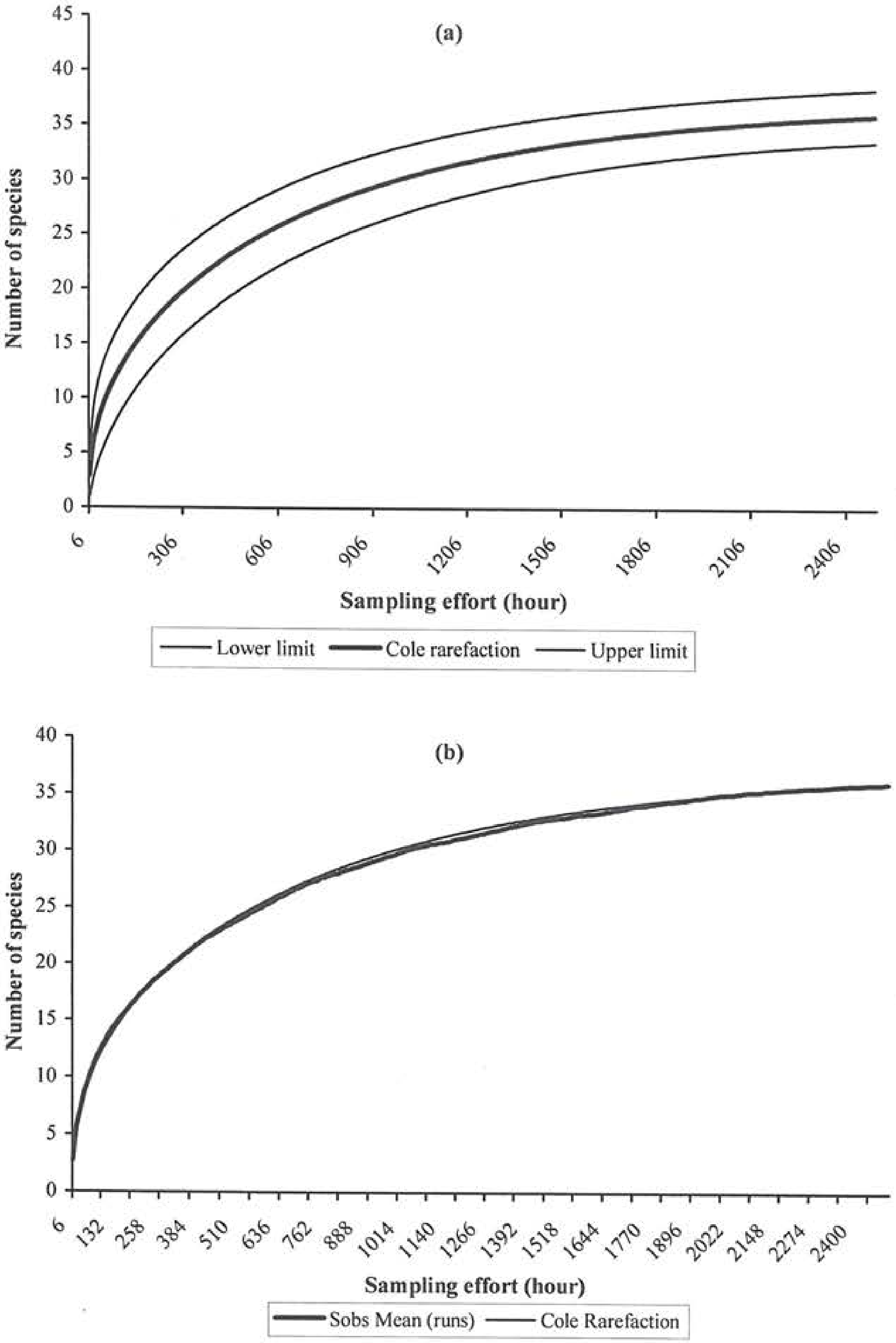


Figure 3.1. Sample based rarefaction curve (a) with 95% confidence intervals and (b) with observed species for the pooled data obtained from all altitude zones along the Teesta valley.

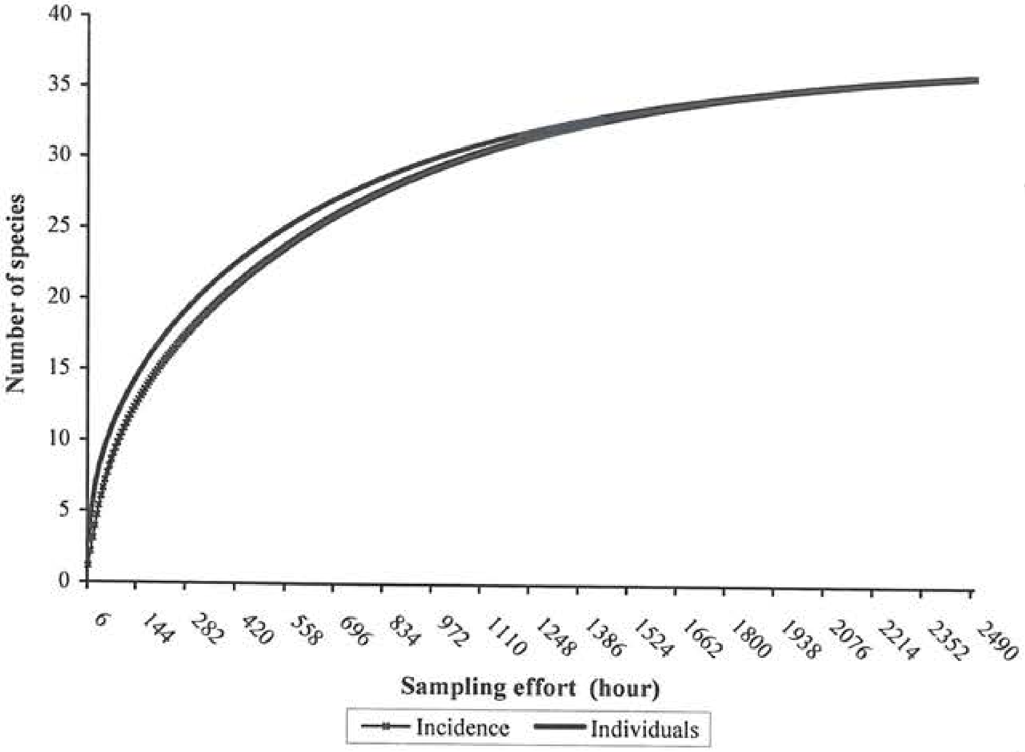


Figure 3.2. Comparison of Incidence-based and Individual-based rarefaction curves based on pooled data from all altitude zones along the Teesta valley.

3.3.3. Reptile Composition

A total of ten families comprising of lizards and snakes (five each) were observed during the study. Among snakes, Colubridae contributed the highest consisting of 18 (64.3 %) species and the least by Boidae with only one species (Fig. 3.3). Gekkonidae with five species (35.7 %) was the most contributing lizard family. Of the ten reptile families observed, three were represented by single genera and species (Fig. 3.3).

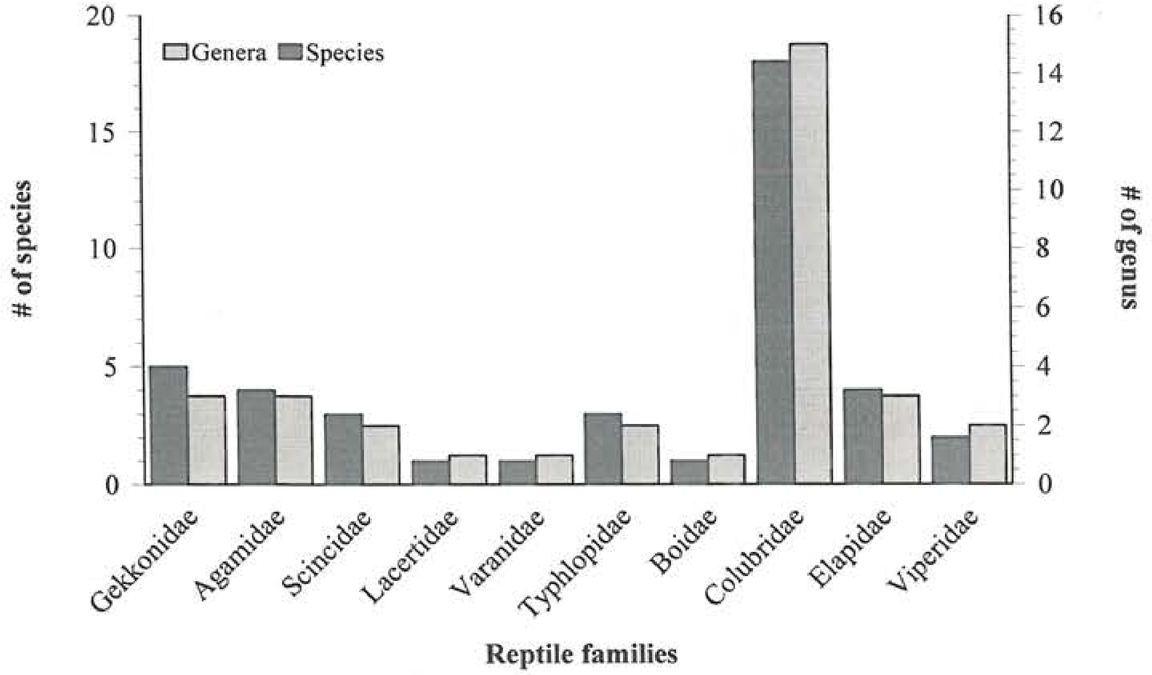


Figure 3.3. Taxonomic representation of reptiles observed along the Teesta valley.

Lizards contributed 58.5% of the total abundance of reptile populations of the Teesta valley and the rest by snakes (41.5%). Overall, members of Scincidae were the most abundant (596 individuals) followed by Colubridae (551 individuals). Among lizard families, Scincidae ranked high in abundance (63.9%) followed by Agamidae (31.4%). Though Gekkonidae had five species and Lacertidae had only one species, relative abundance was almost the same for both the families (Fig. 3.4). Among snakes, Colubridae was the most dominant (83.1%) and Boidae was the least (0.15%) with respect to abundance. Except Colubridae, all other families contributed less than 10% each (Fig. 3.4).

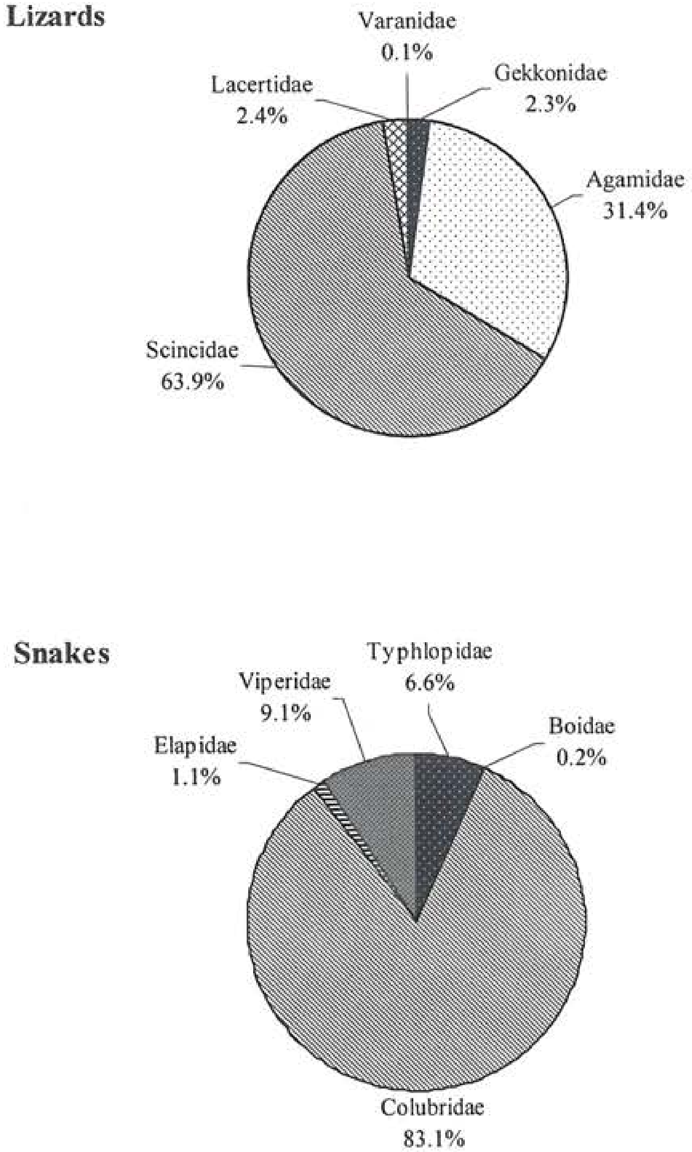


Figure 3.4. Relative abundance of lizards and snakes observed along the Teesta valley.

3.3.4. Relative Abundance of Species

The relative abundance of 14 species of lizards and 28 snakes are presented respectively in Table 3.2 and 3.3. Most of the snake species showed low relative abundance compared to lizards. Among lizards, *Asymblepharus sikimmensis* showed maximum relative abundance (36.55%), whereas *Cosymbotus platyurus*, *Calotes jerdoni*, *Oriotaris tricarinata* and *Varanus bengalensis* showed minimum (0.11%) and were sighted only once. Out of six species with more than 1% relative abundance, three species: *Japalura variegata*, *Sphenomorphus maculatus* and *Asymblepharus sikimmensis* had relative abundance of more than 10%. *Calotes versicolor*, *Takydromus sexlineatus* and *Sphenomorphus indicus* ranged between 1 and 10%. The remaining eight species contributed lower than 1% (Table 3.2).

Among snakes, maximum relative abundance was shown by *Trachischium guentheri* (68.02%) and minimum by *Oligodon albocinctus*, *Python molurus*, *Rhabdophis subminiatus*, *Bungarus bungaroides* and *Ophiophagus hannah* (0.15%). Except *Trachischium guentheri*, none of the species obtained >10% relative abundance. Relative abundance of nine species was within 10%, whereas the remaining 17 species had relative abundance less than 1% (Table 3.3). Singletons (species having only one observation) and doubletons (species having two observations) were represented by five species each.

Overall relative abundance of reptiles showed that five species of lizards and three species of snakes contributed more than or equal to 2% (Fig. 3.5). Remaining 32 species with <2% relative abundance were represented as others, in total these species contributed only 11.78%. The results show that most species were rare along the Teesta valley.

Table 3.2. Relative abundance of lizard species observed along the Teesta valley.

Family	Species	Sample size	Relative abundance (%)
Gekkonidae	*Hemidactylus bowringii*	7	0.75
	Hemidactylus frenatus	5	0.54
	Hemidactylus garnotii	5	0.54
	Cosymbotus platyurus	1	0.11
	Cyrtodactylus khasiensis	3	0.32
Agamidae	*Japalura variegate*	201	21.54
	Oriotaris tricarinata	1	0.11
	Calotes jerdoni	1	0.11
	Calotes versicolor	90	9.65
Scincidae	*Sphenomorphus indicus*	77	8.25
	Sphenomorphus maculatus	178	19.08
	Asymblepharus sikimmensis	341	36.55
Lacertidae	*Takydromus sexlineatus*	22	2.36
Varanidae	*Varanus bengalensis*	1	0.11
	Total no. of species = 14	933	100

Table 3.3. Relative abundance of snake species observed along the Teesta valley.

Families	Species	Sample size	Relative abundance (%)
Typhlopidae	*Typhlops* spp.	44	6.63
Boidae	*Python molurus*	1	0.15
Colubridae	*Pareas monticolus*	4	0.6
	Coelognathus radiatus	2	0.3
	Orthriophis cantoris	3	0.45
	Oreophis porphyraceus	2	0.3
	Ptyas korros	12	1.81
	Ptyas nigromarginata	3	0.45
	Oligodon juglandifer	12	1.81
	Oligodon albocinctus	1	0.15
	Dendrelaphis pictus	2	0.3
	Lycodon aulicus	8	1.21
	Lycodon fasciatus	4	0.6
	Sibynophis collaris	4	0.6
	Xenochrophis sp.	9	1.36
	Rhabdophis himalayanus	6	0.9
	Rhabdophis subminiatus	1	0.15
	Amphiesma platyceps	25	3.77
	Trachischium guentheri	451	68.02
	Boiga multifasciata	2	0.3
Elapidae	*Bungarus bungaroides*	1	0.15
	Bungarus niger	2	0.3
	Naja kaouthia	3	0.45
	Ophiophagus Hannah	1	0.15
Viperidae	*Ovophis monticola*	32	4.83
	Protobothrops sp.	28	4.22
	Total no. of species = 26	663	100

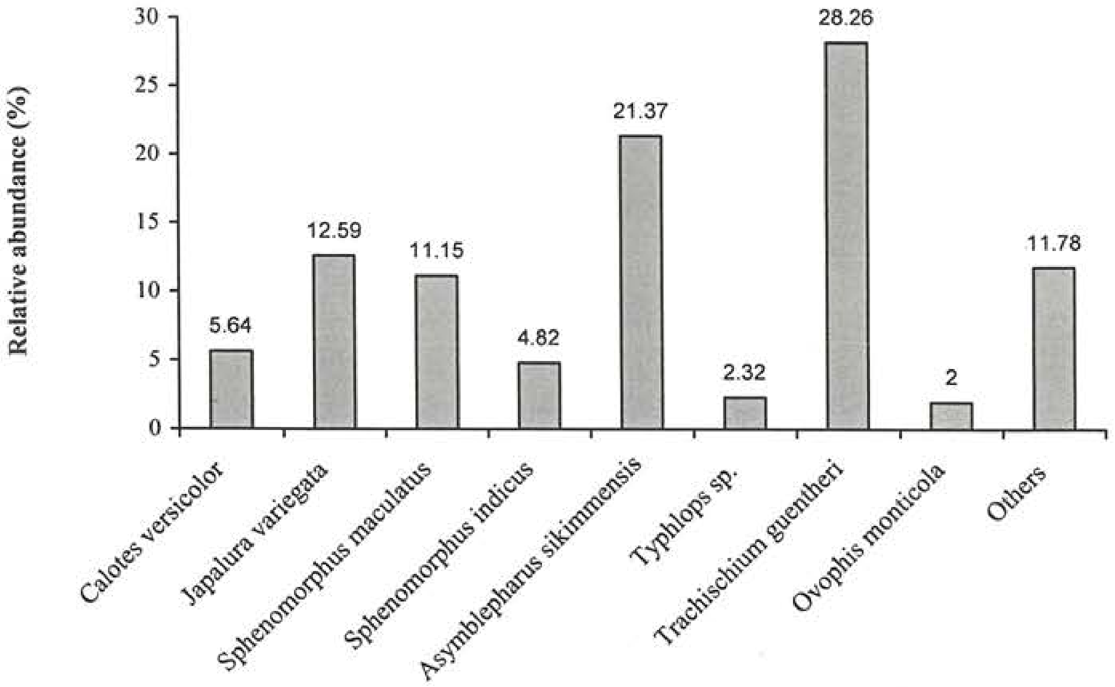


Figure 3.5. Reptile species with >2% relative abundance observed along the Teesta valley; others include low abundance species (<2%).

3.3.5. Morphometry

Data on snout vent length (SVL) of lizard and snake species observed along the Teesta valley are provided in Appendix-II and III. Among all observed species, *Python molurus* (total length– 3600 mm) was the largest followed by *Ophiophagus hannah* (2980 mm). Gekkonid *Hemidactylus bowringii* (105 mm) was the smallest species found during the present study. Among lizards, *Varanus bengalensis* (SVL– 290 mm, TL– 450 mm) and *Hemidactylus bowringii* (SVL– 50 mm, TL– 55 mm) was the largest and smallest species recorded respectively. Among snakes, *Python molurus* (SVL– 2880 mm, TL– 720 mm) was the largest snake and *Typhlops* sp. (total length– 200 mm) was the smallest species observed during this study.

3.3.6. Size Structure

3.3.6.1. Reptile Community

Size structure of a species or community reflects some aspects of the population parameters. In lizards, SVL varied between 50 and 290 mm and the size class was categorized with 20 mm interval. Maximum species of lizards belonged to smaller size class and the number of species decreased with increase in size class. Out of 14 lizard species recorded, SVL of more than 50% was within 70 mm category (Fig. 3.6a). Only one species had SVL more than 130 mm.

In the case of snakes, the size varied from 145 to 3600 mm. However, more than 75% of snakes belonged to SVL lower than 1500 mm (Fig. 3.6b). Snakes largely followed left skewed pattern, but the maximum number of animals were represented by medium sized species (Fig. 3.6b). Overall, reptiles (lizards and snakes together) of Teesta valley followed similar pattern, confirming the general view that in nature smaller bodied species would be represented in higher numbers compared to larger bodied species. (Fig. 3.6c).

3.3.6.2. Size Structure of Selected Species

SVL of selected species of reptiles were categorized into different size classes to know the pattern of their size structure. Representative members of the same family (e.g. Agamids, Scincids, Colubrids and Viperidae; Plate 5, 6, 7) from higher and lower altitudes were considered for comparison.

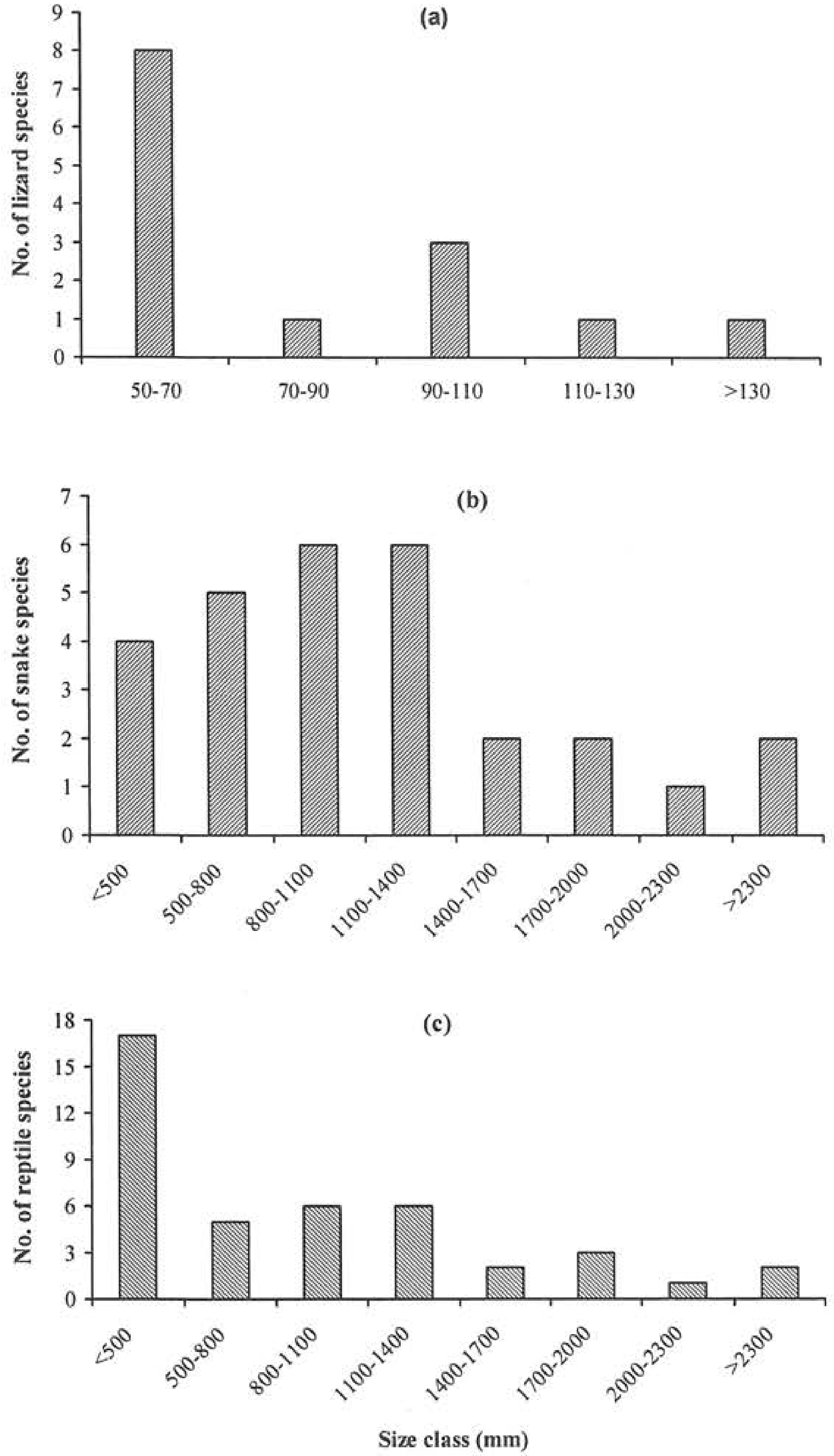


Figure 3.6. Size structure (snout vent length) of reptiles observed along the Teesta valley; (a) Lizard, (b) Snake and (c) Overall.

Agamids

Mean and standard deviation (SD) of variables such as snout vent length (SVL), tail length (TL) and weight (Wt) of 122 *Japalura variegata* were 90.8 ± 22.2 mm, 171.5 ± 49.7 mm and 25.38 ± 14.49 gm respectively. SVL and Wt of the smallest and largest individual measured 33 mm and 123 mm and 1gm and 53 gm respectively. The size structure of *Japalura variegata* followed unimodal right skewed pattern. Size class 100-110 mm had the highest proportion (29.06%) of lizards (Fig. 3.7a). Considerable representation of various size classes reflects the healthy population of this species.

Mean (±SD) SVL, TL and Wt of 47 *Calotes versicolor* were 79.2 mm (±16.1), 201.1 mm (±51.7) and 14.8 gm (±8.42) respectively. SVL of the smallest and largest individual measured 40 mm and 103 mm respectively. Size classes of *Calotes versicolor* showed typical unimodal (bell shaped) pattern though more skewed towards right (Fig. 3.7b). Higher size classes contributed more compared to lower size classes. Unlike *Japalura variegata* considerable number (35%) of individuals reached sub adult stage (60-80 mm), after which the population got more or less stabilized. In both Agamids, lizards were more abundant in smallest size class compared to subsequent size class.

Scincids

Twenty-six *Sphenomorphus maculatus* had SVL, TL and Wt 51.6±10.7 mm, 75.6±23.2 mm and 3.12±1.68 gm respectively. The SVL of the smallest and largest skink varied from 30 to 68 mm respectively and the weight ranged from 0.5 to 6 gm. The size structure of this lower altitude skink showed bimodal pattern with notable peaks at 45-50 and 60-65 mm size classes with dip in the intermediate classes (Fig. 3.8a).

A total of 83 *Asymblepharus sikimmensis* were measured for morphometric variables. Mean ± standard deviation of SVL, TL and Wt were 43.4±9.8 mm, 53.3±17.3 mm, and 1.99±0.94 gm respectively. The SVL of the smallest and largest lizards varied from 11 to 57 mm and their weight ranged from 0.5 to 4 gm. *Asymblepharus sikimmensis* (high altitude skink), largely showed unimodal right skewed pattern (peak at 45-55 mm class representing the highest proportion 53.01%). Representation of smaller sized skinks was low (Fig. 3.8b).

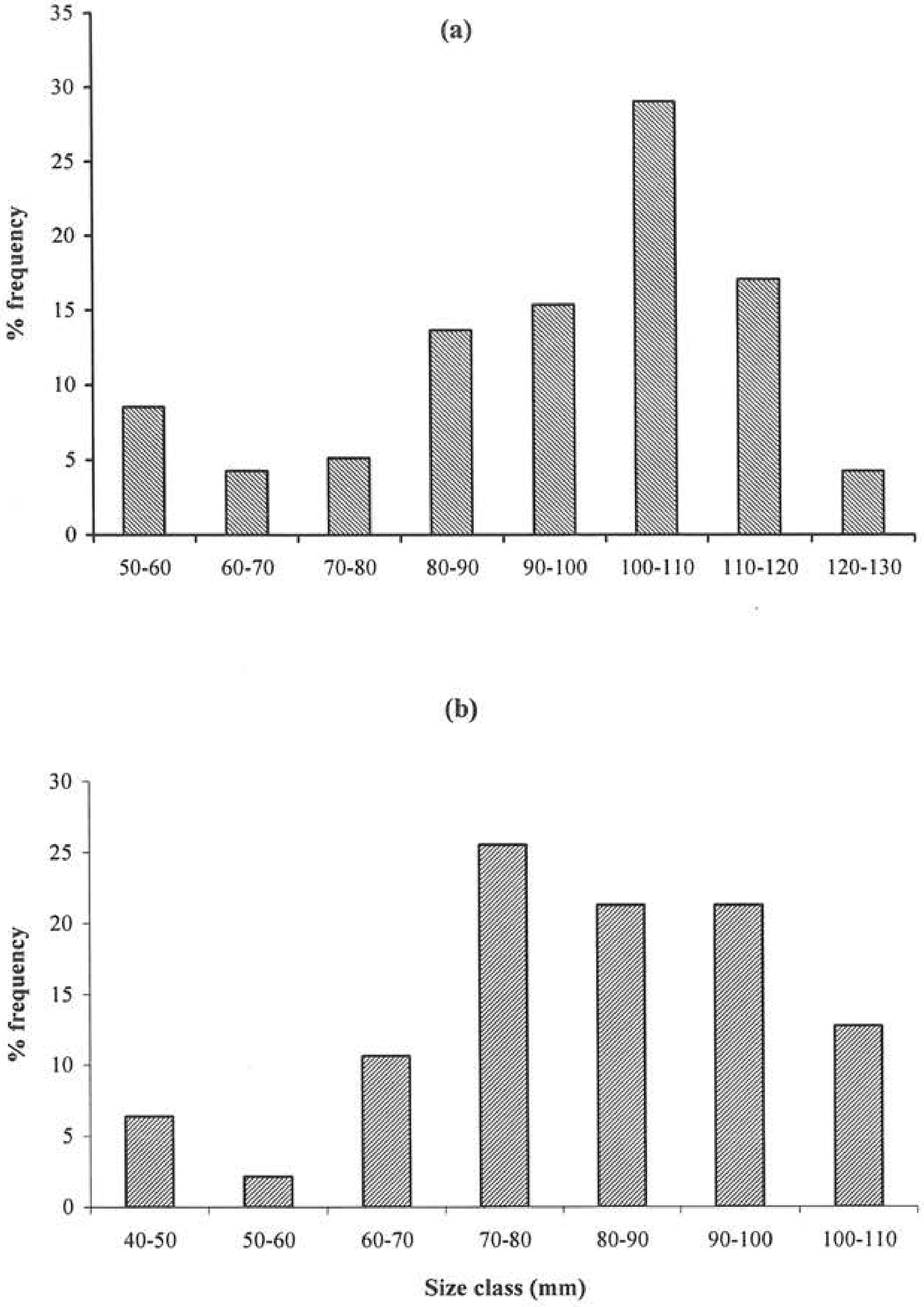


Figure 3.7. Size structure of (a) *Japalura variegata* and (b) *Calotes versicolor* observed along the Teesta valley.

Plate 5. (a) *Calotes versicolor* and (b) *Japalura variegata:* representatives of lower and higher altitude Agamids

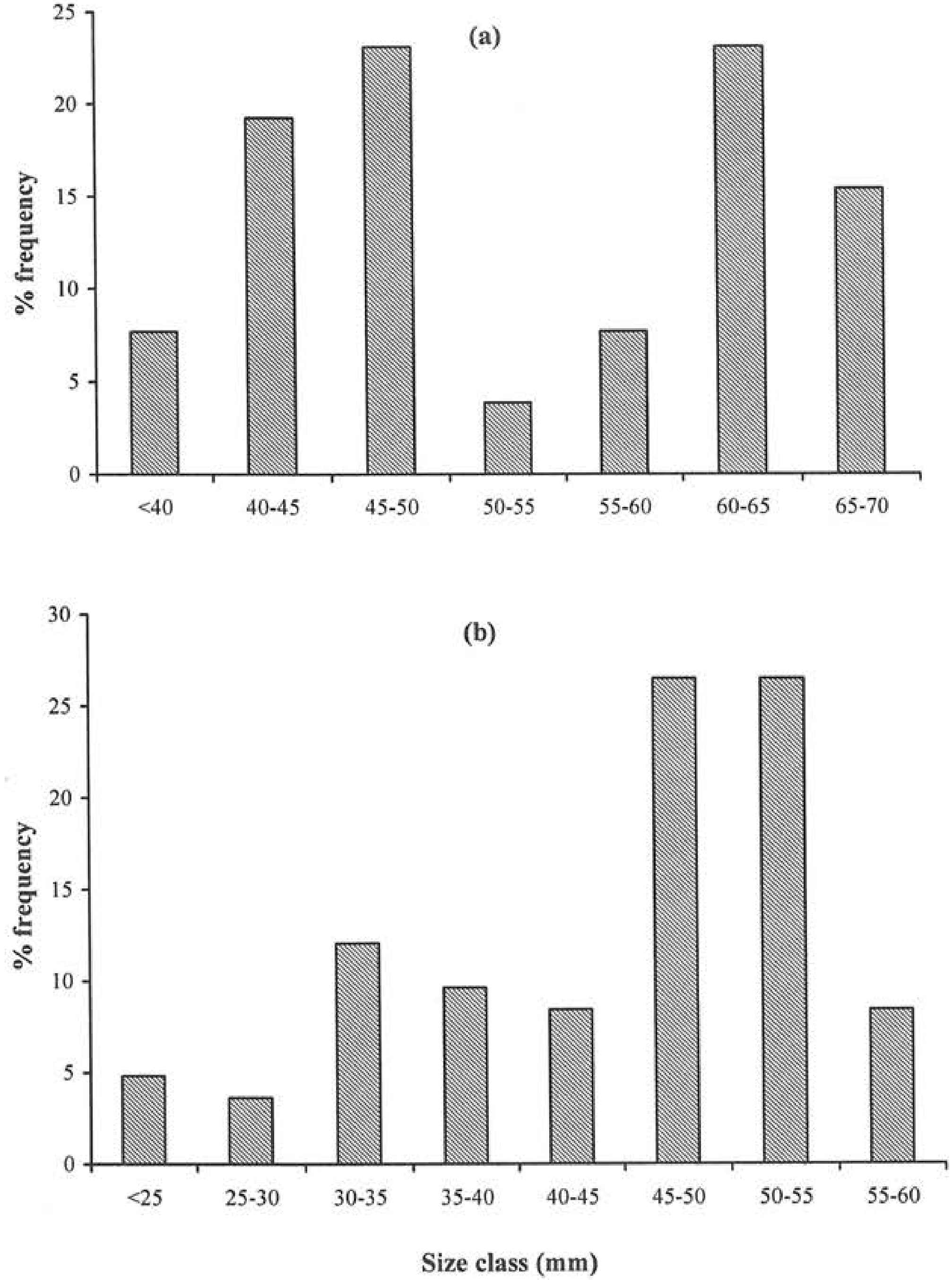


Figure 3.8. Size structure of (a) *Sphenomorphus maculatus* and (b) *Asymblepharus sikimmensis* observed along the Teesta valley.

Plate 6. (a) *Sphenomorphus maculatus* and (b) *Asymblepharus sikimmensis:* representatives of lower and higher altitude Scincid members

Colubrid snakes

Two natricine members (*Xenochrophis* sp. and *Amphiesma platyceps*) and *Trachischium guentheri* were considered for comparison. SVL and TL of the smallest and largest snakes of *Xenochrophis* sp. were 175-820 mm and 22-258 mm respectively. Mean ± standard deviation of SVL and TL of 14 snakes were 554.6±160.9 mm and 186±75.1 mm. The wide variation of SVL with high SD (~30% of the total) indicates that individuals of all age groups were represented in the population. *Xenochrophis* sp. showed typical unimodal (bell shaped) pattern with peak in the middle size class (450-600 mm) contributing 42.86%. Other size classes had nominal representation in the sample (Fig. 3.9a).

Mean ± standard deviation of 33 individuals of *Amphiesma platyceps* had SVL, TL and Wt 524.6±160.9 mm, 186±75.1 mm and 26.69±10.99 gm respectively. SVL of the smallest and largest snakes measured 137 mm and 950 mm respectively. Wide variation of SVL from 137 to 950 mm indicates that the population of *Amphiesma platyceps* is stable. This species largely followed unimodal right skewed pattern with poor representation of the smallest (<150 mm) and largest (>750 mm) size classes (Fig. 3.9b). The size class 450-600 mm contributed the highest proportion in the sample.

SVL and TL of 360 *Trachischium guentheri* ranged from 88 to 440 mm and 12 to 80 mm respectively. Mean and standard deviation of SVL, TL and Wt were 274.6±77.5, 50.9±15.1 and 104.1±57.2. All size classes of this species showed considerable representation, which indicates a healthy population. Size class of *T. guentheri* followed unimodal right skewed pattern with peak at 260-320mm (representing 42.5%; Fig. 3.9c).

Viperids

Mean (±SD) SVL and TL of 32 *Ovophis monticola* were 446.5 mm (±161.2) and 73.8 mm (±24.8) respectively, SVL ranged from 174 to 712 mm and TL from 29 to 105 mm respectively. The weight of this species ranged from 3 to 330 gm. *O. monticola* showed unimodal pattern biased towards right with higher (maximum 43.75%) representation in 450-600 mm size class (Fig. 3.10a). Considerable representation of all size classes indicates the stable population of this species in Teesta valley.

Mean ± standard deviation of snout vent length (SVL) and tail length (TL) of 28 *Protobothrops* sp. measured 997 ± 234.1 mm and 200.9 ± 53.9 mm respectively. SVL of the smallest and largest snakes measured 325 and 1240 mm respectively. *Protobothrops* sp. also followed unimodal right skewed pattern, which peaked at 900-1200 mm representing 64.28% of snakes in this size class (Fig. 3.10b).

Of the nine species selected for size structure analysis, six followed right skewed, two centre peaked unimodal, and one bimodal pattern. Notably, all the (six) species distributed in high altitudes (>1000 m) displayed right skewed pattern. Both the species that showed bell shaped (centre peak) pattern were representatives from low altitudes/tropical forests (<800 m). *Sphenomorphus maculatus* displaying bimodal pattern also belonged to tropical forest.

3.3.7. Altitudinal Variation in Body Size

The effect of altitude on body size (Bergmann's rule) was tested in select species having wide altitudinal distribution range. As per this rule, species become larger in higher altitude than their counterparts in lower altitude.

Calotes versicolor, a tropical agamid, was distributed from 300 to 1000 m in the study area. Hence, below 500 m was considered as low and above 500 m as high altitude. Since *Japalura variegata* was widely distributed from 800 m to 2200 m, 1500 m was selected as cut point between upper and lower altitude. Though *Sphenomorphus* sp. ranged from 300 to 1700 m, very few were observed above 1000 m hence, the area below 700 m was considered as lower and above 700 m as higher altitude. *Asymblepharus sikimmensis* ranged from 1000-2600 m and below 2000 m was treated as lower altitude and above 2000 m as higher altitude as abundance occurred above 2000 m. *Amphiesma platyceps* widely ranged from 700 m to 2600 m and hence, below 1700 m was treated as lower altitude and above it as higher altitude. Though *Trachischium guentheri* ranged from 2080 to 2650 m altitude but maximum individuals were clumped between 2300-2650 m hence, 2500 m was considered as mid point of this species distribution.

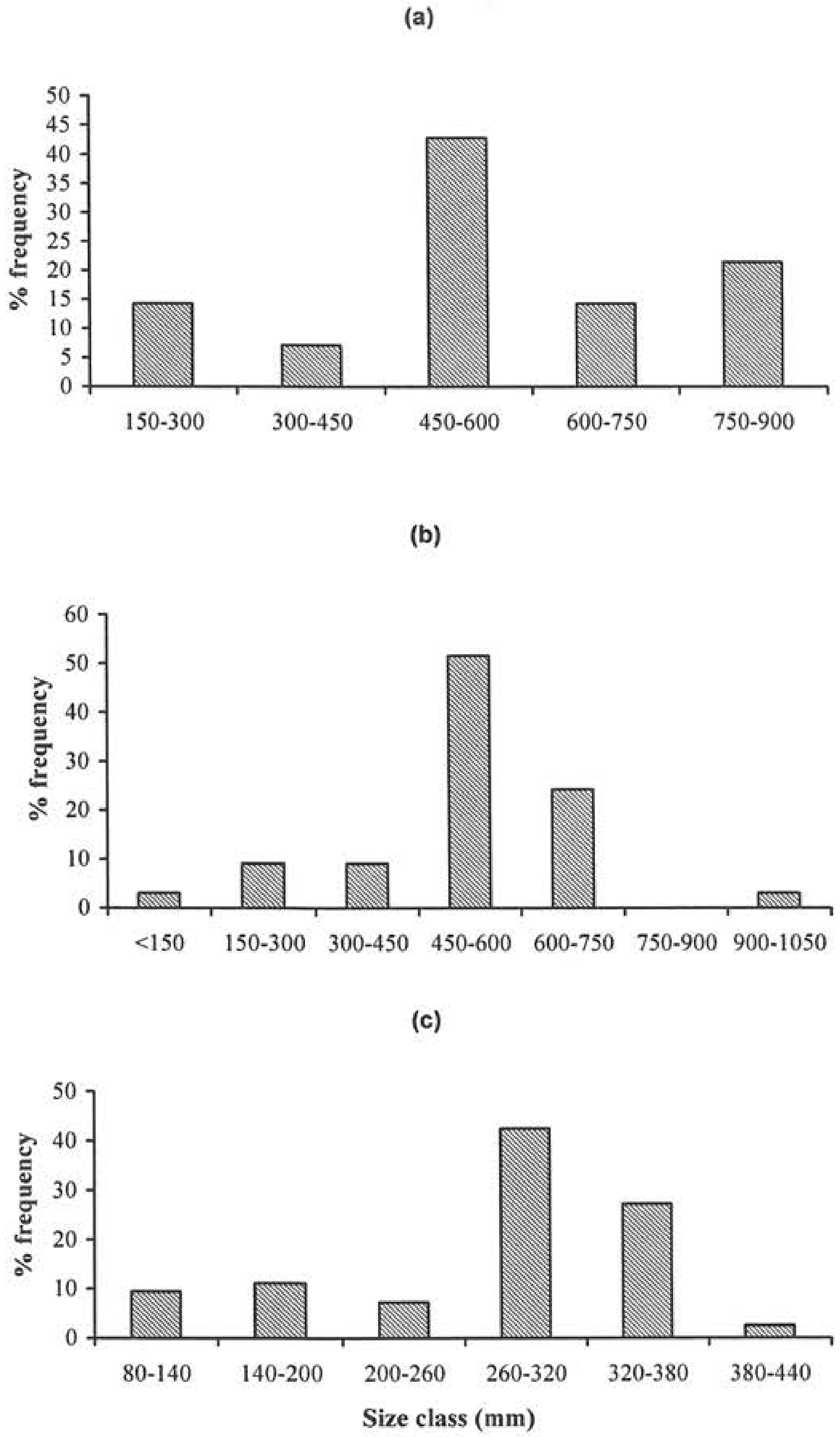


Figure 3.9. Size structure of (a) *Xenochrophis sp.* (b) *Amphiesma platyceps* and (c) *Trachischium guentheri* observed along the Teesta valley.

Plate 7. (a) *Trachischium guentheri* (b) *Ovophis monticola*: high altitude snake species observed along the Teesta valley

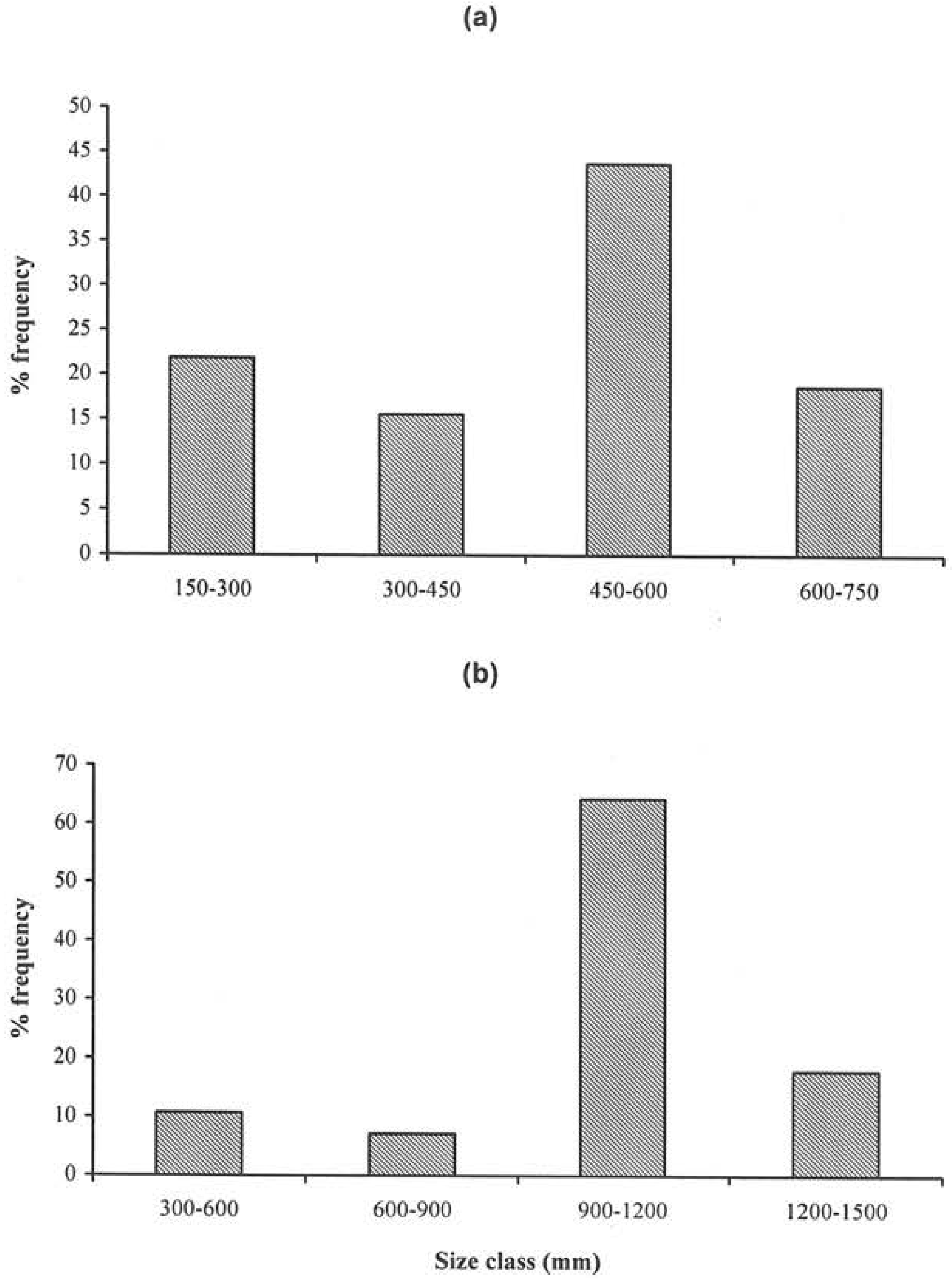


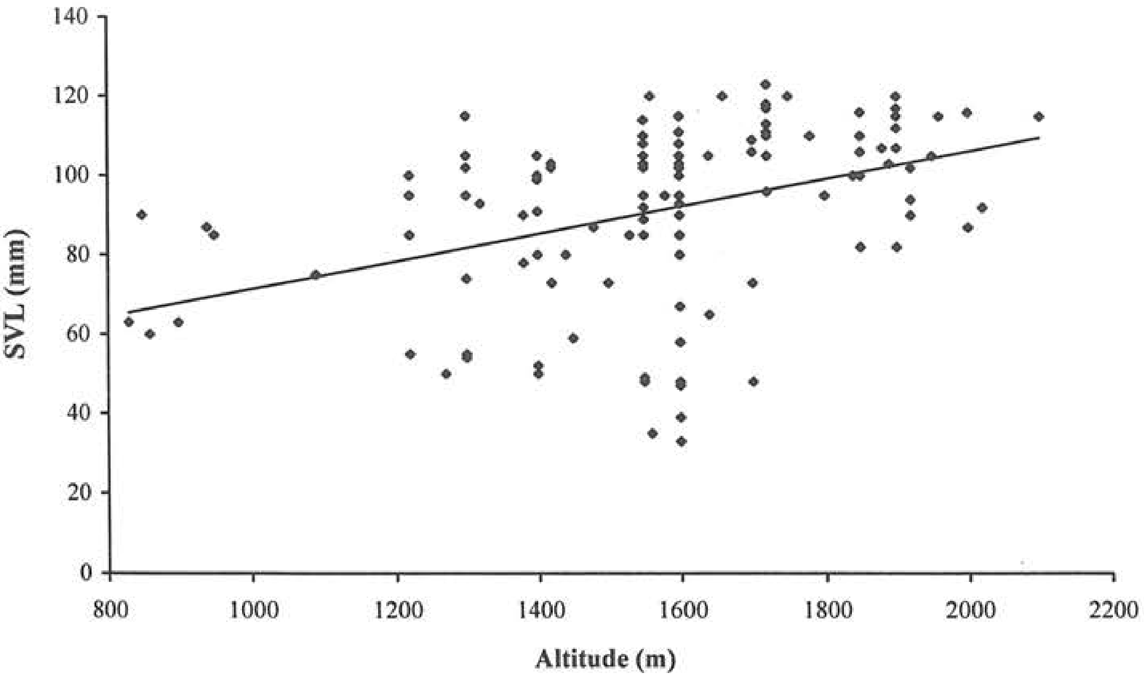
Figure 3.10. Size structure of (a) *Ovophis monticola* and (b) *Protobothrops* sp. observed along the Teesta valley.

The maximum SVL of all species except *Asymblepharus sikimmensis* showed positive relation with altitude showing relatively higher value in high altitude (Table 3.4). However, in the case of mean SVL only four species (*Calotes versicolor*, *Japalura variegata*, *Sphenomorphus* sp., *Amphiesma platyceps*) showed increase with altitude.

Two widely distributed species, *Japalura variegata*, (800 to 2200 m) and *Amphiesma platyceps* (700 to 2600 m) were selected for analysis. There was a significant positive correlation between SVL of *Japalura variegata* and altitude (Pearson correlation $r = 0.41$, $P = 0.000$; n = 122). Body size of lizard was found increasing with increasing altitude (Fig. 3.11a), which is in accordance with the Bergmann's rule. However, *Amphiesma platyceps*, although showed increase in size from low to high altitude, the relationship was not statistically significant (Fig. 3.11b).

Table 3.4. Minimum, maximum and mean SVL (mm) of selected species of reptiles observed in higher and lower altitude along the Teesta valley.

Species	Low Altitude			High Altitude		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Calotes versicolor	40	100	77.4	41	103	81.5
Japalura variegate	33	90	64.8	82	123	103.9
Sphenomorphus sp.	30	58	43.9	57	68	63.2
Asymblepharus sikimmensis	35	57	47.7	11	56	42.3
Amphiesma platyceps	137	718	501	253	950	546.9
Trachischium guentheri	100	428	297.7	88	445	267.2



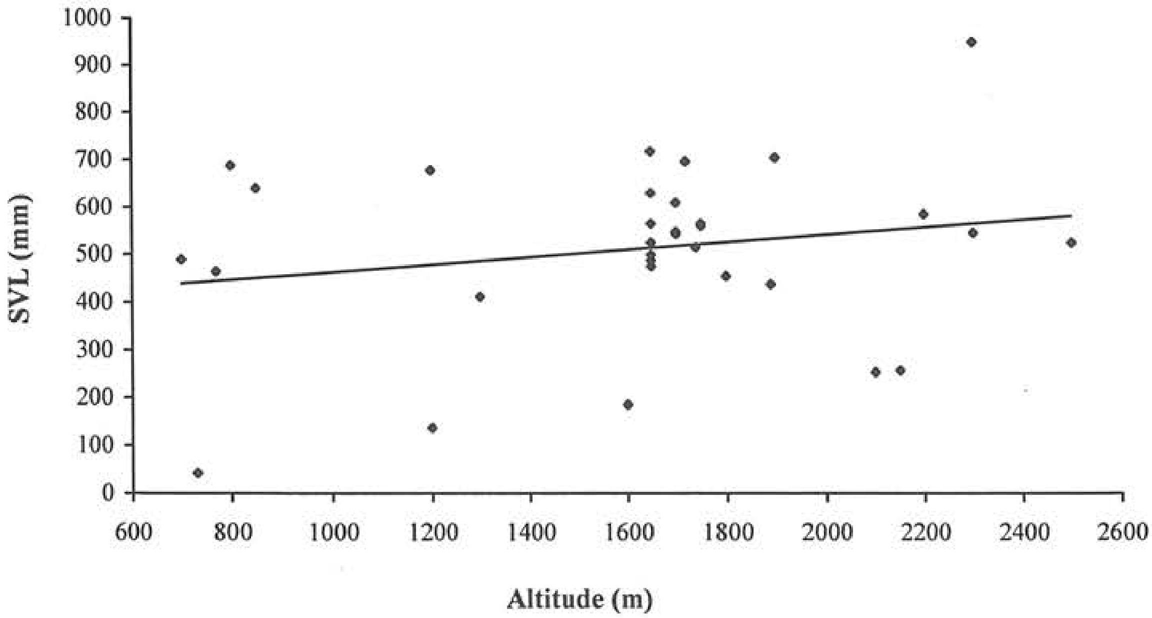


Figure 3.11. Distribution of various size (SVL) classes of (a) *Japalura variegata* and (b) *Amphiesma platyceps* along the altitude zones in Teesta valley.

3.4. DISCUSSION

Chettri and Bhupathy (2007) reported 78 species of reptiles from Sikkim. In this study, 42 species were recorded from the Teesta valley that is 54% of the total species reported to occur in Sikkim. Species such as *Melanochelys trijuga, M. tricarinata, Lissemys punctata* and *Indotestudo elongata*, although reported to occur in Sikkim (Waltner, 1973; Swan, 1993) were not observed during this study. Occurrence of turtles and tortoises in Sikkim appears unlikely due to lack of suitable habitats (Gammie, 1928). The species such as *Trachischium fuscum*, *Oligodon erythrogaster* and *Ophisaurus gracilis* those are likely to be present in the Teesta valley were not observed during the study. This may be due to various factors such as sparse distribution and high seasonal activities of these species, and restricted sampling along a small strip (2 km width) of the Teesta valley. Based on the information available on distribution pattern and habitat use, snake species such as *Pareas macularius*, *Liopeltis stoliczkae*, *L. rappi*, *Dinodon gammiei*, *Oligodon erythrogaster*, *O. melaneus*, *Trachischium fuscum*, *Psammodynastes pulverulentus*, *Sinomicrurus macclellandi*, *Gloydius himalayanus* and lizard *Ophisaurus gracilis* (Smith, 1935, 1943; Shaw *et al.*, 1999; Whitaker and Captain, 2004) are likely to occur in Teesta valley. These species may occur in areas (>2 km width of Teesta valley) not sampled during this study.

This study yielded records from Sikkim for *Takydromus* sp., *Lycodon aulicus*, *L. fasciatus* and *Xenochrophis* sp. after 60 years (Smith, 1935, 1943) and *Cyrtodactylus khasiensis* and *Bungarus niger* after 30 years (Waltner, 1973). These records indicate that the area remained unexplored after the surveys undertaken by British explorers. Sightings of *Naja kaouthia* at an altitude of 1700 m in cardamom plantations is an altitudinal extension, which could be due to several reasons such as expansion of plantation activity and subsequent raise in rodent populations. Altitudinal range extension of *Ptyas mucosus* in Nilgiris is reportedly due to increase in plantation area and other agricultural activities (Nixon and Bhupathy, 2001).

The sampling along Teesta valley for three years (2003-2006) yielded 42 species, which is about 8% of the species found in India (506 species; Das, 2003). A total of 165 species is reported from Western Ghats, which is about 32.6% of the Indian fauna. When compared to the area (159,000 km^2) of Western Ghats (Rodgers and Panwar, 1988) and Teesta valley sampled (170 km^2), the reptile fauna found is relatively high. A compilation by Molur and Walker, (1998) reported 167 species from Northeast India. Occupying 0.07% geographical area of Northeast India (about 255,168 km^2, Pawar *et al.*, 2007), Teesta valley harbours 25.4% of species that occur in Northeast India. The sampled area of Teesta valley represents about 2.4% of the total area of Sikkim. However, it represents 54% of the reptile fauna of Sikkim. The high diversity in comparison to small area is attributed to the unique location of the study area at the cross road of many Biogeographic realms (Palaearctic, Oriental) and regions (Indo-Malayan, Indo-Chinese), and also high variation in climate and vegetation types (Chettri and Bhupathy, 2007). Teesta valley showed high similarity with Darjeeling Hills in faunal composition of reptile species, which might be attributed to their close vicinity and similarity in climate (Swan, 1993).

As mentioned earlier, only 25.4% of the reptile fauna of Northeast India was found in the Teesta valley. Saurofaunas is reported to be richer in arid zones compared to wetter regions (Pianka, 1973; Waltner, 1973). The moist and humid nature of the valley of Teesta might be another possible reason for low species richness in relation to overall faunal diversity of Himalayas. Mountain slopes served as filter bridge for the upward movements of species and the most obvious resistance for this upslope movement is temperature (Scott, 1976). The steep gradient of the Teesta valley would have negatively influenced the dispersion of snakes thus reducing the overall richness. According to ecological and evolutionary time hypotheses (Pianka, 1966b, 2000; Gaston and Blackburn, 2000) species richness in a region will be limited when there is too little time for both colonization (ecological time) or niche diversification and speciation (evolutionary time). Since Himalayan Mountain System is recent in origin in terms of geological time scale, there might not have sufficient time for colonization of many terrestrial species. Finally, single sampling method (VES) mostly focusing terrestrial reptiles would have also contributed to low species richness in Teesta valley compared to entire Himalayan/ Northeast Indian range, missing species such as canopy dwellers.

Reptile encounter rate in Teesta valley was low (0.66/hrs) compared to upper Nilgiri (0.87/hrs, Nixon, 2005), whereas it was higher than in Anaikatty Hills (0.04/hrs, Mukherjee, 2007). The difference in the encounter rate of reptiles of these areas may be due to variation in area, altitude and climatic factors. In upper Nilgiris due to low temperature, most of the species might have remained lethargic, which could have resulted in enhanced basking leading to greater sightings (Nixon, 2005). On the other hand, reptiles in warmer areas such as Anaikatty Hills may be relatively fast moving, active and would escape detection (Andrews, 1990; Bonnet *et al.*, 1999; Mukherjee, 2007). Since, Teesta valley represents extreme cold, hot and intermediate climate, encounter rate is intermediate between upper Nilgiris (cold climate) and Anaikatty Hills (warmer climate). In Teesta valley though sampling was done from 300 to 4800 m, reptiles were observed only up to 2700 m, hence the encounter rate might have reduced.

Rarefaction curve with 95% confidence interval did not reach plateau even after two years of sampling suggests that few species might have gone undetected (Fig. 3.1a), which is a general trend in tropical forests, as high species richness often results in unsaturated species accumulation curve (Cardelus *et al.*, 2006). Rarefaction aids in standardization and comparison of datasets spread over different locations/habitats (Gotelli and Colwell, 2001). Rarefaction assumes that all individuals are randomly dispersed in the community and the more clumped the distributions are, the greater the overestimation of the number of species by this method. Though the present study consists of few clumped species, the large sample size would have reduced the bias related to clumped distribution (Krebs, 1989). In the present study, rarefied value was close to the observed, which shows that sampling was more or less representative of the homogenous distribution of the species (Krebs, 1989; Colwell and Coddington, 1994; Colwell, 2005).

Individual based rarefactions ignore patchiness and thus overestimate the richness that would have found with less effort (Gotelli and Colwell, 2001). In contrast, incidence based rarefaction reflects aggregation within species, which provides realistic estimates of the number of species (Colwell and Coddington, 1994). Comparison of both approaches for the same data set will give idea about patchiness. Incidence based and abundance based rarefaction curves in the same graph indicate that most of the species occur uniformly and independently among the samples (Colwell *et al*., 2004).

Species diversity is central to all conservation issues as high diversity areas capture more attention than that with low diversity (Magurran, 1988). Hill's diversity ($e^{H'}$) provides an index of the number of contributing species to the diversity or the common species, whereas Shannon-Weiner diversity is a measure of richness as well as evenness. Evenness is an expression of the distribution of animals among the species in a sample. Both Shannon-Weiner and Hill's diversity and Evenness value was higher for lizards though species richness was high for snakes. Most snakes were relatively rare in Teesta valley except *Trachischium guentheri*. As compared to snakes, lizards were more evenly distributed in the study area; of the 14 species of lizards, five were abundant. As diversity is a measure of both richness and evenness, lizards scored high diversity value. Lloyd *et al*. (1968) observed greater equitability in lizards compared to other herpetofaunal taxa.

In Teesta valley, among ten families, five each of lizards and snakes, Gekkonidae and Colubridae was the most contributing family. Specious nature of Colubrids was discussed by Parker and Plummer (1987). This may be the general pattern of reptiles in most places in India on the whole including the Western Ghats (Das, 2003; Mukherjee, 2007). Higher number of species under the family Gekkonidae could be due to their adaptability to use various microhabitats including human habitations.

Lizards were relatively abundant than snakes in Teesta valley though species richness was high in snakes. This result is consistent with the findings on reptiles of different locations of Western Ghats (Ishwar *et al*., 2001; Nixon, 2005 and Mukherjee, 2007). This could be due to reasons such as low population density, and relatively extensive and irregular movements in snakes (Parker and Plummer, 1987). Higher abundance of lizards may be due to greater adaptability of the members of these taxa.

Among reptile families, Scincidae in lizards and Colubridae in snakes were dominant with respect to abundance. Presence of different species of Scincidae and Colubridae both in lower as well higher altitude of the study area supports the higher abundance of these families. At species level *Asymblepharus sikimmensis* and *Trachischium guentheri*, had the highest relative abundance, which may be due to their gregarious and clumped distribution.

Barring a few species, relative abundance of reptiles of Teesta valley was low. Most species were seen only once or twice during entire course. The present results augment the fact that in a community few species would be common, whereas most species would be rare (Heatwole, 1982; Magurran, 1988).

Size structure of overall reptiles of Teesta valley largely followed left skewed pattern indicating maximum smaller bodied species and few larger bodied. Hutchinson and MacArthur (1959) reported that environment does not provide adequate space for large number of species having larger body size. Larger animals may require several biotypes each of which may be specific to several small-bodied species. Due to limited resources, natural selection may support fewer larger bodied species in an animal community. Overall reptile size structure of Teesta valley is in consistent with the view of Hutchinson and MacArthur (1959). This view was also supported by May (1986) and Griffiths, (1986). Fowler and MacMahon (1982) stated that extinction rate would be higher among species with low evolutionary plasticity, which may be true for species with long generation time. As the body sizes are positively correlated with the generation time, extinction rate will be higher in larger bodied animals than smaller bodied ones. On the other hand, short generation time of smaller bodied animals with greater plasticity may allow them to adapt to any environment. Even the rate of speciation will be higher in smaller bodied species (Begon *et al*., 1996a, b).

Body size is considered to be one of the most important life history characteristics of a species (Roff, 1992). In all, nine species considered for size structure analysis, small size class was represented by minimum number of individuals (unimodal right skewed). Low temperature of the study area could have resulted in poor hatching and high juvenile mortality (Blair, 1960; Brooks, 1967). Less representation of juveniles could also be due to low detection (owing to small size), high dispersal and predation (Mukherjee, 2007).

Two species (*Calotes versicolor* and *Xenochrophis* sp.), both exclusively tropical and largely restricted to lower altitudes, showed typical unimodal (bell shaped) pattern with maximum individuals representing middle size classes and few individuals on either ends. Unimodal centre peaked pattern is due to higher reduction of juveniles (predation) and adults may be due to disease or other factors (Brown, 1995; Dixon *et al.*, 1995; Trombulak and Frissell, 2000; Etienne and Olft, 2004). Parker and Plummer (1987) reported that early (first-year) survivorship would be low in most Colubrids. However, the post juvenile survivorship will be higher as the number of potential predators and other sources of mortality decreases (Parker and Plummer, 1987).

Six out of nine species (*Japalura variegata, Asymblepharus sikimmensis, Amphiesma platyceps, Trachischium guentheri, Ovophis monticola, Protobothrops* sp.) that displayed unimodal right skewed pattern were mostly restricted to temperate habitats. In temperate regions, due to severity and sudden fluctuation of climatic condition, low hatching success and high juvenile mortality would result in right skewed pattern. Heatwole (1982) reported that high mortality of juveniles, and lack of competition among adult results in stable adult population. Kindlmann *et al.* (1999) reported that body size distribution of species is often skewed towards right.

The size structure of Scincids (*Sphenomorphus maculatus*) followed bimodal distribution pattern. Brooks (1967) reported that if the individuals survive first year then there is a better chance of survivability. Decrease in subsequent size classes may be related to dispersal, which involves movement and exposure to predators. Inger and Greenberg (1966) reported that in tropical forest, the lack of seasonal demarcation results in continuous breeding of lizards. Skinks are reported to have wider thermal tolerance than other lizards due to which they may be active throughout the year (Avery, 1982). Continuous breeding and wider thermal tolerance may be reasons for bimodal distribution in *Sphenomorphus maculatus* dwelling in low altitude tropical forest.

Although Bergmann's rule is related to environmental temperature, latitude and altitude are used as proxies for temperature (Ashton and Fieldman, 2003). Of the six species selected for analysis, maximum SVL of all species except *Asymblepharus sikimmensis* showed positive relation with altitude. Larger body size in higher altitude could be due to many factors. Larger individuals are efficient in food storage in the form of fat for prolonged inactive period during colder conditions (Ashton and Fieldman, 2003) and relaxed/poor competition as few species are found in higher altitude (Ashton *et al.*, 2000). Ergon *et al.* (2004) reported reduced fitness for larger body size due to energy maintenance and risk of predation. In other way, if the animals adjust their energy intake, then larger size may be preferred. Since reptiles reduced their energy expenditure by reduced metabolic rate, hibernation and intake of high quality food, larger size may be beneficial in higher altitude.

The colour of the animals may also help in explaining the Bergmann's rule, which has not been considered so far. The darker or dull body colour in higher altitude may be beneficial for heat absorption and retention. *Asymblepharus sikimmensis*, a high altitude skink is darker in coloration. Notably, this species did not show increase of body size (SVL) with altitude. In case of *Asymblepharus sikimmensis*, dark colour and small body size would have been beneficial for maintaining thermoregulation. However, further studies are required to confirm the role of body colour in determining the size of animals along altitude gradient.

Other environmental factors may also play role in determining body size along the altitude. Low temperature during developmental stages results in larger body size (Ashton and Fieldman, 2003). Due to restricted growing season in high altitude, temperate amphibians exhibit slower growth and development rate and consequently mature later than their lower altitude counterparts (Miaud *et al.*, 1999). The delayed maturation results in larger body size (Ryser, 1996). It is also reported that other factors responsible for larger body sizes are availability of high-energy prey (Ford and Seigel, 1994).

Calotes versicolor along the Teesta valley showed that higher altitude specimens were larger (mean SVL-81.5 mm) than the lower altitude (mean SVL-77.4 mm). However, when latitudes were considered instead of altitude, *Calotes versicolor* showed negative relation. *Calotes versicolor* of southern India was relatively larger than northeast India (Smith, 1935). The mean SVL in high latitude Teesta valley (27°N and 88°E) was smaller (79.23 mm, n = 47) than mean SVL (83.04 mm, n = 25) of low latitude Anaikatty Hills (11°N and 76°E), Peninsular India (Mukherjee, 2007). Arnett and Gotelli (1999) reported increase of body size with latitude but decrease with elevation with respect to ants. The findings of the present study disagree with this view. McNab (1971) examined mammal body length along the latitude and reported that body size showed negative relation at lower latitude and positive relation at higher latitude. The body length of *Calotes versicolor* in Teesta valley, Eastern Himalayas and Peninsular India augments the above statement.

Ashton and Fieldman (2003) reported that in general, squamates follow reverse pattern of Bergmann's rule. However, most data tested were from temperate region of Northern Hemisphere. Laugen *et al.* (2005) concluded that Bergmann's rule might be valid for short geographic distance. This may be the reason why many species in the present study followed Bergmann's rule. It is reported that applicability of Bergmann's rule in different area and taxa appears controversial (Ashton and Fieldman, 2003) and hence before drawing precise conclusions more samples should be examined. To understand body size variation, nutritional aspects, energetics, trophic interaction and life history trade-offs should be considered (Ergon *et al.*, 2004).

3.5. SUMMARY

- Considering the topography and wide variation in altitudinal and climatic conditions of Teesta valley, visual encounter survey method was used for data collection from June 2003 to March 2006. In all, 42 species of reptiles with 1596 individuals (663 snakes and 933 lizards) were observed in 2494 man-hours of visual encounter survey and other methods.

- Encounter rate, diversity and evenness were high in the case of lizards and species richness was high in snakes. In the case of lizards, many species were contributing equally to the population and therefore this taxon showed high diversity and equitability compared to snakes.

- Among the ten families of reptiles comprising five each of lizards and snakes found along the Teesta valley, lizards contributed 58.5% and the rest (41.5%) by snakes in terms of abundance. Gekkonidae and Colubridae contributed maximum species in the case of lizards and snakes respectively. Families such as Lacertidae, Varanidae and Boidae were represented by single genera and species.

- Among 28 species of snakes *Trachischium guentheri* was most abundant (68.02%), whereas it was *Asymblepharus sikimmensis* (36.55%) among 14 species of lizards. Patchy and clumped distribution of both these species in higher altitude of North Sikkim could be responsible for the same. Nine species were singletons and five species were doubletons in the sample.

- *Python molurus* and *Typhlops* spp. were the largest and smallest snakes respectively, whereas *Varanus bengalensis* was the largest and *Hemidactylus bowringii* was the smallest lizard observed in Teesta valley. Of the nine species selected for morphometric analyses, six showed right skewed, two centre peaked unimodal pattern, whereas only one species followed bimodal distribution. Notably, all six species that displayed right skewed distribution were largely high altitude (temperate) species. Two species showing bell shaped unimodal and one bimodal pattern of distribution were restricted to low altitude (<1000 m) tropical forests.

- Six species tested for the applicability of Bergmann's rule showed positive relation with altitude (barring *Asymblepharus sikimmensis*). The larger body size may be an adaptation towards cold in higher altitude. Though body size increased with increasing altitude following Bergmann's rule, substantial conclusions could be drawn in this regard only after further studies.

CHAPTER 4

DISTRIBUTION PATTERN

DISTRIBUTION PATTERN

4.1. INTRODUCTION

Various climatic and vegetation types from the base to mountain summit characterize the mountain ecosystem (Yu, 1994). Understanding factors governing distribution of species along the altitude gradient would help understanding biodiversity and their conservation (Raman, 2001; Vetaas and Grytnes, 2002). Rahbek (1995, 1997) reported three general patterns with respect to the distribution of species along the altitude gradients: (i) a monotonic decline in species richness along the altitude (ii) a hump-shaped pattern with a peak at mid altitude, and (iii) increase in number of species with increasing altitude.

Grinnell and Storer (1924) and Whittaker (1967) pioneered the studies pertaining to species distribution along the altitude gradients and Terborgh (1971, 1977) added most to our understanding on the subject. Studies on different invertebrates and plants displayed varying pattern of species richness, whereas vertebrates followed almost similar richness pattern with altitude (Grytnes and McCain, in press). Irrespective of several studies on different taxa and areas across the globe, a common pattern has to be emerged yet. Generalization of pattern at global scale is important to understand the factors responsible for the same (Rahbek, 1995; Brown, 2001; Heaney, 2001; Lomolino, 2001; Colwell *et al.*, 2004).

Altitude gradient is often considered as proxy for latitude (Brown, 1988, Md Nor, 2001a). Accordingly, one would expect monotonic decrease in species richness with increasing altitude as a general pattern like decline of species number from equator to poles (Rahbek, 1997). Tropical forest litter herpetofauna in Costa Rica followed monotonic decline (Scott, 1976) and Rogers (1976) reported similar trend in Texas. Heatwole (1982) reviewed herpetofaunal distribution patterns in the tropical forests of Guatemala, Panama, Philippines, Borneo, Africa, Costa Rica, Thailand, Ecuador and Sumatra and, reported monotonic decline of species with increasing altitude.

Many explanations are proposed to describe linear decrease of species richness with increasing altitude: decline in area (Lawton *et al.*, 1987; Rahbek, 1997; Lomolino, 2001) primary productivity, resource diversity, habitat diversity (Terborgh, 1971,1977; Rahbek, 1997; Md Nor, 2001b), extreme climatic conditions (temperature, precipitation, humidity, atmospheric pressure), historical effect of past climate e.g. effects of alpine glaciers in higher elevation (Brown, 1988; Rickart *et al.*, 1991; Yu, 1994; Rahbek, 1997; Lomolino, 2001; Sánchez-González and López-Mata, 2005) and isolation of mountain communities (Scott, 1976; Lomolino, 2001). Hofer *et al.* (1999, 2000) reported ecotones for amphibians and altitude gradients for reptiles as factors for declining richness along the altitude gradient in Mount Kupe, Cameroon.

According to Rapoport rule, with increase in latitude, species tend to increase their range size. Stevens (1992) extended this rule to altitude gradients, and reported that monotonic decline of species richness could be due to increasing distribution range of species with increasing altitude. The higher altitude species extends towards lower altitude, whereas lower altitude species are restricted in their distribution range, thus showing decrease of species along the altitude. However, the generality of Rapoport rule is debatable (Gaston, 1999).

Mid altitude peak or hump shaped or unimodal pattern is reported to be a general pattern of species richness in most of the taxa; small mammals (Graham, 1990; Patterson *et al.*, 1998; Heaney, 2001; Li *et al.*, 2003; McCain, 2003, 2004a), birds (Navarro, 1992; Rahbek, 1997; Kessler *et al.*, 2001, Raman *et al.*, 2005), amphibians (Cadle and Patton, 1988; Hofer *et al.*, 1999) and invertebrates (Janzen, 1973; Olson, 1994; Sanders *et al.*, 2003).

Factors responsible for mid altitude pattern of species richness are habitat complexity, resource diversity and productivity (Terborgh, 1977; Yu, 1994), phylogeny and speciation (Cadle and Patton, 1988; Patterson *et al.*, 1996; Duellman, 1999), species-area effects (Rahbek, 1995, 1997; McCain, 2007b), temperature and water availability

(McCain, 2007a), historic events (Brown, 2001) and ecotone effect (Rahbek, 1997; Lomolino, 2001). The most robust explanation for the mid altitude peak is suggested by Colwell and Hurtt (1994), according to which, mid altitude peak in richness is a product of increasing overlap of species ranges towards the centre of the domain due to hard geographic boundaries such as coastlines and mountain top imposed on lowest and highest altitude (Colwell and Lees, 2000; McCain, 2003).

Few studies revealed increasing species richness with increasing altitude. Sanders *et al.* (2003) reported this pattern in ants in the arid ecosystem of Spring Mountains, USA. Naniwadekar and Vasudevan (2007) reported linear increase of amphibian species richness at alpha level in Western Ghats along the altitude gradient.

Several non-parametric methods are developed for estimating species richness from sample data and to measure the completeness of the sampling. Southwood and Henderson (2000) concluded that since the magnitude of different estimators might vary with respect to the observed species, it will be informative to compare more than one estimator.

Comparison between two habitats or zones can be explained by considering either similarity or distinctness of the species assemblages. Species turnover is the change in species composition from one place to another (Whittaker, 1960). High turnover rate reflects higher replacement and hence greater species richness. Turnover of species may be due to change in temperature, rainfall, humidity, vegetation, productivity and area availability (Terborgh, 1971, 1977; Rahbek, 1995, 1997; McCain, 2005, 2006).

Among a few available studies on herpetofauna, most were limited to small altitude gradients (Raxworthy *et al.*, 1997), different sampling design and perhaps small sample size with confounded location. Woinarski and Gambold (1992) found an association of herpetofaunal richness with substrate and moisture availability along the altitude gradient in Australia. Daniels (1992) provided data on geographical distribution of amphibians inhabiting Western Ghats, India and reported that low-medium altitude is more diverse in species than higher hills. Naniwadekar and Vasudevan (2007) studied distribution of anurans within the small range of altitude in Western Ghats, India.

The wide altitude gradient as that of Himalayas offers opportunities to evaluate biogeographical patterns of species richness (Körner, 2000). Heaney (2001) stressed the importance of studies on altitude along the southern aspect of the Himalayas. Despite wide variation of altitude in the Himalayas, till today very few studies were carried out on this aspect, especially on plants in Nepal Himalayas (Bhattarai and Vetaas, 2003; Grytnes and Vetaas, 2002; Bhattarai *et al*., 2004; Carpenter, 2005; Bhattarai and Vetaas, 2006). In-depth studies examining the patterns of reptile species richness along the altitude gradients in India is lacking. This Chapter deals with the distribution pattern of reptiles along the altitude gradient of Teesta valley, Eastern Himalayas, Sikkim and attempts to describe factors governing the same.

4.2. METHODS

4.2.1. Data Collection

Time Constraint Visual Encounter Survey (VES) was followed to sample the reptiles of Teesta valley (Chapter 3). The study area (300-4800 m) was divided into seven altitude zones with 500 m intervals (Fig. 4.1). The lowest altitude of the study area was 300 m and hence, area below 500 m was considered as zone I. No reptiles were observed beyond 2700 m during this study hence, area above 3000 m was considered as zone VII (Table 4.1).

Sampling was done on quarterly (tri-monthly) basis with eight sampling unit in each altitude categories or zones per year. Each sampling unit was equivalent to six hours (3hours by two research personnel). Barring zone I and VII, sampling effort was nearly equal in different zones. Zone I had altitude range of 300-500 m, and highest zone (VII) had no reptiles, hence sampling was limited in these zones.

4.2.2. Data Analyses

Species Richness, Abundance and Diversity

Data from samples within one altitude zone were pooled for analyses. Observed species richness for pooled data includes data from VES, transects and opportunistic sightings. Due to meagre sightings in the transects and irregular opportunistic sightings, data collected using VES were largely used for analyses. The following analyses were done.

1. Total number of species observed in each altitude zone was considered as species richness. Species richness was estimated using non-parametric statistical procedure (EstimateS-version 7.5, Colwell, 2005). The sample order was randomized 100 times (Colwell and Coddington, 1994). Important estimators used are Chao2, Jacknife1, Jacknife2 and Coleman Rarefaction. Given the patchy and uneven distribution of reptiles, the abundance data were more appropriate than hours searched. The number of individuals was considered for estimating species richness. Since, species accumulation curve did not reached asymptote in most cases, observed species and Jackknife2 estimates were plotted against altitude controlling the number of individuals (50, 100, 150 and 200).
2. Species abundance: total number of individuals observed in each altitude zone.
3. Shannon-Weiner and Simpson diversity were calculated using EstimateS (version 7.5) to see the β diversity pattern among different altitude zones.
4. Evenness (E) = H'/Hmax

   where, H' = Shannon-Weiner species diversity;

   Hmax = ln S, (S = Number of species)

   ln = Natural logarithm

Altitudinal Pattern of Species

Regression analyses were used to investigate the altitudinal pattern of observed species richness, abundance, estimated non-parametric richness and diversity. Overall data was processed for the best curve fit using SPSS (10.0) without prior specification for linear or polynomial model. The best fit was chosen depending upon R^2 and P values.

Mid-Domain Effect: Null Model

A Monte Carlo simulation procedure (Mid-Domain Null programme; McCain, 2004a) was used to test the effect of geographical boundaries on species distribution. The Mid-Domain Null models were generated by randomly placing ranges or range midpoints between two hard boundaries based on analytical-stochastic models (Colwell and Hurtt, 1994; Colwell and Lees, 2000; McCain, 2003). Prediction curves (95%) based on 50,000 simulations without replacement from empirical range sizes or midpoints were used to assess the impact of geographic constraints (McCain, 2006). Regression analysis was performed to examine the fitness between observed and simulated curve. The mid-domain null simulation was again run by truncating the data from both ends of the altitude gradient (<500 m and >2500 m; Bhattarai *et al.*, 2004) to determine whether the empirical richness pattern is due to geographic hard boundaries or any other factors.

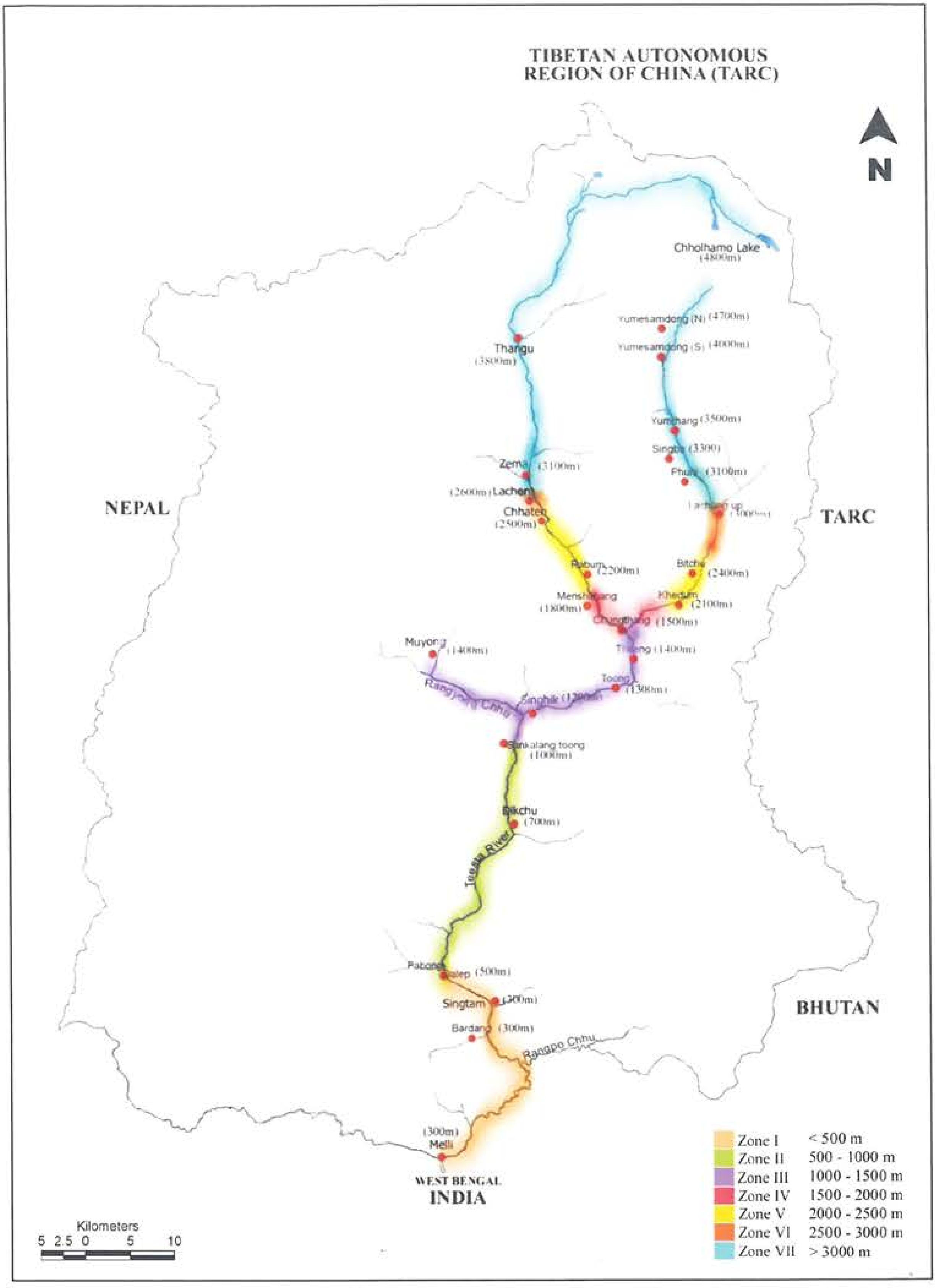


Figure 4.1 Study area showing altitude zones and prominent localities along the Teesta valley, Sikkim

Range Size

The range distribution of each species was estimated as the difference between lowest and highest altitude zones where the species were encountered, assuming the species to be present in all intermediate altitude (Patterson *et al.*, 1998; Md Nor, 2001a; McCain, 2004b). Altitudinal range size was regressed with lower and upper limit distribution of each species to know whether the range size is increasing or decreasing with altitude.

Similarity between Altitudinal Zones

Sorensen similarity coefficient among pairs of elevation zones was calculated using software EstimateS, version 7.5 (Colwell, 2005) and the obtained coefficient was used for assessing the similarity between altitude zones. Cluster analysis was performed using the calculated Sorenson similarity index and a dendrogram obtained based on average linkage among groups.

Species Turnover

Turnover or dissimilarity of species between two consecutive altitude zones was obtained as (1-X), where X is Sorenson similarity index (Wolda, 1981). Pearson correlation was used to test the turnover rate along the altitude zones.

4.3. RESULTS

4.3.1. Altitudinal Pattern of Species Richness, Diversity and Equitability

Maximum of 21 species were observed in zone II (500-1000 m) and minimum of three species in zone VI (2500-3000 m). No reptiles were encountered in zone VII (Table 4.1). The order of species richness along the altitude zones were: zone VI < zone V < zone IV < zone III < zone I < zone II (Table 1). Species richness decreased markedly above zone III. Abundance did not follow increasing or decreasing trend with altitude. Abundance reached maximum at zone VI (2500-3000m) and minimum at zone IV (1500-2000 m): 2500-3000 m > 2000-2500 m > 500-1000 m >below 500 m >1000-1500m > 1500-2000 m (Table 4.1).

Species diversity decreased with increasing altitude. Maximum diversity was obtained in zone I (H′ = 2.22) and minimum in zone VI (0.7). Equitability or evenness also showed similar pattern with highest value in zone I (E = 0.75) and lowest in zone VI (E = 0.43).

Exclusive species (confined to one altitude category) were more in the lower altitude. Maximum number of exclusive species was found in zone I followed by zones III, II and IV in descending order. No species were found exclusive beyond 2000 m (zones V and VI) indicating the wide altitudinal range of species present in the high altitudes.

Species were not evenly distributed along the altitude gradients ($\chi^2 = 36.22$; $P < 0.001$). The species richness decreased significantly and linearly with altitude ($R^2 = 0.93$, $P < 0.000$; Fig. 4.2). Unlike species richness, variation in abundance along the altitude was not significantly different. Species diversity showed linear decrease with altitude ($R^2 = 0.96$, $P < 0.005$). Equitability though decreased along the altitude, showed no significant relation.

Temperature decreased monotonically with elevation ($P = 0.000$) while relative humidity showed unimodal pattern with peak in 1000-1500 m ($P = 0.38$). Species richness showed significant positive relation with temperature ($P = 0.002$), while it showed no relation with relative humidity.

Table 4.1. Data on reptile populations along the altitude gradients of Teesta valley.

Altitude (m)	Sampling (hrs)	Observed species	Abundance	Shannon-Weiner diversity	Equitability	Exclusive species
<500	348	19	213	2.22	0.75	6
500-1000	432	21	216	2.06	0.68	2
1000-1500	462	18	211	1.84	0.64	3
1500-2000	420	12	190	1.37	0.55	1
2000-2500	312	7	246	0.83	0.43	0
2500-3000	300	3	487	0.7	0.64	0
>3000	210	-	-	-	-	-

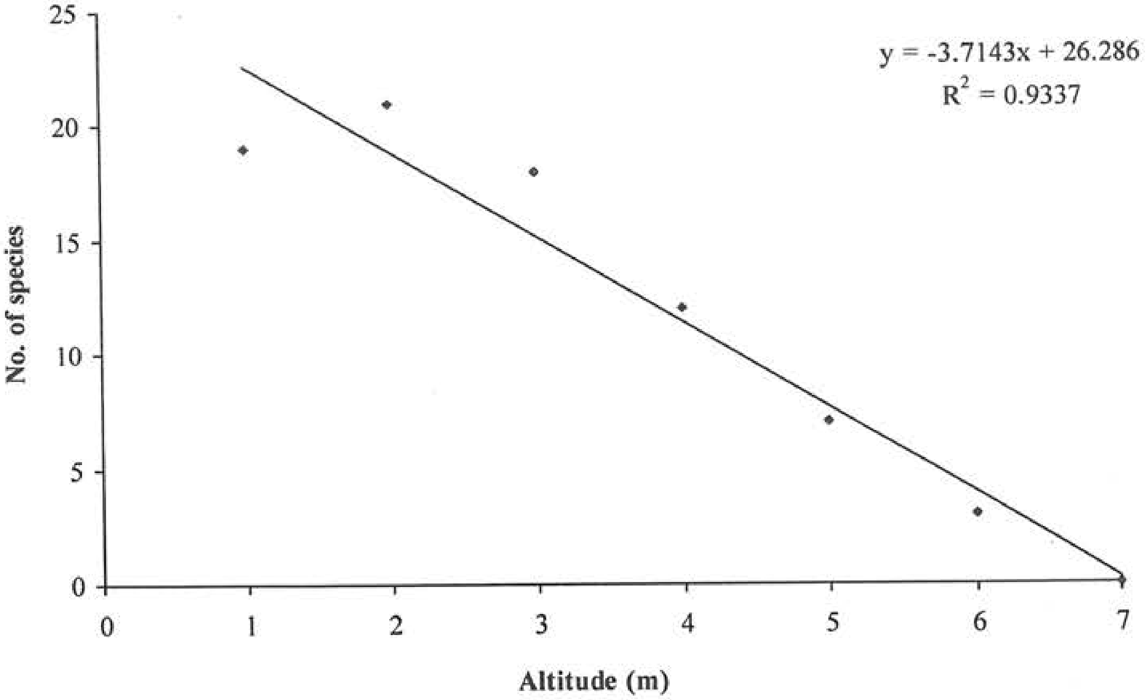


Figure 4.2. Reptile species richness along altitude zones in the Teesta valley, Sikkim; 1 (<500 m), 2 (500-1000 m), 3 (1000-1500 m), 4 (1500-2000 m), 5 (2000-2500 m), 6 (2500-3000 m) and 7 (<3000 m).

Among incidence-based estimators (Chao2, Jackknife1 and Jackknife2), Jackknife2 showed higher values in all altitude categories (except zone IV) compared to the observed value and other estimators (Table 4.2). Jackknife2 had lower standard deviation compared to other estimators.

Estimated values of non-parametric estimators such as Chao2, Jack1, and Jack2 showed significant negative linear trend with altitude (Table 4.2); Chao1 ($R^2 = 0.93$, $F = 49.30$, $df = 4$, $P < 0.01$), Jackknife1 ($R^2 = 0.86$, $F = 24.42$, $df = 4$, $P < 0.01$) and Jackknife2 ($R^2 = 0.84$, $F = 21.45$, $df = 4$, $P < 0.01$). It is to be noted that all estimators yielded higher values compared to the observed species richness in lower altitude zones. In higher altitude zones, it is closer to the observed value.

Table 4.2. Observed and incidence based estimated species richness in different altitude zones of Teesta Valley. (Sobs = Observed species richness; R^2 = Linear regression;

Zones (m)	Sobs	Chao2 ± SD	Jackknife1 ± SD	Jackknife2 ± SD
>500	19	27.25±23.62	24.97±2.41	29.93±0
500-1000	21	24.12±4.8	26.97±2.41	28.97±0
1000-1500	18	23.76±7.48	25.96±2.77	29.94±0
1500-2000	12	12.24±1.03	13.99±1.4	12.03±0.51
2000-2500	7	11.5±0	9.99±1.72	12.96±0.43
2500-3000	3	3.5±0	4±1	4.99±0
R^2 (with altitude)	0.89*	0.93*	0.86*	0.84*

* = Significant at $P \leq 0.01$)

The values of Jackknife2 estimators of six altitude categories were plotted against abundance (Fig. 4.3). Given the patchy and uneven distribution of reptiles, the abundance data were more appropriate than hours searched for analysis. If the search is conducted in abundant area, the number of species recorded per unit time will be higher than non-abundant area leading to overestimation of species. This bias can be reduced if abundance data is used as it estimates the number of species per unit individuals or rather it assumes the probability of capturing new species with the addition of individual in the sample. It is observed that species accumulation curve did not reach an asymptote except in zone IV and VI.

The abundance based rarefaction curves showed that with the increasing effort, species richness in zone III and II would be higher than at the zone I (Fig. 4.4). Although at the present level of maximum effort, zone III had lower number of species than zone I, the former is very likely to surpass the later in species richness with more sampling effort.

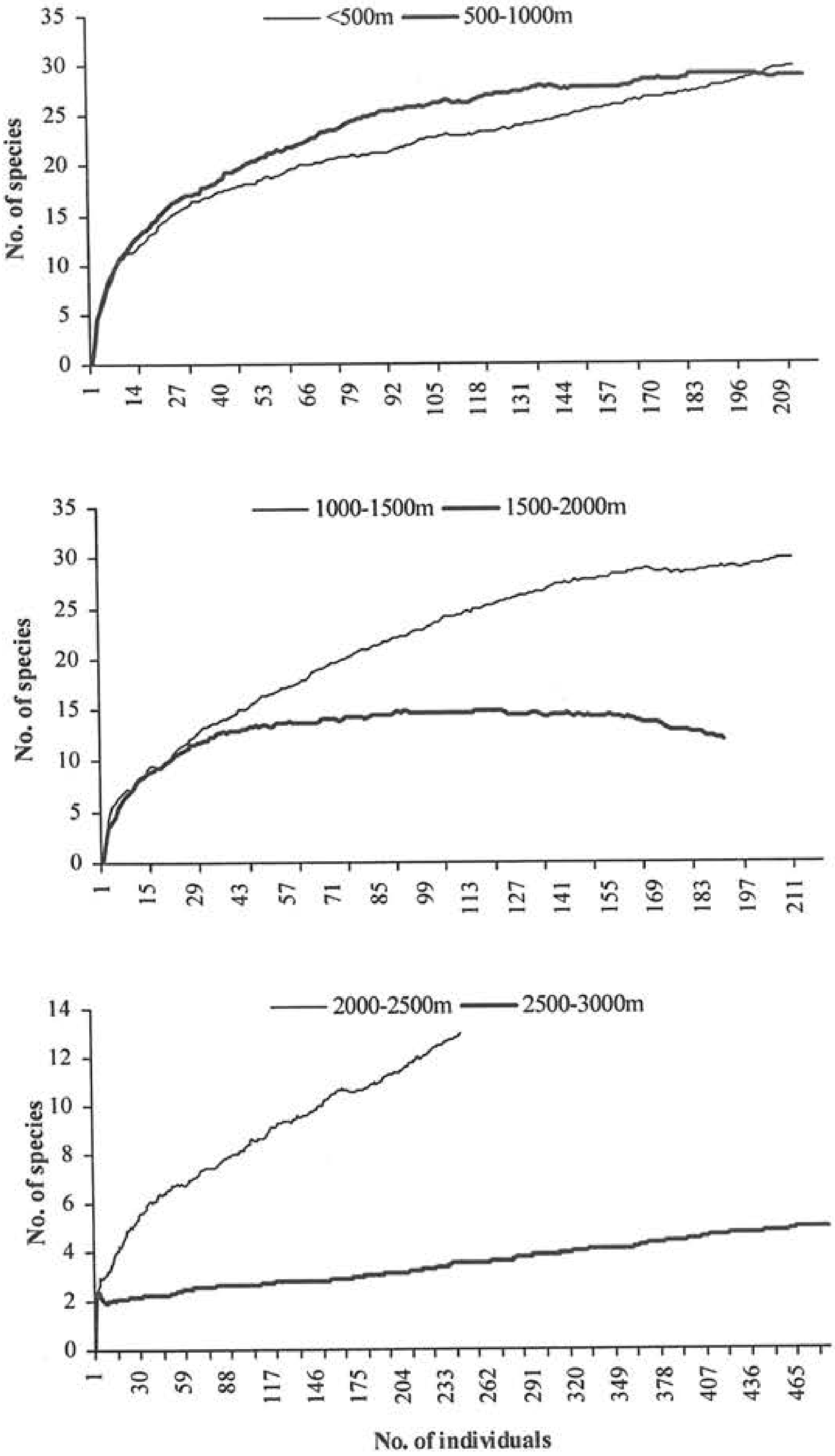


Figure 4.3. Reptile species accumulation curve using Jackknife estimator in different altitude zones of the Teesta valley.

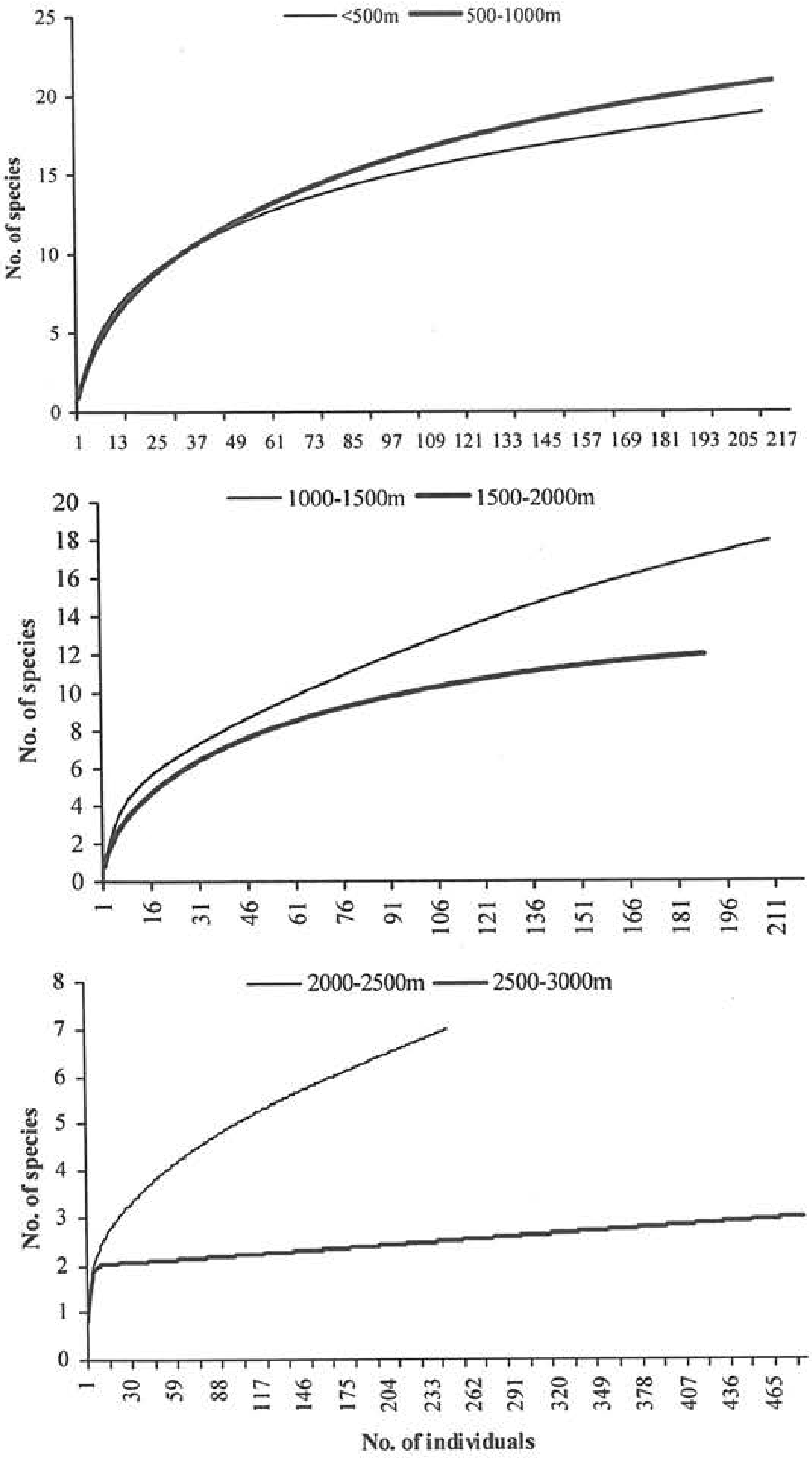


Figure 4.4. Individual based rarefaction curves in different altitude zones of Teesta valley.

Since, species accumulation curve did not reach asymptote in most of the cases, observed species and Jackknife2 estimates were plotted against altitude controlling for individuals (50, 100, 150 and 200, Fig. 4.5). Reptile species richness patterns in Teesta valley, as discerned from this graph, seem to confirm that species richness decreased with increasing altitude with peak in the lower altitude. At individual level, species richness showed peak at zone II. When the sample size is 200 individuals, species at zone I, II and III are the same. Hence, it is observed that species richness is high up to 1500 m and then decline towards higher altitudes. It is to be noted that observed species richness closely corresponds to estimated richness when sample size is 50 individuals. However, the estimated richness, as computed using Jackknife2, increases as the sample size becomes larger. Species accumulation curve with 150 and 200 individuals lies close to each other indicating least chances of additional species after 150 individuals.

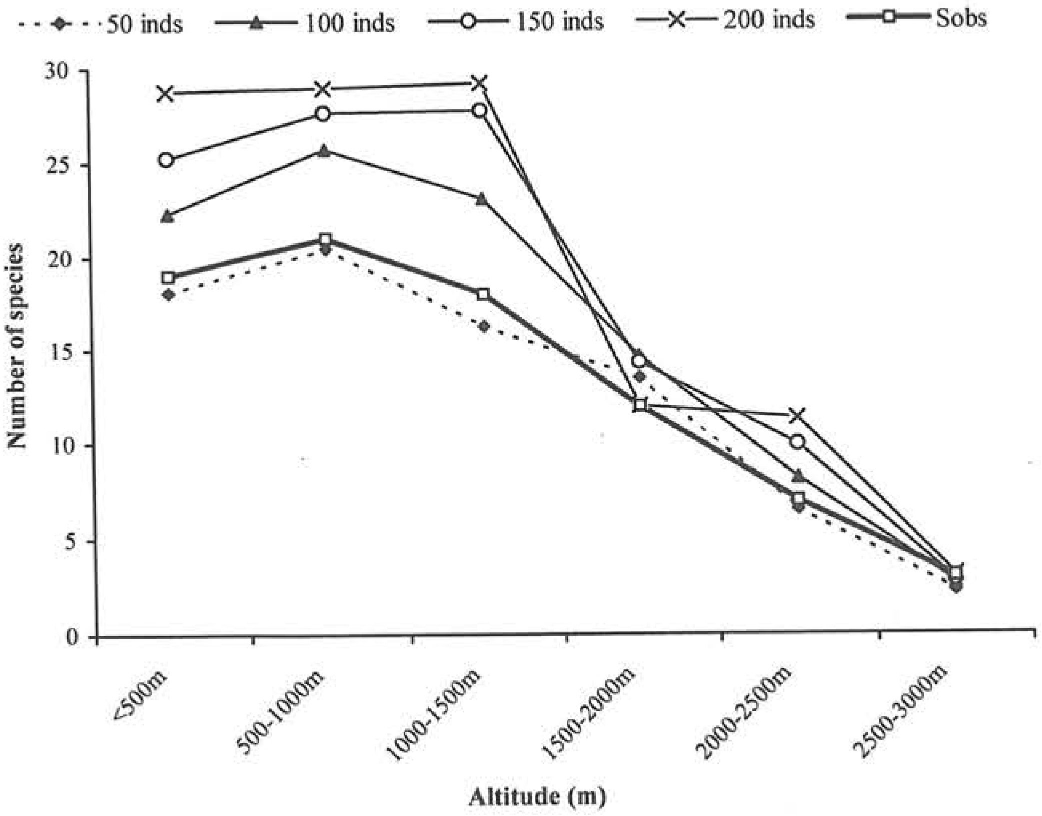


Figure 4.5. Jackknife2 estimator showing predicted number of species after controlling for individuals in different altitude zones of Teesta valley.

4.3.2. Range Size

Most species of reptiles showed narrow altitude range in Teesta valley. Out of 42 species observed during the study, 13 species were restricted to only one altitude zone, whereas 17 to two altitude zones (Fig. 4.6). *Amphiesma platyceps* was the only species distributed widely in all altitude zones except zone I (<500 m). None of the species were present in all the six altitude zones.

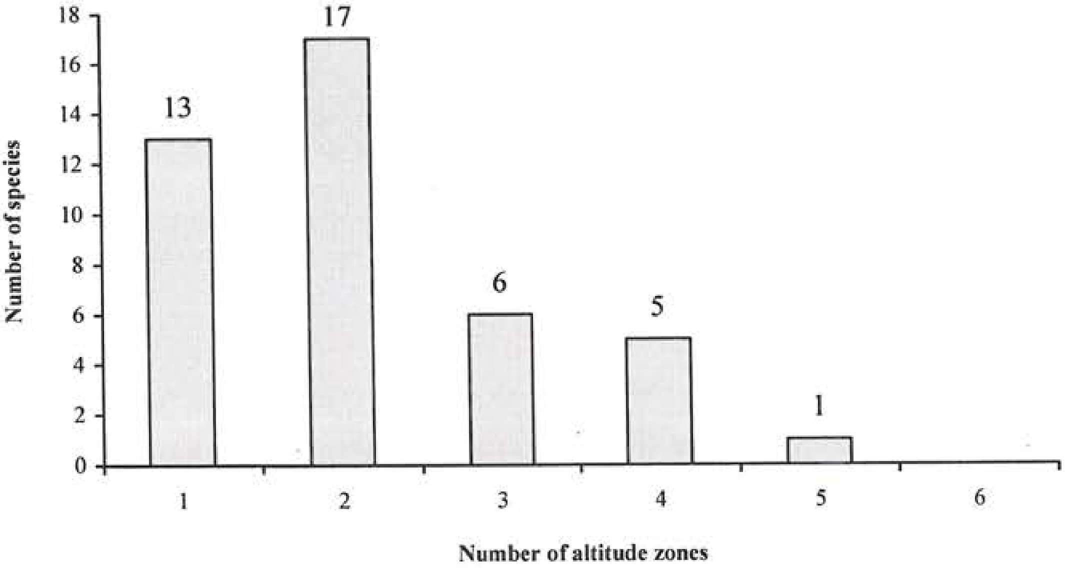


Figure 4.6. Species sharing altitude zones along the Teesta valley.

4.3.3. Altitudinal Range Profile

Most species showed narrow altitudinal width (range size) along the gradient and were concentrated in the lower altitude, hence species showed inverse relation with increasing range size (Fig. 4.7). Range profile showed that most species observed in high altitude extended towards lower altitude (large range size), but reverse is not true. More than 50% of total species in the present study were restricted to <1000 m altitude. However, all the six species present above 2000 m descended up to 1500 m or further below. Regression of altitude range size with the lower limit of altitude range for each species was not significant. However, regression between altitude range size and upper limit of altitude for each species yielded statistically significant relation ($R^2 = 0.67$, $P = 0.00$).

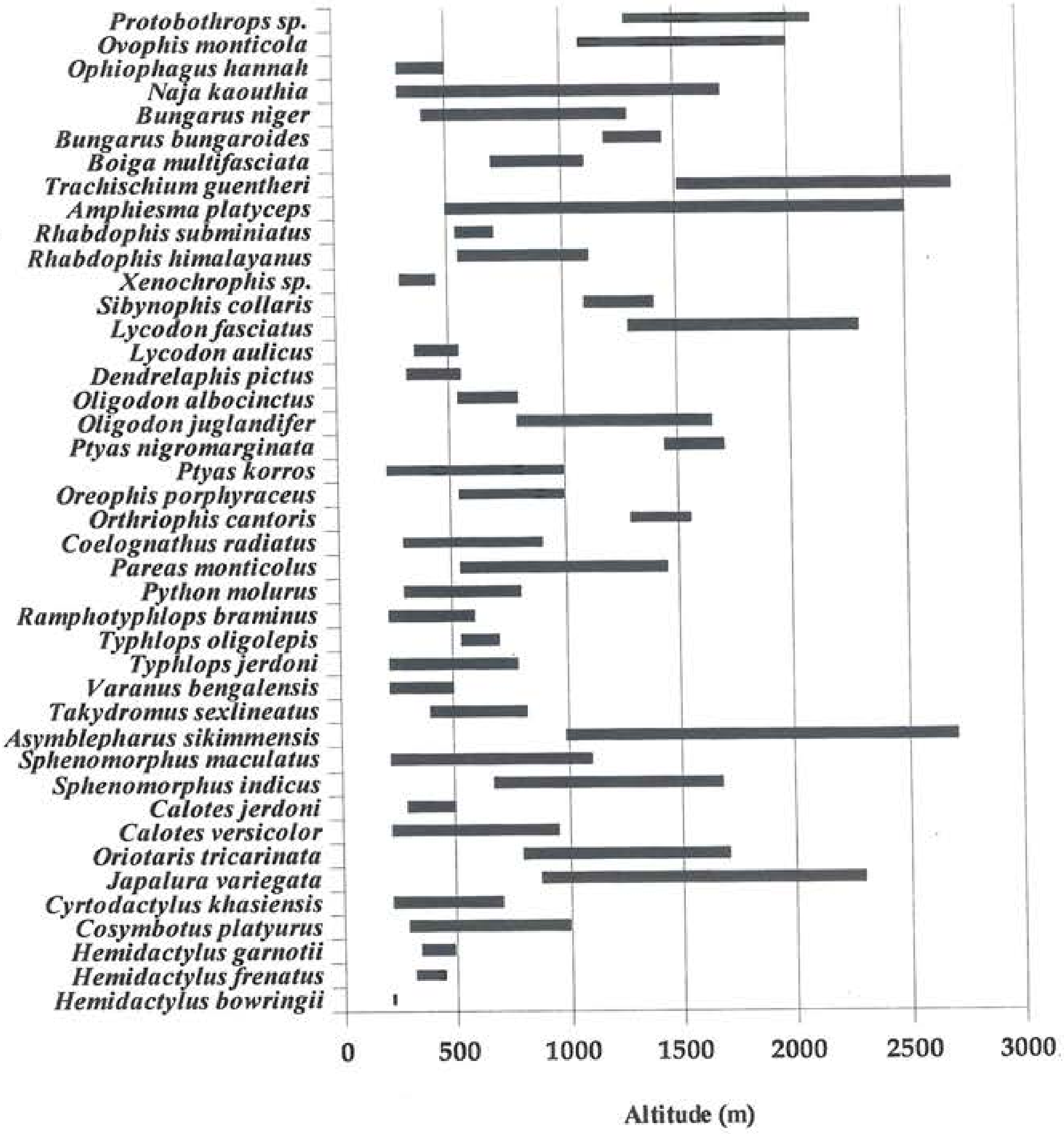


Figure 4.7. Altitude range of reptile species distributed along the Teesta valley.

4.3.4. Similarity between Altitude Zones

Sorenson similarity index between pair wise altitude zones (Fig. 4.8) showed two assemblages. Two lower altitude zones: <500 m and 500-1000 m formed one cluster and the four higher zones: 1000-1500 m, 1500-2000 m, 2000-2500 m and 2500-3000 m formed another cluster. The transition between low and high altitude assemblages was observed at 1000-1500 m. The similarities within clusters were relatively high showing tight cluster with 95% in higher altitude (1500-2000 m and 2000-2500 m) followed by 90% in low altitude (<500 m and 500-1000 m). The highest zone (2500-3000 m) formed a distinct cluster showing about 50% similarity with other clusters.

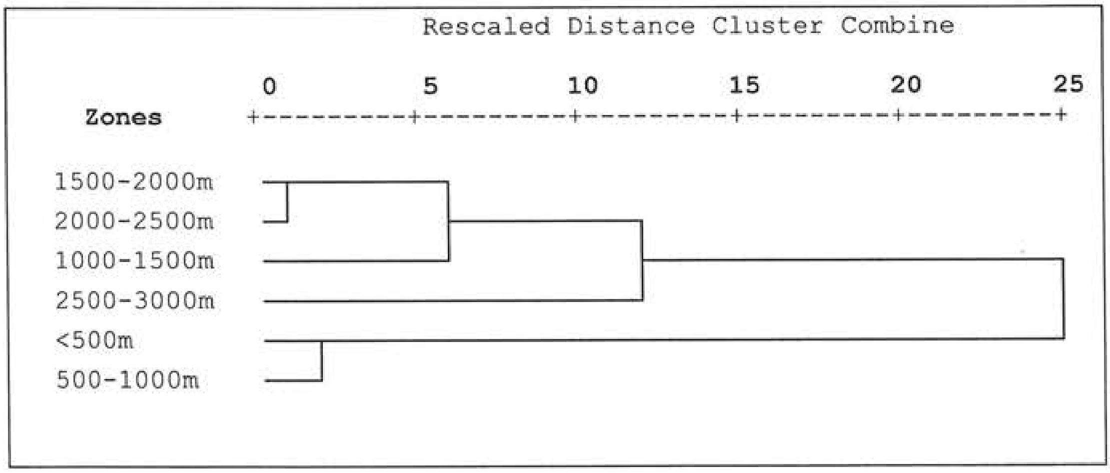


Figure 4.8. Similarity in species distribution among altitude zones of the Teesta valley.

4.3.5. Species Turnover

Species turnover rate was low between consecutive zones, but was high between distant zones (Table 4.3), converse to similarity pattern. The highest turnover among consecutive zones was between zone II and III. The whole set of species was replaced by new species from zone I to V and VI showing complete turnover (1) as no species was shared between them. The next highest turnover (0.93) was observed between zone II (500-1000 m) and VI (2000-2500 m). Zone I and III, I and IV, II and IV, II and V, III and VI showed more than 70% turnover.

Table 4.3. Species turnover (based on Sorensen index) between pairs of altitude zones along the Teesta valley.

Altitude zones (m)	<500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
<500	-	0.4	0.71	0.88	1	1
500-1000		-	0.51	0.73	0.87	0.93
1000-1500			-	0.31	0.56	0.83
1500-2000				-	0.26	0.6
2000-2500					-	0.4
2500-3000						-

4.3.6. Mid-Domain Effect: Null Model

A comparative analysis of empirical data with 95% prediction curve using range midpoints and range (width) size showed that majority of the empirical points, 51/60 and 44/60 respectively occurred within 95% simulation prediction curves (Fig. 4.9). The graph showed the peak towards lower altitude (700-1000 m) and it decreased towards higher altitude. For range midpoints, deviation of empirical data from 95% prediction curve occurred at <500 m, where empirical richness was lower than the simulated curve. For range limits, deviation occurred at 500-1000 m, where empirical species richness was higher than the simulated curve.

Regression of empirical species richness with mean of the simulated richness across simulation per bin gives R^2 value which acts as a tool for assessing the fit of Mid-Domain Effect (MDE) null model (McCain, 2003, 2004b). When range midpoints were regressed, R^2 value was high ($R^2 = 0.85$) compared to range size ($R^2 = 0.37$). Moderate fit to null model predictions were demonstrated by low R^2 value for range size than range midpoint, although both patterns were significant ($P = 0.05$). Even though range midpoints showed better result than range limit with only nine points outside the predicted domain, the midpoint simulations were too constrained by the empirical data giving better fit to MDE null model (McCain, 2007; pers. comm). Hence, empirical range midpoints were not included in the null model analysis when data at the extremes (lowest and highest altitude) were truncated (Fig. 4.10).

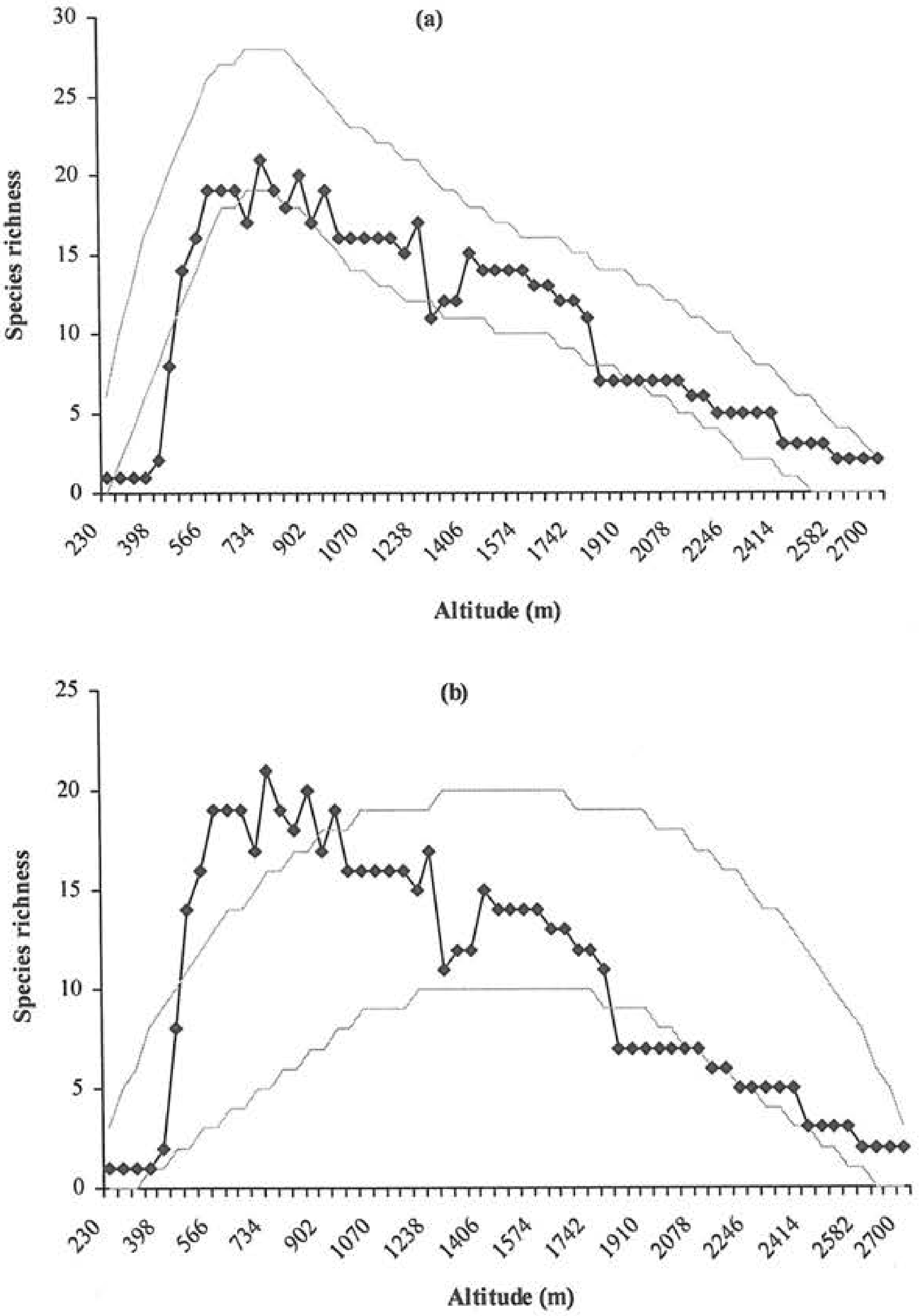


Figure 4.9. Species richness curves (thick line with data point) and 95% prediction curves (thin line) sampled without replacement a) empirical range midpoints b) empirical range size following (McCain, 2004a).

Mid-domain null model simulations using range size after truncating the terminal categories i.e. <500 m and >2500 m (Bhattarai *et al.*, 2004) did not show mid altitude peak, instead it was linear monotonic decline with increasing altitude (Fig. 4.10). Hump shaped pattern disappeared after discarding the data from lower and higher zones. The empirical species richness had no relation with mean of the simulated richness. Between 500 and 900 m the empirical richness was higher than simulated richness, whereas at 1500-2200 m empirical richness was lower than the simulated richness.

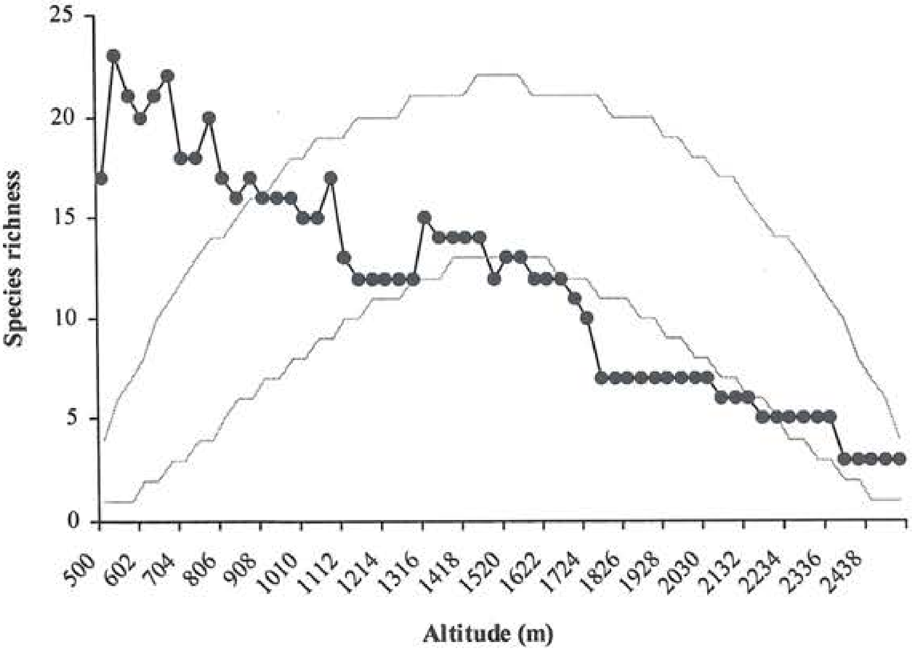


Figure 4.10. Species richness curve (thick lines with data point) and 95% prediction curves (thin line) using empirical range size sampled without replacement (McCain, 2004).

4.4. DISCUSSION

Along the altitude gradient (300-4800 m) of Teesta valley, the species richness decreased sharply from 21 (in 500-1000 m) to three (in 2500-3000 m) and none above 3000 m. Decline in reptile species richness along the altitude is a general pattern observed in many studies (Scott, 1976; Heatwole, 1982; Raxworthy *et al.*, 1997; Hofer *et al.*, 1999). The reptiles in Teesta valley showed peak at 500-1000 m. Many studies have found peak between 500 and 1000 m (Shmida and Wilson, 1985; Daniels, 1992; Sfenthourakis, 1992; Rahbek, 1997). Yu (1994) reported peak at 1000 m in a study carried out on plants in China having similar climatic conditions as that of Teesta valley. Bhattarai and Vetaas (2006) observed the peak at 900-1000 m for tree species richness along the Nepal Himalayas.

Species richness showed peak in 500-1000 m zone, even though the general pattern is a monotonic decline. The absence of species below 300 m would have resulted in high species richness in the particular zone, as the lowest altitude in the study area is 300 m. Kattan and Franco (2004) observed monotonic decline of species richness along the altitude spanned over complete gradients from lowlands to mountain peaks, whereas a mid altitude peak was reported where the lower part of the altitude gradient was truncated.

Abundance showed no significant pattern with altitude. From lower to mid altitude zone (<500-2000 m), abundance decreased simultaneously with species richness along the altitude gradient, but sudden increase was noticed beyond 2000 m with high abundance in zones V and VI. Although, number of species decreased with altitude, abundance showed different pattern with more individuals of certain species in the higher zones. It is documented that in tropical forest, herpetofaunal diversity will be high but their abundance would be low (Heatwole, 1982). Reduction in rare species along the altitude is more than compensated by an increase in the number of individuals of the commonest species (Scott, 1976). The high abundance in zone V and VI is due to clumped distribution of two species (*Trachischium guentheri*; Plate 7 and *Asymblepharus sikimmensis*). Both these species had patchy distribution with aggregation of many individuals. Due to severity of climatic condition, species may become specific to few microhabitats such as under boulders or logs resulting in aggregation of the individuals. According to Lillywhite (1987) aggregation of individuals helps in maintaining thermoregulation through the exchange of body heat that are advantageous to maintain body temperature in colder conditions.

Diversity is a measure of species richness as well as abundance. Since, richness declined along the altitude, diversity also showed negative trend with altitude. Similarly, equitability also decreased with altitude except in 2500-3000 m. As most reptiles of lower tropical forest were sparsely and more or less uniformly distributed, equitability was high. In higher altitude, due to the unequal distribution of species, equitability was lower, which is similar to the findings on the litter dwelling herpetofauna in Costa Rica (Scott, 1976). Unlike other taxa with high exclusive species in higher altitude (for example birds; Hawkins, 1999), exclusive species of reptiles were not found above 2000 m. Raxworthy *et al.* (1997) also reported low herpetofaunal endemism above 1800 m in Madagascar.

Colwell and Coddington (1994) reported that estimators yield higher values than the observed richness, if the sample is too sparse. All non-parametric estimators displayed higher values than observed values as most species of the Teesta valley were homogenously distributed.

Among incidence based estimators, Chao2, Jackknife1 and 2 are more accurate and less sensitive to patchiness of species distribution and variability in the probability of encountering species (Hortal *et al.*, 2006). Palmer (1990, 1991) evaluated the first and second order Jackknife and Bootstrap estimators and found that all the three worked well, but overall Jackknife performed better than Bootstrap. Though Bootstrap estimates are highly precise, its underestimation of species richness made it a poor estimator (Hortal *et al.*, 2006). Walther and Moore (2005) reported better performance of Chao and Jackknife estimators than other methods based on bias, precision and accuracy. Chao and Jackknife are based on species represented by singletons and doubletons and are more accurate and reliable when more species are rare (Colwell and Coddington, 1994). The present study had nine singletons and five doubletons (Chapter 3) and 13 and 17 species restricted to one or two altitude categories (Fig. 4.6), and hence, these estimators have yielded comparatively better results.

Standard deviation (SD) was also low in Jackknife compared to Chao (Table 4.2). Estimator with less variation is reportedly more efficient than others (Walther and Moore, 2005). Estimators which estimate richness to the maximum can be considered as better estimator from conservation point of view. Hence, Jackknife2 is a better indicator in the present case, as it showed minimum variance, maximum richness and approached an asymptote in higher altitude zones.

Species accumulation curve did not reach an asymptote in lower altitude categories (<500 m, 500-1000 m, 1000-1500 m), which predicts that few additional species remains to be documented (Fig. 4.3). Walther and Moore (2005) reported that in a population with many rare species represented by singleton, the chances of encountering new species are higher or singletons may disappear only after infinite sampling. Present data set had nine singletons in lower altitude, which indicates the chances of more new species in this zone. This is the general trend in tropical forests as high species richness often results in unsaturated species accumulation curve (Cardelus *et al.*, 2006). Observing all species in natural communities may not be feasible (Walther and Moore, 2005) and hence, the estimated richness using estimators served as useful tool for assessing the biodiversity of the area. In the present investigation in mid and high altitude, most species would have encountered during sampling, since species richness did not vary with the increasing effort beyond 1500 m (Fig. 4.5).

The distribution of species richness along altitude gradients is governed by various biological, climatic, geographical and historical factors (Colwell and Lees, 2000). Altitude represents a complex gradient along which many environmental variables change simultaneously (Austin, 1996). To segregate the effect of each variable on the altitude pattern of species richness is difficult (Yu, 1994). A few important hypotheses dealing with altitude pattern of species are given below:

Historical Hypotheses - Historical elements such as speciation, extinction and immigration rates were related with altitude pattern of species richness (Lomolino, 2001). Past climatic history such as glaciations may have influenced the altitude pattern of species richness in Teesta valley. Himalayas is considered as a young mountain (Mani, 1974) and hence time is too short for vertebrate speciation. According to evolutionary time hypothesis, speciation is related to time (Gaston and Blackburn, 1996). Limited time for colonization or niche diversification resulting in low speciation could be the reason for low species richness along the altitude gradient.

Climatic Hypotheses – According to this hypothesis, climatic factors associated with altitude is responsible for decrease of species with the increasing altitude. Lower levels of species richness at higher altitudes may be due to ecophysiological conditions such as low temperatures (Sánchez-González and López-Mata, 2005), low productivity (Rosenzweig, 1992, 1995; Mittelbach *et al.*, 2001), lower relative humidity (Vetaas and Grytnes, 2002), low water availability (McCain, 2007) and reduced growing season (Kørner, 1998). Temperature in most cases decreased monotonically with increasing altitude. Rainfall usually follows mid altitude peak, but monotonous increase with altitude is also not surprising (Grytnes and McCain, 2007) especially in low altitude mountains such as Western Ghats. Data of the present study support the climatic hypotheses for the distribution of reptiles, as temperature decreased monotonically with altitude and species richness with temperature.

Spatial hypotheses – According to this hypothesis, the area decreases with increasing altitude due to the conical shape of the mountains (Kørner, 2000; Lomolino, 2001). As the area decreases, number of species also decreases (Rahbek, 1995). The present study area is merged with Tibetan plateau in the higher altitude; hence in general, decrease of area with altitude may not be applicable in this case. Hence, another spatial factor, the Mid-domain effect (MDE), was tested, which is discussed below.

Evaluation of Mid-Domain Effect Null Model agrees partially with 95% prediction limits of the simulation curve (Fig. 4.9). 'The mid-domain effect is an unavoidable consequence of bounded ranges of variable sizes' (McCain, 2003). The moderate fit to null model as indicated by low regression value (R^2 = 0.37) and deviation of empirical data than predicted richness at 500-1000 m from null model emphasized the need to investigate biotic, abiotic and historical causal factors apart from geographic hard boundaries (McCain, 2003). Unlike highly mobile organisms such as birds, reptiles are more likely to be constrained by geographic boundary due to their body physiology and limited movement. The cold desert of Himalayas (Tibetan plateau) and glaciers on the top might have constrained the movement of species, but on the lower side of the study area, no such geographic hard boundaries were available. The lower limit has contiguous forests and coastline is at least 700 km away from the lowest altitude of the study area. Hence, the lower limit may not be constrained by geographic hard boundary and the resulted mid-domain effect could be a consequence of partial geometric constraints i.e. only towards the upper domain.

Bhattarai *et al.* (2004) discarded data from extreme altitude zones on either side to avoid the effect of hard boundaries. Null model simulation after truncating data in the present study <500 m and >2500 m did not show mid-altitude peak. However, empirical species richness deviated from the predicted curve. The deviation of empirical richness from simulated one disagree with MDE null model and indicates that geographic hard boundary played no significant role in governing reptile species distribution along the Teesta valley.

McCain (2006) reported the greater fit to MDE null model in temperate zone than either tropical or tropical-temperate transition zone. According to Dunn *et al.* (2006) MDE perform better fit with large scales and larger range size. Further, the small range size of most species indicates the influence of environmental changes, whereas large range species are more constrained by domain boundaries leading to unimodal pattern (Jetz and Rahbek, 2002; Cardelus *et al.*, 2006). Since, the present study was conducted along the gradient of altitude ranging from tropical (300 m) to temperate (>3000 m) climate and the taxa concerned showed relatively small range size (Fig. 4.7), the MDE null model showed poor fit to 95% prediction curve. The anuran study along the altitude gradient of Western Ghats, South India also reported lack of mid altitude peak (Naniwadekar and Vasudevan, 2007). The small range size and partial effect of geometric constraint opens the way for analyzing climatic and other factors rather than hard boundary, as a causal factor for species distribution along the altitude in the present case.

Climatic variables influence altitudinal species richness patterns in several ways (McCain, 2007a; Naniwadekar and Vasudevan, 2007). In the present case, temperature showed monotonic decline with elevation ($P = 0.000$) while humidity showed unimodal peak at 1000-1500m ($P = 0.38$). Species richness showed positive linear relation with temperature, but no relation with humidity (see results). Hofer *et al.* (1999) reported that terrestrial reptiles respond more strongly to temperature than moisture.

Preferred body temperature (PBT) of majority snakes range from 28 to 34 °C (Lillywhite, 1987). Only the area below 1000 m had temperature within PBT of snakes. Hooker (1854) reported decrease of temperature corresponding to altitude in Sikkim (1° = 130 m at 300 – 1200 m range, 1° = 100 m at 1200 – 2400 m range). The summer temperature at 300 m is 35°C (Hooker, 1854), it is 27 °C at 1300 m and 25 °C at 1500 m and both values are below PTB of reptiles. It is to be noted that temperature up to 1300 m altitude is within the PTB of reptiles. During winter, the temperature of Teesta valley will be three times lower than the summer temperature (Hooker, 1854) and hence the ambient temperature even at the lowest altitude will be lower than the minimum PTB required for reptile species. Hence, the decreasing temperature with increasing altitude constrained the distribution of reptiles, as they cannot escape from harsh local climatic conditions.

Above 1000 m, reptiles were active only for short period from May to September. Species distributed in higher altitude may survive due to physiological adaptations towards cold such as accumulation of fat and adjustable body temperature. Species from colder region have lower Critical Thermal Minimum (CTMin) temperature compared to species from hotter regions (Bennett and John-Alder, 1986; Fischer *et al.*, 2005). Most of the reptiles in higher altitude were recorded under boulder or in road, which may be beneficial for thermoregulation (Chapter 5). Hooker (1854) found that the mean water temperature of Teesta river was 20° F lower than the ambient air temperature. Since present study was carried out along the Teesta river valley (1 km on either side of the river), the impact of temperature on altitudinal distribution of reptiles is more than expected. Unfortunately, the unavailability of long-term climatic data handicapped the process of in-depth/detailed analyses in this regard.

The majority of species showed narrow altitude range being restricted to one or two zones. Out of 42 species observed, 13 species were restricted to only one altitude zone indicating narrow altitude range of reptilian species. Except *Amphiesma platyceps* (five out of six altitude zones), no species extended over the entire altitude range (Fig. 4.6). Due to specialization to particular microhabitat or narrow tolerance to climatic variations, most reptiles were confined to particular altitude zones (Raxworthy *et al.*, 1997) and few species tolerated wide gradient of altitude (Sánchez-González and López-Mata, 2005). Similar to the present trend, the study conducted in southern Peru (Patterson *et al.*, 1998) found none of the mice species extended over the entire range of altitude (350-3500 m).

Small ranged species are less constrained by domain or hard boundary, they may be the best indicators of environmental influence on species distribution (Cardelus *et al.*, 2006). Altitude range size showed no relation with lower limit, whereas it showed statistically significant relation (R^2 = 0.69) with upper limit of altitude for each species. The significant R^2 value between altitudinal range size and upper limit of altitude indicates that higher altitude species has wider range size than low altitude species and extend towards lower altitude (Patterson *et al.*, 1996, 1998). According to Rapoport rule (Stevens, 1992), with the increase of latitude the species tend to increase their range size. The increase in altitude range size of reptiles of Teesta valley with increasing altitude agrees with Rapoport rule. Owing to wide seasonal variations in climate, the temperate fauna shows broad altitudinal range size (Stevens, 1992). In contrast, tropical zone included larger proportion of species with narrow range size as the climatic and seasonal fluctuation will be limited (Heaney, 2001; Md Nor, 2001a). The results of the present study are consistent with the above view.

Cluster analysis enabled identification of two major faunal assemblages with middle and higher as one cluster and lower as separate cluster. The distinct separation of low altitude fauna (<500 m and 500-1000 m) with mid and high altitude shows that 1000 m is the transition zone for reptiles in the Teesta valley. It can be supported by low species similarity between zone II (500-1000 m) and zone III (1000-1500 m) among adjacent zones. The tropical vegetation in the Teesta valley shows transition towards sub-tropical m. Md Nor (2001a) observed changes in the composition of mammals at vegetation transition zones. Raxworthy *et al.* (1997) considered 900 m as a transition zone for herpetofaunal communities in Madagascar. The distinctness of 2500-3000 m from other cluster may be due to coniferous forest, which acts as barrier for species dispersal (Gainsbury and Colli, 2003). In the Teesta valley, the transition of diverse (tropical and temperate) to less diverse (coniferous forest) habitat zones occurred at 2500-3000 m.

Distinct cluster of species at 2500-3000 m could be explained by isolation mechanism (Lomolino, 2001). The snow covered mountain peaks with steep slopes and circulating cold winds would have resulted in the isolation of species in the present case. Reptile clusters correspond with climate, which in turn reflected the vegetation types. The high similarity between high and mid altitude reptiles compared to low and mid or low and high is also due to wide range of higher altitude species, which extend their range to mid altitude (Fig. 4.7).

The species turnover was high between distant zones than consecutive ones (Table 4.3). Due to overlapping vegetation and climatic condition, consecutive zones showed low turnover rate. Among the consecutive zones, relatively high turnover rate was found between 1000 m and 1500 m (0.51) followed by 500 m and 1000 m (0.4) and 2500 m and 3000 m (0.4). Species turnover along the altitude gradient did not correspond fully with the vegetation change. Raxworthy *et al.* (1997) reported similar results in herpetofaunal studies and explained that single vegetation types have several herpetological communities each adapted to narrow altitude range. Such observation was also reported for birds in the Cordillera Vilcabamba, Peru (Terborgh, 1971) and mice in Andes of southeastern Peru (Patterson *et al.*, 1998). The high turnover between 1000 m and 1500 m resulted from dropping out of many lowland species such as *Calotes versicolor*, *Sphenomorphus* sp., *Lycodon aulicus* and *Ptyas korros*. Physical factors such as temperature, precipitation and evaporation might accounted for the distributional limits of lowland and montane species (Hofer *et al.*, 1999).

Range distribution profile of reptiles demonstrates that low altitude species were specialists, whereas high altitude species showed wider range. Hence, preservation of low altitude forests is required for the conservation of herpetofauna in the Himalayas, especially along the Teesta valley.

4.5. SUMMARY

- Distribution pattern of reptiles along the altitude gradient (300-4800 m) of Teesta valley was studied. Maximum of 21 species in 500-1000 m and minimum of three species in 2500-3000 m, and no species above 3000 m zone was observed. Species richness, diversity and equitability decreased along the altitude gradient, whereas abundance did not show any distinct pattern. Highest number of exclusive species was found in zone I (<500 m) and no species was found exclusive to a particular zone >2000 m.

- Jackknife2 appears to be the best estimator as it yielded higher estimated value for species richness and low standard deviation. Species accumulation curve did not reach an asymptote in any zones except in zone IV and VI. The estimated richness increased as the sample size increased indicating the need for more sampling, especially in the lower altitude.

- Most reptiles of Teesta valley showed narrow altitudinal range (width). Range profile showed that most of the high altitude species extended towards lower altitude, and species distributed in low altitudes were restricted to one or two altitude zones.

- Cluster analysis based on Sorenson similarity index showed two distinct assemblages - low (<500-1000 m) and high (1000-3000 m) with less than 5% similarity between them. The transition between low and high altitude assemblages was observed around 1000 m.

- In all the species, turnover rate was less than 50% in the consecutive altitude zones. Comparatively high turnover was observed between 500-1000 m and 1000-1500 m among adjacent zones.

- Mid-Domain Null Model showed that deviation of species richness occurred at 500-1000 m, where empirical species richness was higher than the simulated. Low value of regression between empirical and simulated richness indicates that the distribution pattern of reptiles were not fully governed by geographical hard boundaries. Partial fit of mid-domain test emphasized the need to look for other climatic and ecological factors. Temperature seems to be one of the major factors determining the distribution of reptiles along the altitude gradients of Teesta valley.

CHAPTER 5

SPATIO-TEMPORAL RESOURCE USE PATTERN

SPATIO-TEMPORAL RESOURCE USE PATTERN

5.1. INTRODUCTION

Habitat is broadly known as the place where an organism lives. Habitat plays a vital role in food selection, shelter and avoidance of predators and competition (Pianka, 2000). Habitat can be as broad as topographical features to small patch of an area (McCoy and Bell, 1991). It is considered that habitat structure of an area determines the structure of an animal community (Shenbrot and Krasnov, 1997). Study of habitat utilization provides basic idea how efficiently organisms use an area, their preference in relation to availability and interaction with physical and biological parameters. Complex habitats may increase the species diversity due to the availability of diverse resources, allowing many species to coexist. Hence, habitat utilization data should be considered for the formulation of species conservation and management plans (Bright and Morris, 1990; Chandler and Tolson, 1990; Buhlmann, 1995; Beauchamp *et al.*, 1998). Habitat utilization differs among different species or even different individual or sexes of the same species. Social dominance and thermoregulation may also influence habitat selection (Sabo, 1980). Lillywhite and Henderson (1993) reported differential habitat utilization by juvenile and adult vipers.

Microhabitat is often defined as the immediate environment of an organism. The microhabitat specificity of various reptiles has lead to habitat specialization (Pianka, 1973), which may influence the distribution, abundance and diversity of reptiles (Jones, 1986). Herpetofauna segregate their habitat as the primary resource, which allows several competing species to coexist (Schoener, 1974; Rosenzweig, 1981). Vertical (above ground) position of an animal may also help in segregation of resources through utilization of different strata. This may help in maintaining thermoregulation, foraging, nesting, escape from predators and competitors. Cooper (1993) identified foliage cover as important criteria for selecting arboreal microhabitats to minimize detection by predators.

Use of vertical strata by animals is tied with both biotic (prey availability, predation) and abiotic (moisture, temperature) factors (Stewart, 1985).

Partitioning of time for emergence, breeding and feeding reduces competition among sympatric species. Dichotomy of daily activity leading to temporal partitioning is documented in desert lizard (Pianka, 1973). Nixon (2005) reported difference in the emergence timings of hatchlings of various reptile species inhabiting upper Nilgiris, and speculated that this reduced the competition for food and shelter.

This Chapter describes the spatio-temporal resource use patterns of reptiles distributed along the Teesta valley. Among several parameters, spatial use (macrohabitat, microhabitat and vertical strata) and temporal use (activity on monthly basis) by reptiles were considered for analyses.

5.2. METHODS

5.2.1. Data Collection

Visual encounter survey (Heyer *et al.*, 1994) was used for data collection along the Teesta valley. Detailed account on this and other sampling techniques are given in Chapter 3.

Data collection was done on monthly basis from June 2003 to March 2006. On locating a reptile, data on microhabitat and vertical position (from ground) were recorded. Descriptive information on microhabitats were clumped into eleven categories as follows (1) crevice (2) under boulder (3) above boulder (4) log (5) open ground (6) grass (7) tree (8) shrub (9) ground covered (with litter, moss, dry leaves) (10) artificial habitats and (11) water (Plate 8, 9). Artificial microhabitats include man-made structures such as buildings, bridges, pillar and electric posts. Records of vertical position of species were clumped into the following nine categories – (1) 0 cm (2) 1-30 cm (3) 31-60 cm (4) 61-90 cm (5) 91-120 cm (6) 121-150 cm (7) 151-180 cm (8) 181-210 cm and (9) >210 cm. Temporal data was based on frequency of observations of each species on monthly basis. Data on microhabitat, vertical and temporal parameters were converted into percentage to reduce bias associated with number of species present and resource usage in each altitude.

5.2.2. Data Analyses

1. ANOVA (Analysis of Variance) was performed to find out the difference of species as well as abundance of reptiles in microhabitat, vertical position and temporal patterns along the altitude zones (500 m intervals).
2. Spearman rank correlation was done to know the relationship of microhabitat use by species along the altitude.
3. Principal Component Analysis (PCA) was performed on habitat variables in each altitude zone to assess important factors determining habitat use by reptiles.

5.3. RESULTS

5.3.1. Microhabitat Use

Among all microhabitats, maximum number (16.1%) as well as abundance (37.32%) of reptile species was found under boulders (Fig. 5.1). Minimum number of species utilized shrubs as microhabitat (2.54%). However, minimum number of reptiles (abundance) was found in water and crevices (<1%). The order of microhabitat, based on usage by reptiles is as follows: under boulder > grass > open ground > ground covered > artificial > log = above boulder > crevice > tree > water body > shrub. Abundance showed the following pattern: under boulder > log > above boulder > open ground > grass > ground covered > artificial > tree > shrub > crevice > water body (Fig. 5.1).

5.3.2. Vertical Strata

Maximum species (45.83%) were restricted to ground (0 cm). No species were observed in 151-180 cm height strata, however, a few of them were found in subsequent strata. In terms of abundance, 90.67% were restricted to ground. Very few individuals (0.65%) were observed within 121-210 cm and about 2% were found above 210 cm (Fig. 5.2).

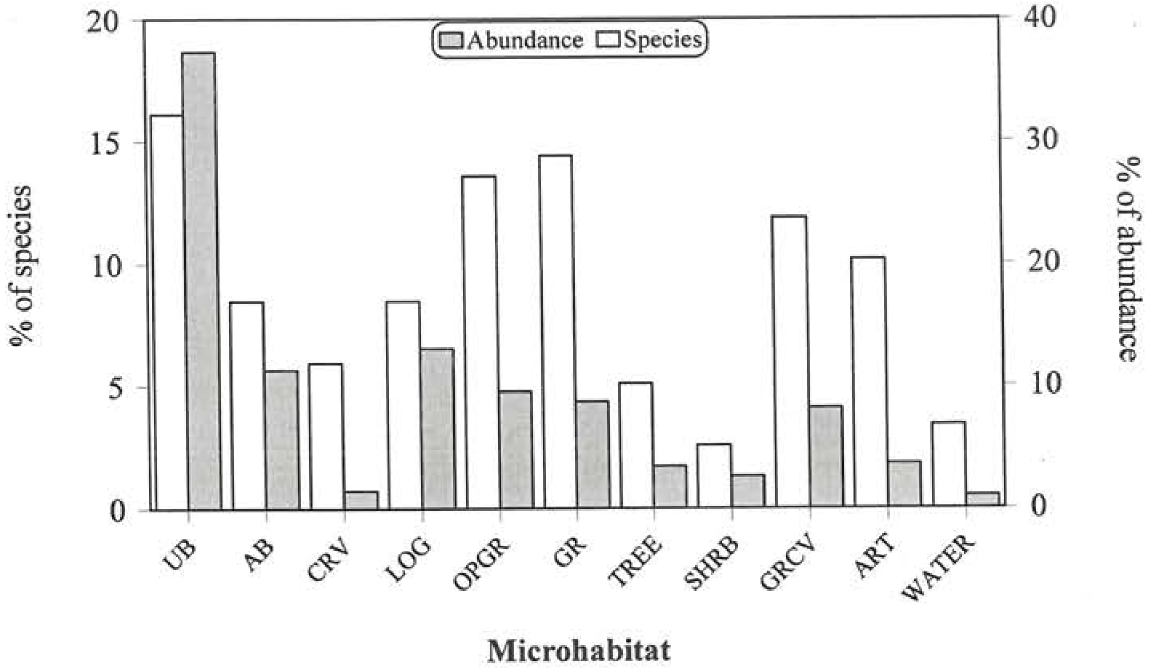


Figure 5.1. Frequency of reptiles observed in various microhabitats along the Teesta valley. UB-Under boulder, AB-Above boulder, CRV-Crevice, OPGR-Open ground, GR-Grass, SHRB-Shrub, GRCV-Ground with cover, ART-Artificial (man made).

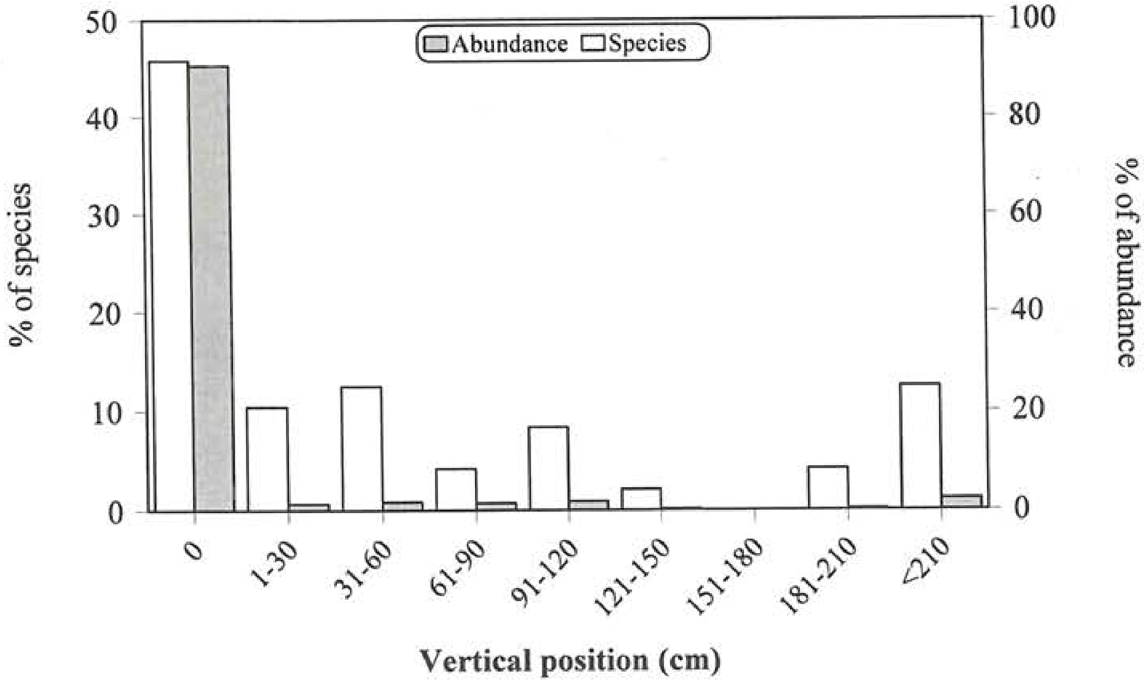


Figure 5.2. Frequency of reptiles observed in various vertical strata along the Teesta valley.

Plate 8. Boulders: the most used microhabitat by the reptiles of Teesta valley

Plate 9. Above ground microhabitat: mostly used by Agamid lizards

5.3.3. Temporal Distribution

Maximum number (86%) and abundance (90%) of species were observed during March – October. Only 14% of species and 10% of abundance were observed from November to February (colder months). Number of species observed was high during May to August, whereas with respect to abundance it was in April, July and August (Fig. 5.3). July was the peak for both species and abundance. Reptile abundance decreased markedly from November to January although few species were observed during these months.

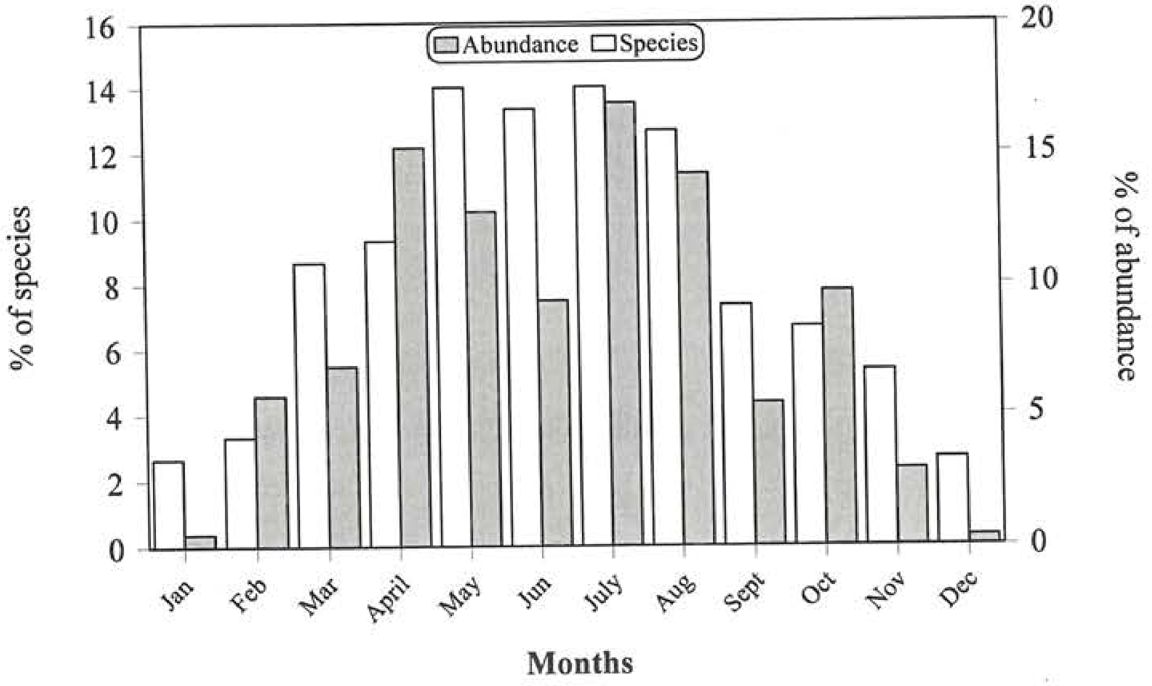


Figure 5.3. Frequency of reptile species and their abundance in various months along the Teesta valley.

5.3.4. Resource Use Pattern along the Altitude Gradient

5.3.4.1. Microhabitat

Reptile species showed significant variation in microhabitat usage among different altitude (ANOVA, $F = 5.84$, $df = 10$, $P < 0.001$). Among eleven microhabitat categories considered, three showed significant correlation with altitude. Number of species found under or inside logs (Spearman $r = 0.83$, $P = 0.04$) and ground covered ($r = 0.94$, $P = 0.005$) microhabitat showed positive correlation with altitude, whereas species observed in artificial structures showed negative correlation (r = -0.93, P = 0.008) with altitude. Abundance also showed significant variation in microhabitat usage among different altitude (ANOVA, F = 3.67, df = 10, P < 0.001). In terms of abundance, three microhabitats showed significant negative relation with altitude (above rock r = -0.83, P = 0.04; crevice r = -0.81, P = 0.05; artificial r = -0.93, P = 0.008). Number of microhabitats used by reptiles decreased monotonically with altitude. Only six out of eleven microhabitats considered were used by reptiles in higher altitude (2500-3000 m) (Table 5.1 and 5.2). Correlation between microhabitats used by reptiles and altitude showed significant negative relation (R^2 = -0.86, P = 0.03).

Table 5.1. Percentage of reptiles observed in different microhabitats along the altitude zones of the Teesta valley.

Microhabitat category	% of species in different microhabitat in different altitude zones (m)					
	<500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
Above rock	10.81	13.16	8.82	9.09	7.14	9.09
Under boulder	27.03	7.89	8.82	15.15	21.43	18.18
Crevice	10.81	2.63	5.88	6.06	0	0
Log	2.7	5.26	14.71	21.21	21.43	18.18
Open ground	8.11	18.42	20.59	9.09	0	9.09
Grass	10.81	18.42	11.76	18.18	14.28	27.27
Tree	2.7	5.26	5.88	3.03	7.14	0
Shrub	5.4	10.53	5.88	3.03	7.14	0
Ground covered	5.4	7.89	8.82	12.12	21.43	18.18
Artificial	8.11	10.53	5.88	3.03	0	0
Water	8.11	0	2.94	0	0	0

Table 5.2. Relative abundance of reptiles observed in various microhabitats along the altitude zones of the Teesta valley.

Microhabitat category	Abundance (%) of reptiles in various microhabitat along the altitude zones (m)					
	<500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
Above rock	19.23	30.38	26.67	16.36	1	0.28
Under boulder	33.85	17.72	7.88	20.61	29.53	86.32
Crevice	3.85	1.89	1.21	3.03	0	0
Log	3.08	2.53	10.3	15.15	63.73	6.84
Open ground	10	13.92	14.54	4.85	0	1.42
Grass	8.46	12.02	13.94	15.76	1.55	1.71
Tree	0.77	2.53	7.27	7.88	0.52	0
Shrub	6.15	6.33	11.51	9.69	0.52	0
Ground covered	5.38	6.96	3.03	4.24	3.11	3.42
Artificial	3.08	5.69	3.03	2.42	0	0
Water	6.15	0	0.61	0	0	0

5.3.4.2. Vertical Strata

In all altitude zones, maximum numbers of species were observed at ground level (0 cm) and as the altitude increased more species were restricted to the ground (Table 5.3). With the increase of altitude, the number of vertical strata used by reptiles decreased, but the correlation was not statistically significant. Higher numbers of vertical strata were used in the lowermost (<500 m) and middle (1000-1500 m) altitudes by the reptiles. Percentage of species on ground strata showed positive correlation with altitude (Spearman $r = 0.84$, $P = 0.03$), whereas species using >210 cm showed negative correlation with altitude ($r = -0.94$, $P = 0.005$). Analysis of variance showed significant variation in number of species found in different vertical strata along the altitude ($F = 15.86$, $df = 8$, $P < 0.001$).

Abundance of reptiles also showed a decreasing trend in the use of vertical strata along the altitude (Table 5.4). Higher numbers of strata were used in middle (1000-1500 m) followed by the lowest (<500 m) altitude. Towards the higher altitude (>2000 m) maximum individuals were restricted to ground. Above 1500 m, most of the species used the vertical strata <120 cm. Number of individuals significantly varied among vertical strata used along the altitude ($F = 26.30$, $df = 8$, $P < 0.001$). Percentage of abundance in the highest vertical strata (>210 cm) showed negative trend with altitude ($r = -0.88$, $P = 0.02$), whereas the other height categories did not show any significant pattern.

Table 5.3. Percentage of reptiles observed in different vertical strata along the altitude zones of the Teesta valley.

Vertical strata (cm)	% of species in different vertical strata in different altitude (m)					
	<500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
0	59.09	68.42	50	66.67	100	75
1-30	4.54	10.53	16.67	6.67	0	0
31-60	9.09	5.26	16.67	6.67	0	25
61-90	0	0	0	6.67	0	0
91-120	4.54	5.26	4.17	6.67	0	0
121-150	0	0	4.17	0	0	0
151-180	0	0	0	0	0	0
181-210	4.54	0	4.17	6.67	0	0
>210	18.18	10.53	4.17	0	0	0

Table 5.4. Relative abundance of reptiles in different vertical strata along various altitude zones of Teesta valley.

Vertical strata (cm)	Relative abundance of reptiles in different vertical strata in different altitude (m)					
	<500 m	500-1000 m	1000-1500 m	1500-2000 m	2000-2500 m	2500-3000 m
0	90.84	94.30	87.88	83.73	100	99.72
1-30	2.29	2.53	4.24	1.20	0	0
31-60	1.53	0.63	3.64	6.63	0	0.28
61-90	0	0	0	0.60	0	0
91-120	0.76	1.26	1.21	7.23	0	0
121-150	0	0	0.61	0	0	0
151-180	0	0	0	0	0	0
181-210	0.76	0	0.61	0.60	0	0
>210	3.82	1.26	1.82	0	0	0

Mean vertical position of all species across the altitude zones showed unimodal centre peaked pattern decreasing towards both upper and lower altitudes. However, the decrease towards higher altitude was abrupt compared to lower altitude. In higher altitudes, the mean and standard error was close to each other, whereas the standard error was high in lower and middle altitudes, showing versatility in vertical strata usage by reptiles. In total, vertical strata use decreased with increasing altitude (Fig. 5.4), however, no significant relation was found between altitude and mean height used by reptiles.

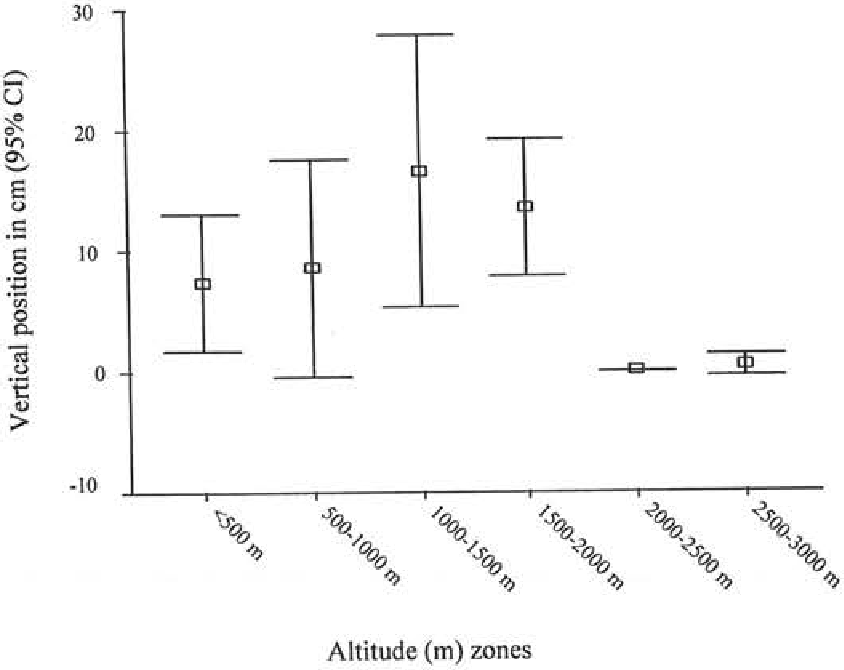


Table 5.5. Mean height (from ground) used by reptile species along the altitude zones of Teesta valley.

5.3.4.3. Temporal Distribution

ANOVA showed significant variation in number of species along the altitude with respect to monthly observations ($F = 3.78$, $df = 11$, $P < 0.001$). Higher numbers of species were sighted from March to August in all altitude zones. Species were active in most of the months in lower altitudes compared to higher altitudes (Table 5.5). From November to January, no species were sighted above 1500 m. During April to August, species were sighted in all altitude zones. Correlation between altitude and percentage of species observed in different months showed significant negative correlation with three months (January: $r = -0.84$, $P = 0.03$; March: $r = -0.81$, $P = 0.05$; November: $r = -0.88$, $P = 0.02$). Number of months in which species were found active decreased significantly with increasing altitude ($r = -0.94$, $P = 0.005$).

Abundance also followed similar pattern as species showing high abundance from March to August. Abundance varied significantly in different months along the altitude gradient ($F = 4.02$, $df = 11$, $P < 0.001$). Correlation between altitude zones and relative abundance of reptiles in different months also showed negative relation with three months (January: $r = -0.84$, $P = 0.03$, March: $r = -0.93$, $P = 0.008$, November: $r = -0.89$, $P = 0.01$) and positive relation with only one month (June: $r = 0.89$, $P = 0.01$). Other months showed no significant correlation with reptile abundance along the altitude. The abundance was high during March in lowest altitude (<500 m) and during July and August in other altitude zones (Table 5.6).

5.3.5. Habitat Characteristics

Principal component analysis (PCA) was performed to describe habitat characteristics used by reptiles in respective altitudes along the Teesta valley. Results of PC I, PC II and PC III of all altitudes are given in Appendix-III. As PC I accounts for high variation and provides pertinent information for comparative purpose PC I value in all altitude zones was considered for description (Table 5.7).

Table 5.6. Percentage of reptiles observed in different months along the altitude zones of Teesta valley.

Month	% of species in different months in different altitude (m)					
	<500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
January	9.091	3.12	0	0	0	0
February	0	0	5.41	0	5.882	12.5
March	20.45	3.12	18.92	4.17	0	0
April	2.27	6.25	13.51	12.5	5.887	12.5
May	9.09	9.37	2.70	4.17	17.65	12.5
June	11.36	3.12	8.11	12.5	11.76	12.5
July	6.82	25	10.81	16.67	17.65	18.75
August	6.82	15.63	13.51	20.83	23.53	12.5
September	6.82	9.37	5.40	12.5	0	6.25
October	13.64	0	13.51	16.67	17.65	12.5
November	9.09	18.75	8.11	0	0	0
December	4.54	6.25	0	0	0	0
No. of months	11	10	10	8	7	8

Table 5.7. Relative abundance of reptiles observed in different months along the altitude zones of Teesta valley.

Month	Relative abundance of reptiles in different months along the altitude (m)					
	<500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
January	3.65	0.68	0	0	0	0
February	0	0	1.81	0	8.81	4.07
March	29.2	0.68	8.14	0.59	0	0
April	2.92	19.05	9.96	17.86	0.52	10.77
May	9.49	2.721	1.81	1.79	16.58	7.42
June	6.57	0.68	8.14	8.33	30.05	15.55
July	2.92	30.61	25.34	19.64	22.28	20.1
August	14.6	12.93	14.48	13.69	16.58	22.73
September	5.84	8.84	7.24	10.12	0	0.24
October	10.22	0	21.72	27.98	5.18	19.14
November	12.41	21.09	1.36	0	0	0
December	2.19	2.72	0	0	0	0

Three principal components were extracted from nine habitat variables, which accounted for 53.3% variance in the data of <500 m. Principal component (PC) I accounted for 26.1% variance and was positively influenced by tree number, litter cover, canopy cover and slope. None of the variables showed strong negative influence. In 500-1000 m, PCI explained 26.4% variance and was positively influenced by herb cover, slope and tree number and negatively by others and number of boulders. In 1000-1500 m, cumulative variance of PCA was 49.6%. PC I explained 22.7% variation and the number of boulders had positive while herb cover had negative influence. In 1500-2000 m altitude, PC I accounted for half (27.5%) of the total (54.5%) variance and was influenced positively by boulders and soil and negatively by herb cover. PC I explained more than half of the total variance (30.6/57.1%) in 2000-2500 m. It was influenced positively by number of boulders, slope and distance to water and negatively by herb cover and logs. Three principal components explained 53.36% variance of habitat variable in the data in 2500-3000 m zone. PC I accounted for 24.62% variation and was influenced positively by herb cover and negatively by others (moss, gravel) and number of boulders.

Among all altitude zones, tree related factors such as tree number, litter cover and canopy cover influenced PC I positively in two lower zones (<500 and 500-1000 m). In the middle and higher zones 1000-1500, 1500-2000 and 2000-2500 m, other cover (gravel, moss, fern, sand) and boulders positively influenced PC I, whereas herb cover showed negative influence. In 2500-3000 m, PC I was positively influenced by herb cover, whereas boulders and others showed negative impact (Table 5.7).

Table 5.8. Factor loadings of habitat variables used by reptiles along the Teesta valley with respect to PC I.

Habitat variable	Altitude zones (m)					
	<500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
Tree number	0.73	0.51	-0.13	-0.33	0	0.06
Shrub number	0.2	-0.03	0.21	0.08	0	0.49
Herb cover (%)	-0.3	0.8	-0.82	-0.95	-0.85	0.8
Soil cover (%)	0.04	0.19	-0.1	0.53	0.22	0.22
Litter cover (%)	0.74	0.16	-0.14	0.02	0.35	-0.05
Other cover (gravel, stone, moss %)	-0.32	-0.9	0.93	0.72	0.79	-0.78
Number of boulders	-0.26	-0.71	0.75	0.44	0.72	-0.8
Canopy cover (%)	0.79	0.37	-0.23	-0.13	-0.12	0.09
Slope	0.56	0.61	-0.04	0.01	0.66	0.49
Log	-0.16	-0.02	-0.09	-	-0.69	-0.05
Distance to water	0.11	0.07	-0.02	-0.31	0.57	0.08
Eigen value	2.87	2.91	2.49	2.75	3.36	2.71
Variance explained (%)	26.11	26.42	22.72	27.49	30.58	24.62
Cumulative variance of PC I, PC II & PC III (%)	53.27	52.65	49.57	54.52	57.08	53.36

5.4. DISCUSSION

Resource utilization pattern in reptiles is poorly understood, especially in tropics (Parker and Plummer, 1987). The present study showed that most of the reptiles of Teesta valley used under ground microhabitats such as boulder. This finding is in consistent with the microhabitat usage of reptiles in Upper Nilgiris, Western Ghats (Nixon, 2005). Usage of under ground habitats should be beneficial for thermoregulatory activities in the colder climatic condition of Teesta valley and Upper Nilgiris. Rocks absorb and retain heat for longer duration (Bishop and Echternacht, 2003). The present result differed from reptile study of Anaikatty Hills, where maximum numbers of species were reported to use forest floor and minimum under boulders (Mukherjee, 2007). Anaikatty Hills (mean min. temp. 17.3 °C, max. temp. 36.3 °C) located at 650 m altitude on the drier eastern slope of Western Ghats is comparatively hotter than Teesta valley (min range 4.2 – 17.1 °C, max range 13.9 – 23.9 °C) and the reptiles used forest floor that may be comparatively cooler to cope hotter climatic conditions in the Anaikatty Hills.

The thermal benefits due to use of boulders or rocky substratum as microhabitat was elaborated by the studies on *Anolis carolinensis* (Bishop and Echternacht, 2003). The under boulder microhabitat can be advantageous escaping from predators for most reptile species. Selection of appropriate microhabitats is important to maintain the body temperature especially for poikilothermic reptiles (Greenberg, 1976, Nixon, 2005) and also to avoid unsuitable weather and predators (Boykin and Zucker, 1993). The infrequent limited use of shrub and water bodies by the reptiles of Teesta valley is due to colder condition and low water temperature respectively.

Number of reptile species as well as abundance was more on the ground compared to other (higher) strata. The cold climatic conditions would have restricted the reptiles to the ground along this valley. Agamids (*Japalura variegata* and *Calotes versicolor*) displayed arboreality than other lizards in the Teesta valley. Arboreality in Agamids is well documented (Sunderesan and Daniels, 1994; Bhupathy and Kannan, 1997; Iswar *et al.*, 2003; Bhupathy and Nixon, 2004; Mukherjee, 2007). Kastle *et al.* (1993) studied the biology and ecology of two species of *Japalura* (*O. tricarinata* and *J. polygonata*) in the

Kathmandu valley. It is reported that lizards suffered from temperature fluctuations with slightest variation of the ambient temperature and these lizards moved on to tree trunks for basking. It is also reported that resting (sleeping) requires certain height above the ground in *Japalura* spp. (Kastle *et al.*, 1993).

The biotic factors (competition, tree density, shrub cover, ground cover) and abiotic (temperature, boulder availability, slope) influence the microhabitat use by reptiles (Martin, 2001). Nixon (2005) found significant relationship between reptile density and factors such as temperature, boulder availability and tree density. Present study also showed significant role of climatic factors in determining the distribution of reptiles (Chapter 4). Role of temperature regulating the microhabitat use by reptiles in temperate region is well documented (Greenberg, 1976; Huey *et al.*, 1989; Bishop and Echternacht, 2003). Further studies focusing on habitat and microhabitat variables such as aspect, slope and microhabitat availability will provide significant insights into the habitat use pattern of reptiles, especially in montane environments.

Study on the seasonality (temporal use) of Indian reptiles is scanty (Duda and Koul, 1977; Nixon, 2005). Due to the ectothermic nature, reptiles are constrained by environmental conditions to maintain body temperature, which affects their daily and monthly/seasonal activities (Pough *et al.*, 1998). Favorable weather conditions during April to July, when summer temperature is brought down by frequent showers, might be responsible for the maximum number of species as well as abundance of reptiles during this period compared to colder winter months. Huey *et al.* (1977) reported that reptiles might avoid both hottest summer as well as coldest winter months due to constraints in thermoregulation. High abundance of reptiles during monsoon (May–August) may also be due to the abundance of prey (insects) and increased reproductive activity (Mukherjee, 2007). It is reported that reproduction of many vertebrates coincides with the onset of rain (Fitch, 1982; Pough *et al.*, 1998). In Sikkim, rainy season starts during mid-April and monsoon extends up to September. However, from mid-September, high altitude areas experience snowfalls, which reduce the activity of most reptiles. The most common high altitude snake (*Trachischium guentheri*) became rare from early winter due to hibernation in deep crevices. A few species inhabiting low altitudes were active round the year.

Agamids (*Calotes versicolor*, *Japalura variegata*) and Scincids (*Sphenomorphus maculatus*, *Sphenomorphus indicus*, *Asymblepharus sikimmensis*) were active for 9-11 months. Daniel (2002) reported round the year activity for *Calotes versicolor*. Preferred body temperatures of skinks are generally lower than most other groups of lizards (Licht *et al*., 1966; Avery, 1982) and hence they were active in colder conditions. *Asymblepharus sikimmensis* were observed even during the colder month (February) at 2500 m. Avery (1982) reported that compared to heliothermic lizards especially skinks, snakes are not efficient thermoregulators. Limited thermophilic ranges of snakes force them to be more seasonal than lizards (Chapter 6). Combination of various factors such as climate, vegetation structure, physiography of the area, availability of food and reproductive habits of the species may limit their spatio-temporal use.

Microhabitat use by reptiles varied in different altitude depending on the availability of resources and suitability of environmental conditions. Number of species under logs and ground cover (with moss, gravel or piled stones) showed positive relation with altitude. As altitude increased, temperature decreased hence most of the species used relatively warmer microhabitats such as boulder covered with moss to escape from severe climatic condition. Selecting appropriate microhabitats may have enhanced the thermoregulation in fluctuating climatic condition (Greenberg, 1976). In the higher altitude of the study area, the habitat is more open compared to lower altitude. As the avian predators are common, ground covered with gravels or mosses may be useful camouflage and retreat for reptiles. Decrease in number of species as well as individuals in artificial structure with increase in altitude is due to the poor availability of the same, as in higher altitudes, the area becomes isolated and remote with a few habitations and infra structures. Number of individuals in three microhabitats (above rock, crevice and artificial structure) showed negative relation with altitude. Local climatic condition seems to be one of the driving forces in microhabitat selection by reptiles.

Number of species and abundance showed variation in use of vertical strata ($P < 0.001$) along the altitude. Percentage of species in the lowest vertical strata (0 cm or ground) increased positively with altitude, whereas the highest height category (>210 cm) decreased with altitude. Highly fluctuating atmospheric temperature in higher altitude may not be advantageous for arboreality. The arid and windy conditions prevailed in the higher altitudes would have restricted the use of above ground strata. Doan (2004) reported descending of arboreal frogs to lower levels to avoid the cold temperatures and desiccating winds.

Mean vertical strata use by reptiles along the altitude showed peak in the mid altitude. In higher altitude all animals were found in underground microhabitats, hence mean as well as standard error was at 0 cm (ground). In lower and middle altitude, species were found in various vertical strata using both terrestrial as well as arboreal microhabitats. Mean vertical position used by reptiles was highest at 1000-1500 m altitude zone. This zone has a moderate temperature, neither too hot nor too cold, and permitted the reptiles to use different strata flexibly. The high mean value at this altitude zone is due to the presence of an agamid, *Japalura variegata* that showed maximum versatility in vertical strata use. Utilization of different height category may depend on temperature, moisture, prey availability, and predation pressure (Stewart, 1985; Lillywhite and Henderson, 1993). Mean vertical strata used by reptiles were also high in <500 m and 500-1000 m, and this is due to the presence of another agamid *Calotes versicolor*. Versatility of Agamids in using habitats is already discussed. Brown (1992a) reported that *Calotes versicolor* juveniles used ground while adults used more arboreal habitats.

Significant monthly variation was observed in the number of species as well as abundance of reptiles along the altitude gradient of Teesta valley ($P < 0.001$). During winter months (November to January), species were active only below 1500 m. Reptiles have inherent tendency to hibernate during winter months to avoid harsh climatic conditions. The atmospheric temperature during these periods may be much lower than the preferred body temperature of many reptiles. Preferred body temperature (PBTs) for many snakes falls within a range of 28 to 34°C (Lillywhite, 1987). However, only below 1000 m in the Teesta valley, had the temperature equivalent to preferred body temperature for snakes (Chapter 2). Hence, reptiles were active for short period above 1000 m. Peak in their activity during July-August may be due to suitable temperature, moisture, food abundance and reproductive activity as well.

In <500 m and 500-1000 m altitude categories, PC I was positively influenced by tree number and cover by herb, canopy and litter. Trees may offer ideal condition to bask during morning and provide shade during hot mid-day. Shade or sheltered environment due to canopy cover may be preferred by some species to maintain relatively low temperature in tropics (Greer, 1989; Fischer *et al.*, 2005). Herb cover may be safer than bare ground for immediate refuge, besides it may provide shade during midday. The hot tropical condition below 1000 m might have driven the species to use habitats with tree and herb covered ground to maintain the optimal temperature.

In contrast to the two lower zones, PC I was positively influenced by boulders and other ground cover (with moss and gravel) microhabitats in higher zones (1000-2500 m). Nixon (2005) reported that in Upper Nilgiris (2000-2500 m), most of the reptiles occupied under boulder microhabitat due to prevailing colder climate. The orientation on rocks facilitates the net intake of radiation and close contact with heliothermic substrate that enhances heat gain through conduction (Castilla and Bauwens, 1992). Other ground covers such as moss and gravel may provide immediate and safe shelter in addition to thermoregulation.

Among habitat variables, herb cover showed positive influence above 2500 m. In this zone tree cover was sparse and ground was covered with herb layers. The general area is dominated by coniferous forest interspersed with open grasslands. *Asymblepharus sikimmensis*, *Trachischium guentheri* and *Amphiesma platyceps* observed in this zone were patchily distributed in open grasslands with moss-covered rocks. Open grasslands may be suitable habitat for *Trachischium guentheri* and the heliothermic skink *Asymblepharus sikimmensis*. The heliothermic lizard (*Adolfus africanus*) in Mount Kupe, Camerron, depended on grassy patches and rocky outcrops to meet the preferred microclimatic condition, which might ultimately be limited by temperature (Hofer *et al.*, 2000). Utilization of moss covered wet areas by *Asymblepharus sikimmensis* is reported by Daniel (2002).

Habitat loss is considered as a major factor for declining species diversity (Myers *et al.*, 2000). Many studies showed that microhabitat plays vital role in conservation and management of threatened and endangered species (Howes and Lougheed, 2004). Further study in this aspect may help in understanding microhabitat selection and specificity to particular microhabitat and macrohabitat by reptiles.

5.5. SUMMARY

- Spatial (microhabitat and vertical position) and temporal (monthly) use patterns of reptiles in Teesta valley were analyzed. The dimensions such as microhabitat and vertical position were considered for spatial use and months were considered for temporal use. Data on microhabitat and vertical position (from ground) were divided into 11 and nine, and temporal into 12 categories.
- Maximum number (16.1%) as well as abundance (37.3%) of reptile species was found under boulders. In terms of vertical strata, maximum 64.3% of species and 90.7% of abundance were restricted to 0 cm (ground). Reptiles were active for short period in Teesta valley. 86% of species and 90% reptiles (abundance) were observed during March–October.
- Usage of microhabitat, vertical strata and active time of reptiles showed significant variations along an altitude gradient. Percentage of species found on fallen log (Spearman $r = 0.83$, $P = 0.04$) and ground covered ($r = 0.94$, $P = 0.005$) showed positive correlation with altitude, whereas species using artificial structure showed negative correlation with altitude ($r = -0.93$, $P = 0.008$). Number of microhabitat categories used by reptiles also decreased with altitude.
- Number of vertical strata used by reptiles decreased with the increasing altitude. Maximum numbers of vertical strata were used in lowermost (<500 m) and middle (1000-2000 m) altitudes by reptiles. The number species using ground (0 cm) strata increased with altitude (Spearman $r = 0.84$, $P = 0.03$), whereas highest strata showed significant negative trend with altitude ($r = -0.94$, $P = 0.005$).

- No species were sighted >1500 m from November to January. Number of months with active reptile observations decreased significantly with increasing altitude ($P<0.001$). Correlation between altitude and percentage of species in different months showed negative relation with three months; January, March and November.
- Tree related factors such as tree number, litter cover, canopy cover, herb cover and canopy cover influenced PC I positively in <500 m and 500-1000 m (lower altitudes). In higher three zones (1000-1500 m, 1500-2000 m and 2000-2500 m) other microhabitats (ground covered with gravel, moss and piled stones) and boulders positively influenced PC I. Herb cover influenced PC I positively in 2500-3000 m. Further study in this aspect may help in understanding microhabitat selection by reptiles and their specificity to particular microhabitat, which would help in the conservation of species.

CHAPTER 6

RESOURCE PARTITIONING

RESOURCE PARTITIONING

6.1. INTRODUCTION

In a competitive environment, coexistence of different species is possible largely through effective partitioning and optimum utilization of resources. Resources are partitioned in three basic ways: temporal (time), spatial (place) and trophic (food) (Pianka, 1973). Schoener (1974) identified five resource dimensions such as macrohabitat, microhabitat, food type, time of activity (day) and seasonality in natural communities by which the organism would partition their resources. This study emphasized food as one of the important factors responsible for segregation of animals especially those feeding on large food items relative to their own size (e.g. snakes). Food is considered as the prime resource for many species and in turn food plays a major role in determining the niche of an animal (Weatherly, 1963). Terrestrial poikilotherms partition the food by being active during different time of the day (Pianka, 2000).

Though niche is variously defined, it is considered as the focal point of community ecology (Tokeshi, 1999). From the time when Grinnell (1917) used the term "niche", its definition is being continuously revised. Pianka (2000) summarized the ecological niche as the "sum total of the adaptations of an organismic unit." Farlow and Pianka (2002) reported that when coexisting species do not differ morphologically, they may reduce dietary overlap by handling prey differently. The microhabitat specificity has lead to specialization in their habitat use in many lizards (Pianka, 1973). Nature of prey and size were attributed as important factors in coexistence of lizards (Pianka, 1975). Morphological adaptations are evolved by species to exploit various resources (Pianka, 1969; Pöysä, 1983; Armstrong and Nudds, 1985; Bhupathy, 1991).

Vertical stratification, though regarded significant only for birds (Pöysä, 1983; Bhupathy, 1991), is considered as an important aspect in resource partitioning among reptiles as well (Nixon, 2005; Mukherjee, 2007). Temperature and humidity are important factors in determining the vertical strata used by animals (Doan, 2004). Temporal segregation, active during different hours or months or seasons also plays important role in resource partitioning among various species (Pianka, 1973). Temporal variations in activity are reported even between male and female Texas horned lizards, *Phrynosoma cornutum* in southern Texas by Moeller *et al.* (2005).

Niche breadth is an index of relative variability of resource utilization in a species, measured in terms of particular niche dimension (Noon, 1981). Generally specialist tends to have narrow/lower niche breadth, whereas generalists have broader/higher niche breadth (Pianka, 2000). The differences in niche breadth may influence the structure and diversity of communities.

The extent to which two organisms use similar resources in one or more dimensions is known as niche overlap (Noon, 1981). Complete overlap occurs when a pair of species has identical resource requirements. No overlap occurs if the requirements are completely different. However, in nature usually partial overlap occurs, sharing some resources while certain resources are exclusive to each species (Pianka, 2000).

According to Hutchinson (1957), high niche overlap leads to competition. However, in nature the overlap of niches does not necessarily lead to competition e.g. two organisms can share the same resource without competition if resources are unlimited. In fact, habitat overlap indicate that competition have diversified in other ways (Tokeshi, 1999). Potential competitor species with high overlap in one dimension often overlaps relatively little or not at all along other dimensions thus reducing competition between them (Pianka, 1973). Niche overlap is a function of several factors such as vegetation structure, productivity, food abundance, competition, social dominance, seasonality, size and morphology of species (MacArthur, 1968; Cody, 1974). Despite the fact that there is no direct relation between overlap and competition, the degree of overlap in resource utilization pattern unravels the concept of community organization such as species coexistence, diversity and abundance (Tokeshi, 1999).

Pianka (1973) studied lizard communities in North America, Australia and South Africa and predicted that overall niche breadth of species of an area has collinear relation with species richness or diversity and inverse relation with niche overlap. MacArthur (1972) put forward "latitude-niche breadth hypothesis", which states that niche breadth decreases with decreasing latitude or niche becomes narrower towards the tropics (equator). Greater stability and lower seasonality in tropics compared to temperate region leads to stable populations, which in turn, results in narrower niches. Brown (1988) considered altitude as proxy for latitude, and in this study niche breadth hypothesis was tested with altitude.

Very few studies pertaining to resource utilization are available on Indian reptiles, and were largely undertaken in Western Ghats. Inger *et al.* (1987) documented ecological structure of a herpetofaunal assemblage in Ponmudi Hills, Western Ghats. Brown (1992a, b) studied microhabitat relations of herpetofauna in South India and revealed the existence of spatial guilds among species. Nixon (2005) analyzed resource utilization pattern of reptiles in trophic, spatial (microhabitat, vertical position) and temporal dimensions in the higher altitudes of Western Ghats (Nilgiris). Mukherjee (2007) studied resource utilization of reptiles at spatial and temporal dimensions in the tropical dry mixed deciduous forest of Anaikatty Hills (Western Ghats). However, all these studies are limited to a specific forest type or a particular altitude zone.

This Chapter deals with the aspects of resource utilization pattern of reptiles along the altitude gradients of Teesta valley in spatial and temporal dimensions. An attempt is also made to test the applicability of latitude niche breadth hypothesis (McArthur, 1972) along the altitude gradient.

6.2. METHODS

6.2.1. Data Collection

Time constrained visual encounter survey (VES) was largely used for data collection. Details of sampling protocol are provided in Chapter 3. Though sampling was done up to alpine meadow (4800 m altitude), the data from coniferous forest (3000 m), alpine and sub-alpine habitats were excluded from the analysis due to lack of observation of reptiles. Larger landscape based on major vegetation combinations was considered as macrohabitat and the immediate environment of a species as microhabitat. Six macrohabitats were considered: Cardamom plantation, Tropical-semi-deciduous, Sal, Tropical-broadleaved, Temperate-broadleaved and Coniferous forests. Vertical stratum is the location of reptiles found above the ground when first sighted. Description of microhabitat and vertical stratum are given in Chapter 5. Temporal data were sorted out based on monthly sightings of reptiles.

6.2.2. Data Analyses

Following analyses were performed.

1. Niche breadth (β) for habitat, microhabitat, vertical strata/position, and temporal dimensions were calculated using Simpson's diversity index.

$$\beta = 1/\Sigma p_i^2$$

where, p_i is the proportion of individuals of species in i^th resource category.

Niche breadth of each species for each resource dimension was calculated and average niche breadth was computed using data from all resource dimensions (Pianka, 1973). Niche breadth was categorized as low (0-33%), moderate (34-66%) and high (67-100%) depending upon niche breadth value and number of categories in each resource dimension.

2. Niche overlap between two species was calculated in each resource dimension (macrohabitat, microhabitat, vertical position and temporal) for each altitude zones and overall using Pianka's overlap index (Pianka, 1973).

$$\text{Pianka's overlap index } (\Phi i) = \frac{\sum p_{ij} p_{jk}}{\sqrt{\sum p_{ij}^2 p_{jk}^2}}$$

where, p_{ij}, p_{jk} = Proportion of individual of species j and k occupying the i^{th} resource category.

Average niche overlap in each niche dimension and altitude category was calculated as the mean of all inter-specific overlaps. Overall niche overlap along each altitude was obtained as an average of three resource dimensions.

The test of significance of overlap value is not available (Fuselier and Edds, 1994). Many studies considered different overlap values such as greater than 0.90 as "nearly complete" and 0.75 or greater as "very high". In this study, niche overlap value was categorized as low (Φi = 0.01-0.33), medium (Φi = 0.34-0.66), high (Φi = 0.67-0.99), no (Φi = 0) and complete (Φi = 1) overlap.

6.3. RESULTS

6.3.1. Niche Breadth

Niche breadth (β) of an organism varies from one (using only one resource) to *n* (using all resource categories considered).

Spatial

Six macrohabitat categories were considered; accordingly niche breadth should range from one to six. Niche breadth from 1 to 2.67 (<33% resource category) was considered as low, 2.68-4.35 (33-66%) as moderate and 4.36-6 (67-100%) as high. Number of microhabitats considered was 11 and niche breadth should range from one to eleven. Niche breadth 0-3.6 was considered as low, 3.7-7.3 as moderate and 7.4-11 as high. Nine categories of vertical strata were considered and the resultant value should range from 1 to 9. Niche breadth from 0 to 2.9 was considered as low, 3 to 5.9 as moderate and 6 to 9 as high.

Lizards

Habitat niche breadth of lizards of Teesta valley ranged from 1 to 3.17 (Table 6.1). Out of 10 lizard species considered for analysis, highest habitat niche breadth was obtained for *Sphenomorphus indicus* (β = 3.17) followed by *Japalura variegata* (β = 3.07) and lowest (β = 1) by three species (*Hemidactylus bowringii*, *Hemidactylus frenatus*, *Takydromus sexlineatus*) indicating their restricted use of only one habitat. Two belonged to moderate and eight to low niche breadth category (Table 6.2).

Niche breadth in microhabitat dimension varied from 1.32 to 6.56 (Table 6.1). *Japalura variegata* had the highest niche breadth (β = 6.56) followed by *Calotes versicolor* (β = 5.95). Lowest niche breadth was obtained by *Hemidactylus garnotii* and *Cyrtodactylus khasiensis* (β = 1.32). Out of 10 lizards, six showed low niche breadth, four showed moderate and none belonged to high niche breadth category (Table 6.2).

Niche breadth of lizards in vertical dimension varied from 1 to 2.99 (Table 6.1). Only two species of lizards showed relatively higher niche breadth (*Hemidactylus bowringii*, β = 2.92 and *Japalura variegata*, β = 2.09). All lizards fell under low niche breadth category (Table 6.2).

Snakes

In habitat dimension, maximum niche breadth was obtained by *Amphiesma platyceps* (β = 3.88) and minimum (β = 1) by five species (Table 6.3). Barring *A. platyceps*, all (12 out of 13) snake species came under low niche breadth category.

A. platyceps obtained maximum niche breadth (β = 4.83) followed by *Lycodon aulicus* (β = 4.45) in microhabitat dimension, and minimum by *Typhlops* sp. (β = 1; Table 6.3). Out of 13 species considered for analysis, 10 belonged to low, three to moderate and none to high niche breadth category (Table 6.2).

Nine vertical strata were considered for analysis. Highest niche breadth (β = 2) was obtained by *Dendrelaphis pictus* and lowest (β = 1) by ten species (Table 6.3). In vertical strata, all snakes belonged to low niche breadth category (< 33%).

In macrohabitat, microhabitat and vertical dimensions both lizards and snakes were specialists, as all species obtained relatively low niche breadth and none belonged to high niche breadth category.

Temporal

In temporal dimension, niche breadth should range from 1 to 12 based on months of a year. The niche breadth from 0 to 3.9 (<33% of 12 months) was considered as low, 4-7.9 (33-66%) as moderate and 8-12 (>66%) as high.

Lizards

Niche breadth of lizards in temporal dimension ranged from 2.58 to 6.67. *Sphenomorphus indicus* scored the highest (6.67) and *Cyrtodactylus khasiensis* the lowest value (2.58). All the three Scincids found in Teesta valley, *Sphenomorphus indicus* (β = 6.67), *Sphenomorphus maculatus* (β = 6.49), *Asymblepharus sikimmensis* (β = 5.44) obtained relatively higher niche breadth (Table 6.1) than other lizards; but none of them belonged to high niche breadth category (Table 6.2). *Japalura variegata* also obtained moderate niche breadth (β = 6.31).

Snakes

Niche breadth of snakes in temporal dimension ranged from 2.4 to 5 (Table 6.3). *Trachischium guentheri* obtained the highest niche breadth (β = 5) and *Xenochrophis* sp. the lowest (β = 2.4). Compared to the other resource dimensions, maximum number of snakes (eight) belonged to moderate niche breadth category and minimum (five) in low category and none of the snakes belonged to high niche breadth category (Table 6.2). In temporal dimension, 60% each of lizard and snakes belonged to moderate, 40% to low and none to high niche breadth category (Table 6.2).

In all, 38 resource categories belonging to 26 spatial (6-habitat, 11-microhabitat, 9-vertical position) and 12 temporal categories of four dimensions were considered for niche breadth analysis. In the spatial dimension, more number of species belonged to low niche breadth category. However, in the temporal dimension, maximum number of species belonged to moderate category. In both spatial and temporal categories, none of the species belonged to high niche breadth category (Table 6.2). Among four dimensions considered, niche breadth was low in vertical strata compared to habitat, microhabitat and temporal dimensions (Table 6.1 and 6.3).

6.3.2. Niche Overlap

Niche overlap between two reptile species was calculated in four resource dimensions – macrohabitat, microhabitat, vertical strata and temporal use. Niche overlap value ranges from 0 to 1. Overlap values were categorized as: 0 (no overlap), 0.01-0.33 (low), 0.34-0.66 (moderate), 0.67-0.99 (high) and 1 (complete overlap).

Spatial

Lizards

Ten species of lizards were considered for spatial niche overlap analysis, which in combination resulted in 45 pairs. Among them, *Asymblepharus sikimmensis* showed low overlap with four species and no overlap with five species in macrohabitat dimension. *Hemidactylus bowringii*, *Hemidactylus frenatus* and *Takydromus sexlineatus* showed complete overlap with each other. Congeneric and sympatric species such as *H. garnotii*, *H. bowringii*, *H. frenatus* and *Sphenomorphus maculatus* and *Sphenomorphus indicus* showed high overlap. All sympatric species, *H. garnotii*, *H. bowringii*, *H. frenatus*, *Cyrtodactylus khasiensis*, *Takydromus sexlineatus*, *S. maculatus*, *S. indicus* and *Calotes versicolor* showed high overlap. *Asymblepharus sikimmensis* and *Japalura variegata* showed low overlap with rest of the species (Table 6.4).

Out of 45 species pairs, none of the pairs showed complete overlap in microhabitat dimension. *Takydromus sexlineatus* showed no overlap with three species (*H. bowringii*, *H. frenatus* and *Cyrtodactylus khasiensis*; Table 6.4). Highest overlap was observed between *H. garnotii* and *A. sikimmensis*. Of the 45 pairs of species, higher number (22) belonged to low overlap category, 14 to moderate and six to high category. Three pairs showed no overlap in their microhabitat use (Table 6.5). In the vertical strata, eleven lizard pairs showed complete overlap and one pair (*H. frenatus* and *Cyrtodactylus khasiensis*) showed no overlap (Table 6.4). Twenty-five pairs belonged to high overlap, eight low and none to moderate overlap (Table 6.5).

Snakes

Thirteen species of snakes were considered for analysis, which resulted in 78 pairs.

In habitat dimension, 29 pairs showed no overlap and only six pairs showed complete overlap (Table 6.6). Twelve pairs of snake species showed high overlap, 18 pairs belonged to moderate and 13 pairs to low overlap. Ten species pairs of snakes showed no overlap and none showed complete overlap in the microhabitat dimension. *Oligodon juglandifer* and *Rhabdophis himalayanus* had highest overlap in microhabitat use (Table 6.6). Both low and high overlap categories had twenty-one pairs of snakes. Maximum of 26 pairs (33.33%) showed medium overlap (Table 6.5). Most of the snakes had high overlap in vertical dimension. Out of 78 pairs, 45 had complete overlap and 33 showed high overlap, whereas none belonged to low, medium and no overlap category (Table 6.7).

Temporal Use

Lizards

In temporal dimension, none of the species pairs showed complete overlap, whereas one pair (*Hemidactylus garnotii* and *Cyrtodactylus khasiensis*) had no overlap (Table 6.8). Fifteen pairs showed low overlap, 20 moderate and nine high overlap (Table 6.5). Among 10 species of lizards, *Takydromus sexlineatus* showed low overlap (0.08 to 0.37) with rest of the species.

Snakes

In temporal dimension, none of the species pair had complete overlap and only one pair (*Dendrelaphis pictus* and *Typhlops* sp.) showed no overlap (Table 6.9). Ten pairs belonged to low overlap, 17 to moderate and maximum (50/78 pairs) to high overlap category (Table 6.5). Among four resource dimensions considered here, niche overlap was high in the vertical strata for both lizards and snakes.

Table 6.1. Niche breadth of lizards observed along the Teesta valley with respect to various resource dimensions; number in parenthesis indicates number of categories.

Species	Resource dimension				Average niche breadth (9.5)
	Habitat (6)	Microhabitat (11)	Vertical (9)	Temporal (12)	
Hemidactylus garnotii	1.72	1.32	1	2.88	1.73
Hemidactylus bowringii	1	2.27	2.92	3.51	2.42
Hemidactylus frenatus	1	1.75	1.5	5.73	2.49
Cyrtodactylus khasiensis	2	1.32	1	2.58	1.72
Japalura variegate	3.07	6.56	2.09	6.31	4.51
Calotes versicolor	2.09	5.95	1.6	4.76	3.6
Sphenomorphus maculatus	2.1	4.7	1.18	6.49	3.62
Sphenomorphus indicus	3.17	4.73	1.03	6.67	3.9
Asymblepharus sikimmensis	2.54	1.55	1.04	5.44	2.65
Takydromus sexlineatus	1	3.45	1.08	2.67	2.05
Average	1.97	3.36	1.44	4.7	2.87

Table 6.2. Summary of niche breadth categories of lizards and snakes with respect to various resource dimensions. Number in parenthesis indicates number of lizard and snake species considered for analysis.

Taxa	Niche breadth category	Resource category			
		Habitat	Microhabitat	Vertical position	Temporal
Lizards (10)	Low	8	6	10	4
	Medium	2	4	0	6
	High	0	0	0	0
Snakes (13)	Low	12	10	13	5
	Medium	1	3	0	8
	High	0	0	0	0

Table 6.3. Niche breadth of snakes observed along the Teesta valley with respect to various resource dimensions; number in parenthesis indicates number of categories.

Species	Resource category				Average niche breadth (9.5)
	Habitat (6)	Microhabitat (11)	Vertical (9)	Temporal (12)	
Typhlops sp.	1.61	1	1	3.35	1.74
Pareas monticolus	1.8	1.69	1	4.45	2.23
Ptyas korros	1	4.12	1	4.65	2.69
Oligodon juglandifer	2.14	3.19	1.55	3.93	2.7
Dendrelaphis pictus	1	3	2	3.6	2.4
Lycodon aulicus	1	4.45	1.56	4.26	2.82
Sibynophis collaris	1	3.27	1	3.6	2.22
Xenochrophis sp.	1	1.95	1	2.4	1.59
Rhabdophis himalayanus	1.28	3.56	1	4.76	2.65
Amphiesma platyceps	3.88	4.83	1	4.49	3.55
Trachischium guentheri	2.02	2.24	1	5	2.56
Ovophis monticola	1.8	2.71	1	4.74	2.56
Protobothrops sp.	2.32	1.27	1	4.12	2.18
Total	1.68	2.87	1.6	4.1	2.45

Table 6.4. Niche overlap among ten species of lizards in various spatial dimensions along the Teesta valley, Sikkim.

Species										
Habitat	H g	H b	H f	C k	J v	C v	S m	S i	A s	T s
Hemidactylus garnotii (H g)		0.92	0.92	0.93	0.1	0.99	0.87	0.84	0	0.92
Hemidactylus bowringii (H b)			1	0.71	0.11	0.92	0.89	0.81	0	1
Hemidactylus frenatus (H f)				0.71	0.11	0.92	0.89	0.81	0	1
Cyrtodactylus khasiensis (C k)					0.08	0.91	0.72	0.74	0	0.71
Japalura variegata (J v)						0.21	0.41	0.58	0.33	0.11
Calotes versicolor (C v)							0.93	0.91	0.02	0.92
Sphenomorphus maculatus (S m)								0.95	0.06	0.89
Sphenomorphus indicus (S i)									0.09	0.81
Asymblepharus sikimmensis (A s)										0
Takydromus sexlineatus (T s)										
Microhabitat										
Hemidactylus garnotii (H g)		0.3	0.15	0.97	0.1	0.14	0.49	0.65	0.99	0.08
Hemidactylus bowringii (H b)			0.11	0.3	0.39	0.06	0.15	0.17	0.31	0
Hemidactylus frenatus (H f)				0.31	0.08	0.17	0.11	0.22	0.15	0
Cyrtodactylus khasiensis (C k)					0.01	0.06	0.38	0.56	0.98	0
Japalura variegata (J v)						0.9	0.65	0.65	0.09	0.77
Calotes versicolor (C v)							0.69	0.71	0.12	0.81
Sphenomorphus maculatus (S m)								0.94	0.45	0.62
Sphenomorphus indicus (S i)									0.61	0.66
Asymblepharus sikimmensis (A s)										0.09
Takydromus sexlineatus (T s)										
Vertical strata										
Hemidactylus garnotii (H g)		0.68	0.23	1	0.98	0.99	0.98	0.98	0.98	0.98
Hemidactylus bowringii (H b)			0.2	0.68	0.76	0.73	0.71	0.68	0.69	0.7
Hemidactylus frenatus (H f)				0	0.25	0.23	0.23	0.24	0.23	0.23
Cyrtodactylus khasiensis (C k)					0.98	0.99	1	1	1	1
Japalura variegata (J v)						1	0.98	0.98	0.98	0.98
Calotes versicolor (C v)							0.99	0.99	0.99	0.99
Sphenomorphus maculatus (S m)								1	1	1
Sphenomorphus indicus (S i)									1	1
Asymblepharus sikimmensis (A s)										1
Takydromus sexlineatus (T s)										

Table 6. 5. Summary of niche overlap in various resource dimensions among various species pairs along the Teesta valley; Number in parenthesis is percentage.

Niche overlap category	Resource dimension			
	Habitat	Microhabitat	Vertical position	Temporal
Lizards				
0	5 (11.11)	3 (6.67)	1 (2.22)	1 (2.22)
0.01-0.33	10 (22.22)	22 (48.89)	8 (17.78)	15 (33.33)
0.34-0.66	2 (4.44)	14 (31.11)	0	20 (44.44)
0.67-0.99	25 (55.55)	6 (13.33)	25 (55.56)	9 (20)
1	3 (6.67)	0	11 (24.44)	0
Snakes				
0	29 (37.18)	10 (12.82)	0	1 (1.28)
0.01-0.33	13 (16.67)	21 (26.92)	0	10 (12.82)
0.34-0.66	18 (23.08)	26 (33.33)	0	17 (21.79)
0.67-0.99	12 (15.38)	21 (26.92)	33 (42.31)	50 (64.1)
1	6 (7.69)	0	45 (57.69)	0

Table 6.6. Niche overlap among 13 species of snakes in spatial dimensions (habitat and microhabitat) along the Teesta valley.

Species													
Habitat	T sp.	P m	P k	O j	D t	L a	S c	X sp.	R h	A p	T g	O m	P sp.
Typhlops sp. (T sp.)	-	0	0.32	0.25	0.32	0.32	0	0.32	0.13	0.19	0	0	0
Pareas monticolus (P m)		-	0	0.61	0	0	0.89	0	0.89	0.56	0.02	0.8	0.91
Ptyas korros (P k)			-	0.76	1	1	0	1	0	0.6	0	0	0
Oligodon juglandifer (O j)				-	0.76	0.76	0.65	0.76	0.64	0.71	0.01	0.34	0.45
Dendrelaphis pictus (D t)					-	1	0	1	0	0	0	0	0
Lycodon aulicus (L a)						-	0	1	0	0.6	0	0	0
Sibynophis collaris (S c)							-	0	0.99	0.36	0.02	0.45	0.64
Xenochrophis sp. (X sp.)								-	0	0.6	0	0	0
Rhabdophis himalayanus (R h)									-	0.35	0.02	0.44	0.63
Amphiesma platyceps (A p)										-	0.38	0.64	0.69
Trachischium guentheri (T g)											-	0.01	0.11
Ovophis monticola (O m)												-	0.96
Protobothrops sp. (P sp.)													-

Microhabitat													
Typhlops sp. (T sp.)	-	0	0.39	0.27	0	0.3	0	0.81	0.47	0.27	0.8	0.05	0.04
Pareas monticolus (P m)		-	0	0	0	0	0.72	0	0.22	0.78	0.28	0.28	0.08
Ptyas korros (P k)			-	0.69	0.5	0.52	0.37	0.71	0.71	0.44	0.32	0.59	0.5
Oligodon juglandifer (O j)				-	0.71	0.79	0.6	0.22	0.91	0.55	0.23	0.9	0.83
Dendrelaphis pictus (D t)					-	0.52	0.45	0	0.68	0.44	0.01	0.73	0.57
Lycodon aulicus (L a)						-	0.51	0.25	0.6	0.43	0.25	0.53	0.46
Sibynophis collaris (S c)							-	0	0.67	0.89	0.06	0.77	0.58
Xenochrophis sp. (X sp.)								-	0.38	0.22	0.65	0.04	0.04
Rhabdophis himalayanus (R h)									-	0.74	0.4	0.89	0.74
Amphiesma platyceps (A p)										-	0.4	0.69	0.42
Trachischium guentheri (T g)											-	0.1	0.04
Ovophis monticola (O m)												-	0.9
Protobothrops sp. (P sp.)													-

Table 6.7. Niche overlap among 13 species of snakes in vertical dimensions along the Teesta valley.

Species													
Vertical strata	T sp.	P m	P k	O j	D t	L a	S c	X sp.	R h	A p	T g	O m	P sp.
Typhlops sp. (T sp.)		1	1	0.96	0.71	0.98	1	1	1	1	1	1	1
Pareas monticolus (P m)			1	0.96	0.71	0.98	1	1	1	1	1	1	1
Ptyas korros (P k)				0.96	0.71	0.98	1	1	1	1	1	1	1
Oligodon juglandifer (O j)					0.88	0.96	1	0.96	0.96	0.96	1	0.96	0.96
Dendrelaphis pictus (D t)						0.76	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Lycodon aulicus (L a)							0.98	0.98	0.98	0.98	1	0.98	0.98
Sibynophis collaris (S c)								1	1	1	1	1	1
Xenochrophis sp. (X sp.)									1	1	1	1	1
Rhabdophis himalayanus (R h)										1	1	1	1
Amphiesma platyceps (A p)											1	1	1
Trachischium guentheri (T g)												1	1
Ovophis monticola (O m)													1
Protobothrops sp. (P sp.)													

Table 6.8. Niche overlap among ten species of lizards in temporal dimension along the Teesta valley.

Species										
Temporal	H g	H b	H f	C k	J v	C v	S m	S i	A s	T s
Hemidactylus garnotii (H g)	-	0.59	0.42	0	0.18	0.25	0.23	0.46	0.12	0.28
Hemidactylus bowringii (H b)		-	0.71	0.2	0.38	0.37	0.34	0.5	0.13	0.11
Hemidactylus frenatus (H f)			-	0.61	0.74	0.7	0.8	0.64	0.4	0.16
Cyrtodactylus khasiensis (C k)				-	0.44	0.77	0.5	0.41	0.3	0.11
Japalura variegata (J v)					-	0.38	0.89	0.76	0.71	0.1
Calotes versicolor (C v)						-	0.55	0.43	0.33	0.37
Sphenomorphus maculatus (S m)							-	0.7	0.53	0.29
Sphenomorphus indicus (S i)								-	0.53	0.34
Asymblepharus sikimmensis (A s)									-	0.08
Takydromus sexlineatus (T s)										-

Table 6.9. Niche overlap among 13 species of snakes in temporal dimension along the Teesta valley

Species													
Temporal	T sp.	P m	P k	O j	D t	L a	S c	X sp.	R h	A p	T g	O m	P sp.
Typhlops sp. (T sp.)	-	0.45	0.18	0.04	0	0.13	0.03	0.01	0.08	0.08	0.1	0.05	0.04
Pareas monticolus (P m)		-	0.85	0.64	0.67	0.58	0.67	0.7	0.66	0.62	0.64	0.59	0.52
Ptyas korros (P k)			-	0.92	0.85	0.81	0.95	0.88	0.89	0.74	0.83	0.9	0.82
Oligodon juglandifer (O j)				-	0.72	0.85	0.96	0.79	0.96	0.66	0.8	0.9	0.83
Dendrelaphis pictus (D t)					-	0.75	0.8	0.78	0.69	0.78	0.76	0.83	0.77
Lycodon aulicus (L a)						-	0.79	0.51	0.82	0.71	0.72	0.86	0.9
Sibynophis collaris (S c)							-	0.9	0.92	0.63	0.78	0.92	0.81
Xenochrophis sp. (X sp.)								-	0.78	0.48	0.62	0.72	0.55
Rhabdophis himalayanus (R h)									-	0.65	0.76	0.83	0.76
Amphiesma platyceps (A p)										-	0.91	0.79	0.84
Trachischium guentheri (T g)											-	0.89	0.84
Ovophis monticola (O m)												-	0.96
Protobothrops sp. (P sp.)													-

6.3.3. Resource Utilization along the Altitude Gradient

Macrohabitat (forest type) closely followed altitude zones, this dimension was excluded from pattern analysis, and microhabitat, vertical strata and temporal dimensions were considered.

Niche Breadth

Among three-resource dimensions in all the altitude, none of the reptile species belonged to high (67-100%) niche breadth category (Fig. 6.1). Maximum species belonged to low niche breadth category, while a few species to moderate in all altitude zones. Species of the highest altitude (2500-3000 m) fell within low niche breadth category with respect to microhabitat and vertical strata. In microhabitat dimension, the species were restricted to low and moderate niche breadth categories. In vertical strata, irrespective of altitude all species came under low niche breadth category. As altitude increased, low niche breadth category in temporal dimension decreased, whereas moderate category increased (Fig. 6.1). Number of species belonging to different niche breadth categories in various resource dimensions along the altitude zones is provided in Appendix-IV.

Simpson diversity and niche breadth (mean of all species) at each altitude zones is presented in Table 6.10. Overall niche breadth (average of three resources) was minimum in 2500-3000 m and maximum in 2000-2500 m zones. The correlation of overall niche breadth and Simpson diversity showed no significant relation. Overall niche breadth showed decreasing trend with increasing altitude except in 2000-2500 m, where the niche breadth was highest (Fig. 6.2). However, correlation of overall niche breadth and altitude showed no significant relation.

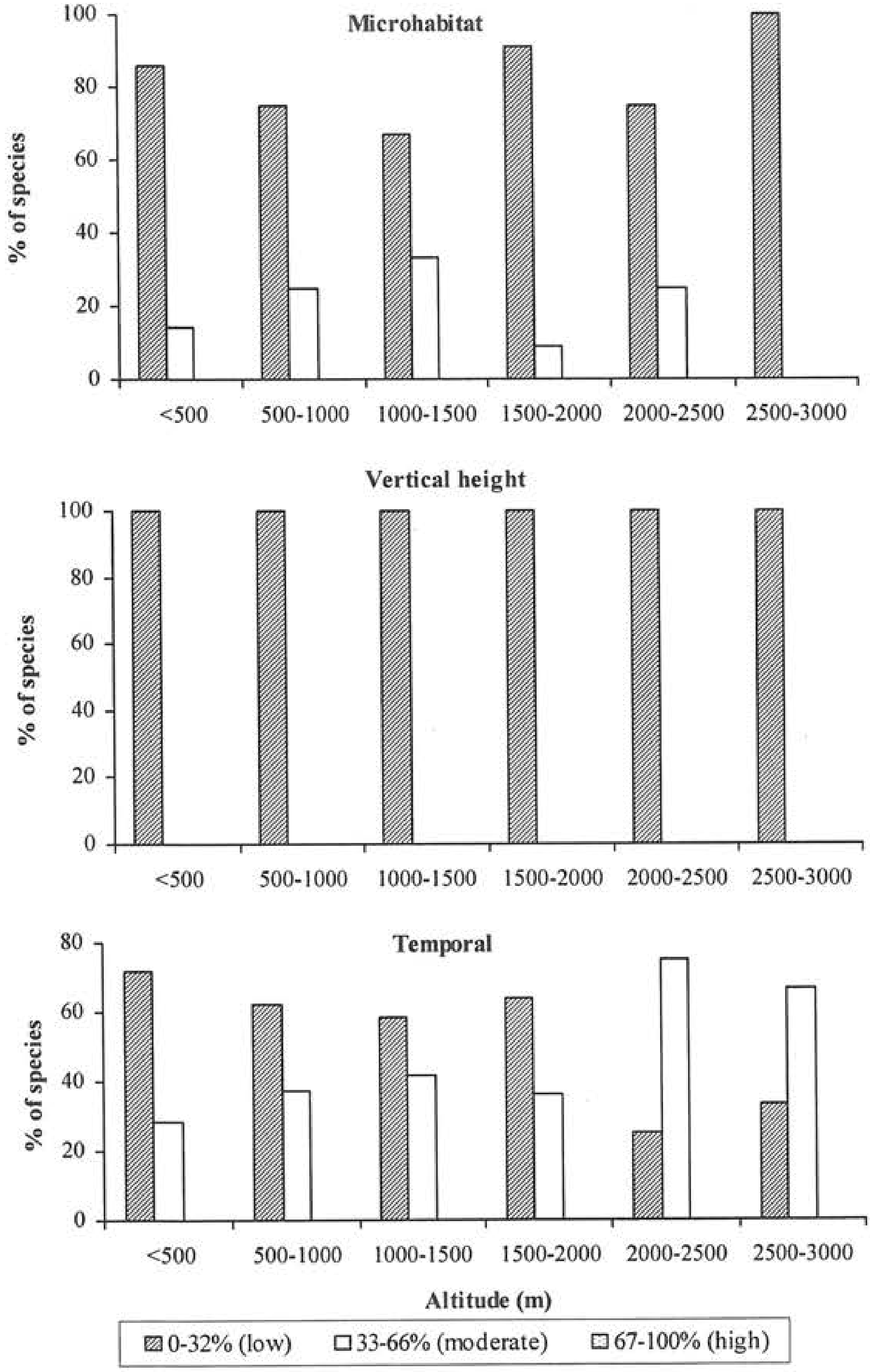


Figure 6.1. Percentage of reptiles representing three-niche breadth category in various resource dimension along the altitude gradients of the Teesta valley.

Table 6.10. Simpson species diversity and mean niche breadth observed along the altitude zones of Teesta valley, Sikkim.

Altitude (m)	Simpson diversity	Microhabitat	Vertical	Temporal	Overall
<500m	6.9	2.66	1.44	3.33	2.48
500-1000 m	4.48	2.83	1.34	3.24	2.47
1000-1500 m	4.68	2.8	1.19	3.07	2.35
1500-2000 m	2.41	2.31	1.14	2.62	2.02
2000-2500 m	1.84	2.44	1.6	3.83	2.62
2500-3000 m	1.98	1.2	1	3.19	1.79

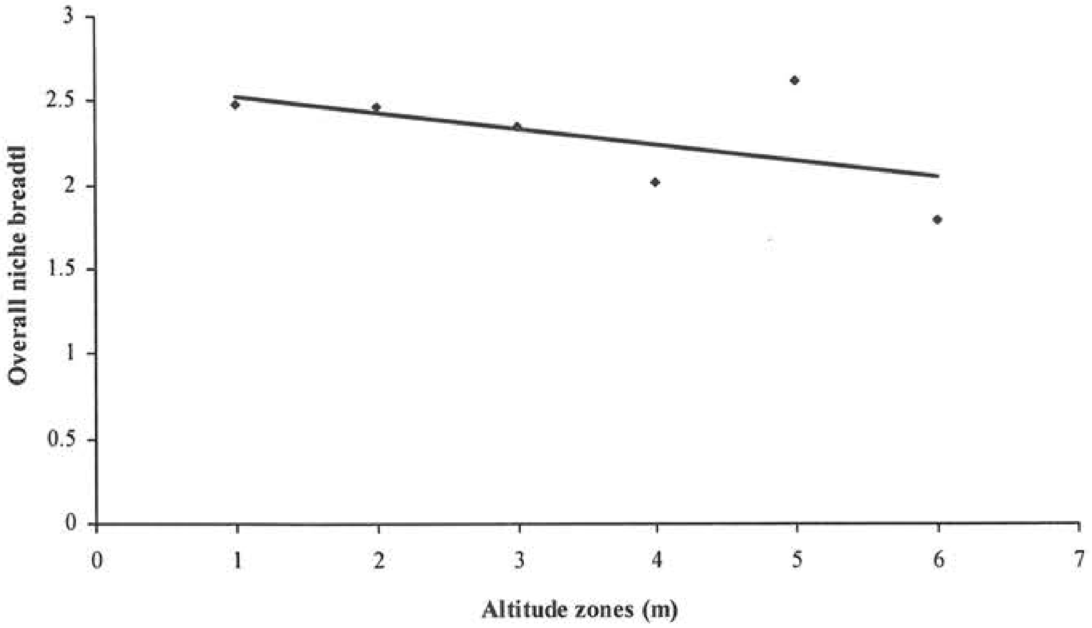


Figure 6. 2. Relation between overall niche breadth of reptiles and altitude along the Teesta valley; 1 (<500 m), 2 (500-1000 m), 3 (1000-1500 m), 4 (1500-2000 m), 5 (2000-2500 m), 6 (2500-3000 m).

Niche Overlap

In microhabitat dimension all species pairs came under high overlap category in the highest altitude zone (2500-3000 m). In other zones, species pairs were distributed in various categories and very few species pairs showed complete overlap (Fig. 6.3). In the two higher zones (2000-2500 m and 2500-3000 m), none of the species pairs belonged to no and complete overlap categories indicating considerable sharing of resources by species in this dimension.

In vertical dimension, number of species pairs showing complete overlap increased with altitude. Above 1000 m, all species pairs belonged to high or complete overlap category and in 2500-3000 m all species pairs showed complete overlap (Fig. 6.3). In 500-1000 m, species pairs belonged to various overlap categories indicating use of considerable vertical strata in this zone.

Temporal dimension showed reverse pattern in comparison with other dimensions i.e. barring 1500-2000 m, no altitude zones had species pairs with complete overlap. In all altitude zones, maximum species pairs belonged to low or moderate overlap category (Fig. 6.3).

In all resource dimensions up to 2000 m, most of the overlap categories were represented indicating various degrees of overlap. Beyond 2000 m, species pairs belonged to higher overlap categories (Fig. 6.3). Number of species belonging to different niche overlap categories in various resource dimensions along the altitude zones is provided in Appendix-V.

Overall niche overlap was maximum in the highest altitude zone (2500-3000 m) and minimum in 500-1000 m (Table 6.11). Correlation of overall niche overlap and Simpson diversity showed no significant relation. However, altitude had positive influence on niche overlap of community (Spearman $r = 0.89$, $P < 0.01$; Fig. 6.4). Among the three resource dimensions, vertical strata use showed highest niche overlap in all the altitude zones.

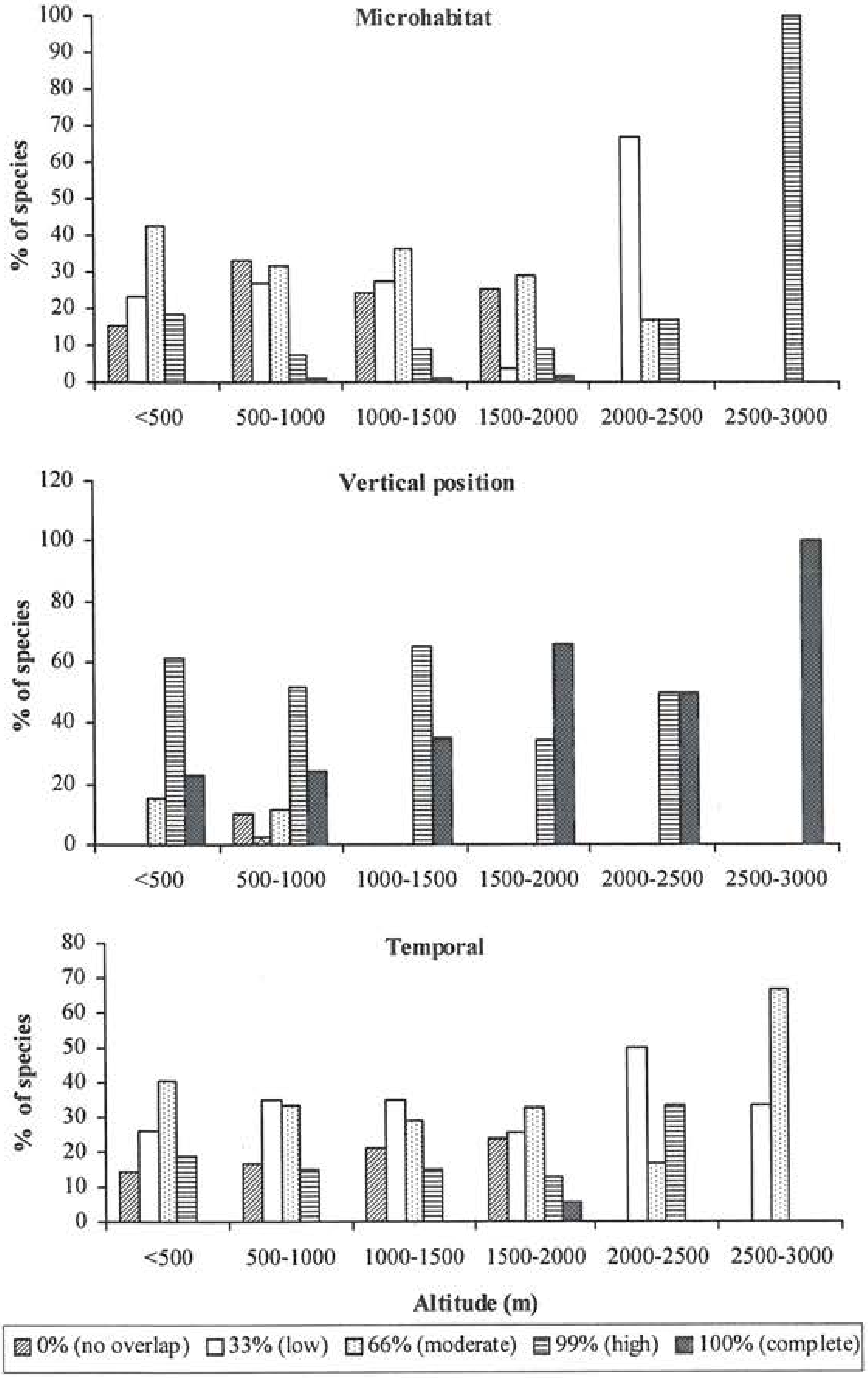


Figure 6.3. Percentage of reptile species occupying five niche overlap categories along the altitude gradients of the Teesta valley.

Table 6.11. Simpson species diversity and niche overlap (three resource dimensions and overall) of reptiles along the altitude zones of the Teesta valley.

Altitude (m)	Simpson diversity	Resource dimension			Overall
		Microhabitat	Vertical	Temporal	
<500	6.9	0.40	0.83	0.39	0.54
500-1000	4.48	0.29	0.78	0.36	0.48
1000-1500	4.68	0.36	0.97	0.32	0.55
1500-2000	2.41	0.29	0.98	0.37	0.55
2000-2500	1.84	0.32	0.88	0.53	0.58
2500-3000	1.98	0.84	1	0.45	0.76

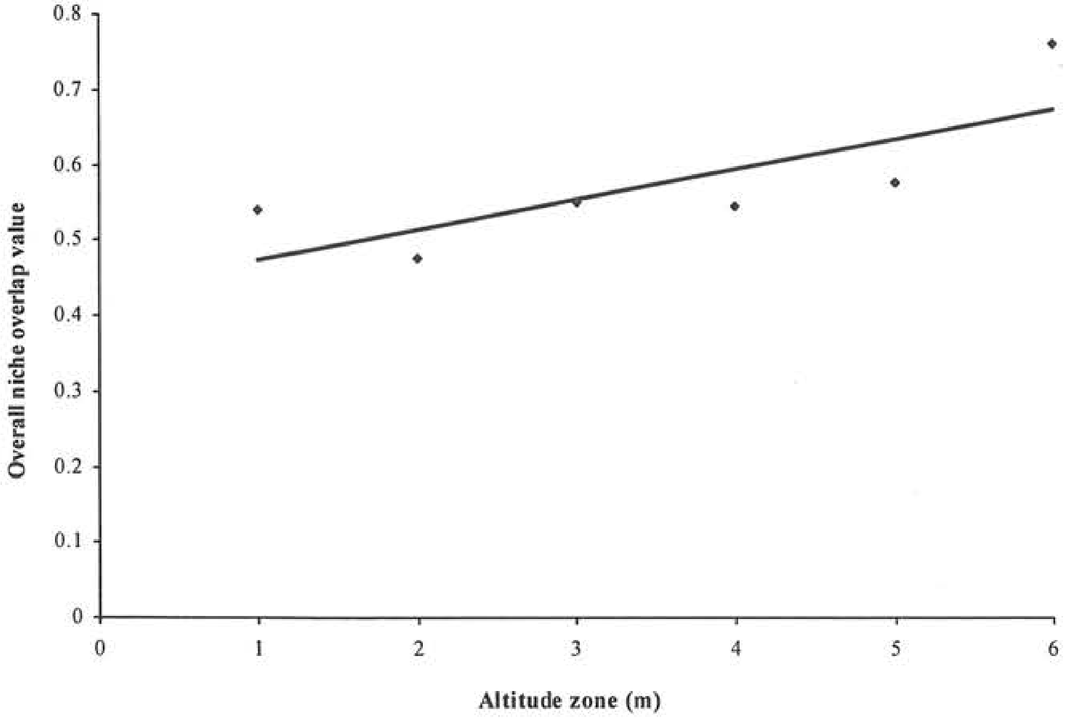


Figure 6. 4. Relation between mean overall niche overlap of reptiles and altitude along the Teesta valley; 1 (<500 m), 2 (500-1000 m), 3 (1000-1500 m), 4 (1500-2000 m), 5 (2000-2500 m), 6 (2500-3000 m).

6.4. DISCUSSION

Understanding the mechanism of species coexistence remains the prime goal of the study in community ecology (Begon *et al*., 1996a). Competition plays an important role in the organization of community structure (Nudds, 1983). Specialization in resource utilization at various dimensions reduces competition and allows the coexistence of numerous species.

Among lizards, overall niche breadth was highest in Agamids and Scincids and lowest in Gekkonids. The present result is in consistent with herpetofaunal study conducted in South India (Brown, 1992b), where members of Agamids, Scincids and Gekkonids showed similar trend. Nixon (2005) also reported highest niche breadth for Agamid *Salea horsfieldii* followed by Scincids *Scincella bilineatum* in Nilgiris. Versatility of Agamids and Scincids in using various habitats and microhabitats is discussed in Chapter 5.

Low niche breadth obtained for Gekkonids was due to their restricted use of one or two specific microhabitats such as boulder. Boulders might provide protective shelter for soft-bodied Gekkonids, in addition to thermoregulation (Weintraub, 1968; Boykin and Zucker, 1993; Pough *et al*., 1998). Castilla and Bauwens (1992) reported that rock crevices or piled stones provide shelter from predators. However, high niche breadth of Gekkonids such *H. frenatus* and *H. bowringii* in vertical dimension was due to their partial arboreal habit. Differential use of vertical strata by adults and juveniles could be one of the reasons for high niche breadth of *H. frenatus*. Similar results were reported for *Hemidactylus prashadi* by Baur and Giri (2006).

Amphiesma platyceps (the most widely distributed snake) in Teesta valley had maximum overall niche breadth among snakes, which is due to its adaptation to diverse resource dimensions (Chapter 5). *Typhlops* sp. showed minimum overall niche breadth due to their restricted use of under ground microhabitat. The subterranean nature of *Typhlops* sp. is reported in various literatures (Smith, 1943; Daniel, 2002; Whitaker and Captain, 2004). The selection of subterranean microhabitats must be due to the suitable microclimate, soft substrate and availability of food such as soft-bodied larvae. Soft substratum may help this species to escape from predators, and perhaps avoid desiccation.

Among four resource dimensions studied, niche breadth was low in vertical strata. The cold condition prevailing in the study area might restricted the cold-blooded reptiles to ground rather than occupying various vertical strata above ground. Vertical strata use of an animal is associated with biotic factors such as prey availability and predation and, abiotic factors such as temperature and moisture regimes (Stewart, 1985). Doan (2004) reported the usage of ground layer by frogs due to cold climate.

With respect to niche breadth, lizards were more generalists compared to snakes. The present study supports the observations of Nixon (2005) and Mukherjee (2007). As lizards are largely generalist arthropod feeders, they can occupy diverse microhabitats as arthropods are found in various microhabitats (Inger and Colwell, 1977). The lower niche breadth in snakes compared to lizards could be due to their specialized food habits feeding on relatively larger prey such as small mammals, birds, lizards and frogs.

About 50% of lizards showed high overlap in habitat dimension. Habitat represents larger geographical area with diverse food resources and microhabitat availability that can support large number of species and allow them to co-exist. As lizards are generalists in feeding habits (Inger and Colwell, 1977) most of the lizards occupy similar habitat showing high overlap. As most lizards of Teesta valley except *Asymblepharus sikimmensis* and *Japalura variegata* were restricted to tropical forests resulting in high overlap in habitat dimension.

At microhabitat dimension most of the lizards showed low overlap. Though lizard species used similar landscape (e.g. habitat/forest type) there is a difference in microhabitat use. Lizards of Teesta valley showed high overlap in vertical dimension (37/45 pairs). This is due to the occupancy of ground layer by most species. It is reported that in colder conditions, reptiles may be restricted to ground layer (Doan *et al.*, 2004). They showed moderate overlap (44.44%) in temporal dimension indicating that they were active together for only some period.

In the present study, high overlap in habitat and vertical position dimension might have compensated by low or absence of complete overlap in microhabitat and temporal dimensions. Lizard community in a Chihuahuan desert of New Mexico showed no overlap temporally, but high overlap spatially (Creusere and Whitford, 1982).

Compared to lizards, snakes showed low overlap in the habitat dimensions indicating dissimilarities in habitat use or specificity to a particular habitat. As snakes partition their resources at trophic level (Brown and Parker, 1982; Toft, 1985), specific prey may be available in specific habitat. Hence, partitioning the food may result in partitioning of habitat, thus resulting in low niche overlap. Species with different types of diet may be more separated by habitat than those with similar diets (Brown, 1992b). Medium and low overlaps in microhabitat dimension by snakes indicate that a few of them partially share, while others are specific to particular microhabitats. In the vertical dimension, all species of snakes belonged to high or complete overlap. This shows that maximum species were utilizing similar vertical strata. Utilization of lower vertical strata or ground with some refuge must be advantageous to escape from predator as well as from unpredictable weather conditions (Stewart, 1985; Moffett, 1993; Doan *et al.*, 2004). About 64.1% snake species showed high overlap in temporal dimension. The required body temperature in snakes is high compared to lizards; all snakes remain active during warm summer months from April to August resulting in high overlap in temporal dimension.

A total of 1035 pairs resulted from species pairing in both spatial and temporal dimensions. In lizards high overlap in habitat and vertical dimension is compensated by low overlap in microhabitat and temporal dimension. Similarly in snakes, high overlap in microhabitat, vertical strata and temporal dimensions is compensated by low overlap in habitat dimensions. High overlap in one dimension is compensated by low overlap in other dimensions thus reducing the competition (Pianka, 1973). However, competitive interactions were assigned as minor importance for limiting species distribution along the altitude gradient (Hofer *et al.*, 2000). Hence, the high overlap in Teesta valley might have resulted due to other factors such as climatic (temperature) or biological (ectothermal property, physiology) factors.

The present study was conducted along the altitude gradient of Teesta valley, where the altitude changes from 300 to 4800 m within a short distance of 85 km (Ali, 1962). Spatial (altitude) gradient representing different vegetation types and climatic condition might play significant role in segregating reptiles along the gradient than other resources. Hofer *et al.* (1999) reported that abiotic factors plays major role for spatial organization of herpetofauna along the altitude gradient unlike endotherms, where biotic factors (competition, predation, prey availability) limit the altitude distribution. Hofer *et al.* (2000, 2004) observed that reptiles partition niche space with respect to physical (altitude) gradient than ecotone and competitive interactions. Hofer *et al.* (2003) found high overlap among three chameleon species of Mount Kupe in microhabitat use and prey type selection, but they were distinctly segregated along the altitude gradient. In the present study, *Hemidactylus garnotii* and *Asymblepharus sikimmensis* had highest overlap in microhabitat dimension, but far separated by altitude, the former species is distributed in lower altitude (<1000 m) and later in higher altitude (>1500 m).

Species with broader niche in one dimension need not always be narrow in other direction (Pianka, 1973). Species such as *Japalura variegata* showed broader niche breadth in all the three resources, whereas *Typhlops* sp. showed narrow niche breadth in all resources dealt here. The unpredictable climatic condition of the study area can make behavioral flexibility profitable occupying broader niches, once the competition severity is unlikely along the altitude gradient. However, the generalist species having broader niche breadth may not reflect wider geographical occupancy (Eterovick and Barros, 2003). This view was augmented by present study showing high niche breadth value by lower altitude reptiles whose range size is smaller (Chapter 4).

Pianka (1973) found positive relation of species diversity with overall niche breadth and negative with overall niche overlap in the study on lizard communities from three deserts. The present study showed highest overall niche breadth in species rich zone and lowest in species poor zone. Similarly, highest overlap was obtained in species poor zone and lowest in species rich zone. However, both niche breadth and overlap did not show significant relation with Simpson species diversity. Niche partitioning may be greater in more diverse communities to reduce competition resulting in low overlap (Pianka, 1973).

Low overlap in species rich zone may be due to 'diffuse competition' (Pianka, 1975). Diffuse competition may be due to high proportions of non-interacting or non-competing pairs of species in a niche axis (Tokeshi, 1999).

Pianka's study was conducted in similar latitude and area with similar climatic conditions. The widely varying climatic conditions of the present study area might not allow significant comparison between species richness and niche breadth which are likely to be affected by climate. Hence, Pianka's study of similar climatic condition and present study with diverse climatic conditions may not be comparable.

MacArthur (1972) explained that niche breadth decreases with decreasing latitude. This hypothesis is tested along the altitude gradient considering altitude as proxy for latitude gradients (Brown, 1988). It is justified that low climatic variation in tropics than temperate areas leads to stable populations, which in turn allow narrow or fixed niche breadth. Narrow niche breadth is considered as explanation for higher species richness in tropics (Vazquez and Stevens, 2004). Accordingly, low altitude of the present study area (<500 m) should have lower average niche breadth compared to higher zones (2500-3000 m), but the data showed reverse pattern, though the relation was not significant.

Overall niche overlap showed significant positive relation with altitude. This may be due to other factors associated with altitude such as climatic condition, vegetation structure, habitat diversity, productivity and reduced microhabitat availability. Species responded to reduce availability of microhabitats associated with streams along the altitude gradients (Inger and Stuebing, 1992). Eterovick and Barros (2003) showed linear relation between microhabitat use and its availability. Reduced availability of microhabitat may lead to reduction of niche breadth along the altitude gradient. However, in the present case, reduced niche breadth and increased overlap in higher altitude might have resulted due to climatic constraints rather than microhabitat availability. Severity of climatic condition in higher altitude might restrict the species to selective microhabitats thus reducing the niche breadth and increasing the overlap.

Low niche breadth and high overlap for most of the reptiles, especially snakes, indicate their specificity in both spatial and temporal dimensions. Snakes were comparatively more specialists than lizards in the Teesta valley. Among three resource dimensions, reptiles of Teesta valley showed low overlap at microhabitat dimension followed by temporal. Overlap at vertical dimension was maximum which is temperature driven as mentioned above. Inger *et al.* (1987) found herpetofaunal distribution along the altitude corresponding to climatic zonation rather than restriction to suitable microhabitats at certain altitudes. Hence it is deemed that the distribution of reptiles of Teesta valley is driven by climatic factors than the availability and restriction of particular resource.

6.5. SUMMARY

- Thirty-eight resource categories were considered for niche analyses, including 26 in spatial (6-habitat, 11-microhabitat, 9-vertical strata) and 12 in temporal dimensions.

- In spatial dimension, more number of species belonged to low niche breadth category compared to moderate category. However, in temporal dimension, maximum number of species belonged to moderate category than lower category. In both spatial as well as temporal category, none of the species belonged to high niche breadth category.

- Among four dimensions, niche breadth was low in vertical strata compared to habitat, microhabitat and temporal dimensions. Both lizards as well as snakes were specialists, as all species obtained less than 50% of average niche breadth, however, snakes were more specialists than lizards in the Teesta valley.

- Among 45 lizard pairs, none of them showed complete overlap in microhabitat and temporal dimensions, whereas three pairs showed complete overlap in macrohabitat and 11 pairs in vertical strata indicating their segregation in microhabitat and temporal dimensions.

- Among 78 combinations of snake species, six pairs in macrohabitat and 45 pairs in vertical strata showed complete overlap, whereas in microhabitat and temporal dimensions none of the snake pair showed complete overlap. None of the snakes belonged to no overlap category in the vertical strata. Similar to lizards, snakes were also segregated in microhabitat and temporal dimensions. Among four resource dimensions, niche overlap was high for vertical strata for both lizards and snakes.

- Three sympatric congeneric geckos (*Hemidactylus garnotii*, *Hemidactylus bowringii*, *Hemidactylus frenatus*) showed high overlap in macrohabitat, but low in microhabitat dimension. However, two sympatric congeneric skink species (*Sphenomorphus maculatus* and *Sphenomorphus indicus*) showed high overlap in all resource dimensions.

- Overall niche breadth was high in species rich zone and low in species poor zone, but the correlation of overall niche breadth and overlap showed no significant relation with species diversity. With respect to altitude, overall niche breadth was high in lower altitude and low in higher altitude and reverse in the case of niche overlap. Overall niche breadth showed no significant correlation with altitude, whereas overlap showed significant positive relation. The present results are in contrary to MacArthur's latitude-niche breadth hypothesis.

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APPENDICES

Appendix I. Checklist of reptiles recorded from Teesta valley, Sikkim and Darjeeling Hills, Eastern Himalayas.

Family	Species	Present study	Sikkim	Darjeeling
Bataguridae	*Melanochelys tricarinata*	-	+	+
	Melanochelys trijuga	-	+	+
Testudinidae	*Indotestudo elongata*	-	+	+
Trionychidae	*Lissemys punctata*	-	+	+
Gekkonidae	*Hemidactylus frenatus*	+	+	+
	Hemidactylus bowringii	+	+	+
	Hemidactylus garnotii	+	+	-
	Cosymbotus platyurus	+	+	+
	Cyrtodactylus khasiensis	+	+	+
	Cyrtodactylus gubernatoris	-	+	+
Agamidae	*Calotes versicolor*	+	+	+
	Calotes jerdoni	+	+	+
	Oriotaris tricarinata	+	+	+
	Japalura variegata	+	+	+
Scincidae	*Sphenomorphus indicus*	+	+	+
	Sphenomorphus maculatus	+	+	+
	Mabuya carinata	-	+	+
	Asymblepharus sikimmensis	+	+	+
Lacertidae	*Takydromus sexlineatus*	+	+	-
Anguidae	*Ophisaurus gracilis*	-	+	+
Varanidae	*Varanus bengalensis*	+	+	+
	Varanus salvator	-	+	+
Typhlopidae	*Typhlops oligolepis*	+	+	+
	Typhlops jerdoni	+	+	+
	Ramphotyphlops braminus	+	+	+
Boidae	*Python molurus*	+	+	+
	Eryx conicus	-	+	+
Colubridae	*Elaphe prasina*	-	+	+
	Coelognathus radiatus	+	+	+
	Orthriophis hodgsonii	-	+	+
	Orthriophis cantoris	+	+	+
	Oreophis porphyraceus	+	+	+
	Orthriophis taeniurus	-	+	+
	Coelognathus helena	-	+	+
	Pareas monticolus	+	+	+
	Pareas macularius	-	+	+
	Elaschistodon westermanni	-	+	+
	Ptyas mucosa	-	+	+
	Ptyas korros	+	+	+
	Ptyas nigromarginata	+	+	+
	Argyrogena fasciolata	-	+	+
	Liopeltis stoliczkae	-	+	+
	Liopeltis rappii	-	+	+
	Oligodon albocinctus	+	+	+
	Oligodon erythrogaster	-	+	+
	Oligodon melaneus	-	+	+
	Oligodon cyclurus	-	-	+
	Oligodon juglandifer	+	+	+

Family	Species	Present study	Sikkim	Darjeeling
	Dendrelaphis tristis	+	+	+
	Dendrelaphis pictus	-	+	+
	Dendrelaphis cyanochloris	-	+	+
	Dendrelaphis gorei	-	+	+
	Chrysopelea ornate	-	+	+
	Lycodon jara	-	+	+
	Lycodon aulicus	+	+	-
	Lycodon fasciatus	+	+	-
	Dinodon gammiei	-	+	+
	Dinodon septentrionalis	-	+	+
	Xenochrophis piscator	-	+	+
	Xenochrophis sanctijohannis	+	+	+
	Sibynophis collaris	+	+	+
	Amphiesma parallelum	-	+	+
	Amphiesma stolatum	-	+	+
	Amphiesma platyceps	+	+	+
	Rhabdophis subminiatus	+	+	+
	Rhabdophis himalayanus	+	+	+
	Pseudoxenodon macrops	-	+	+
	Trachischium fuscum	-	+	+
	Trachischium guentheri	+	+	+
	Trachischium tenuiceps	-	+	+
	Boiga trigonata	-	+	-
	Boiga ochraceus	-	+	+
	Boiga gokool	-	+	+
	Boiga cyanea	-	-	+
	Boiga multifasciata	+	+	+
	Boiga ocellata	-	+	+
	Boiga forsteni	-	+	+
	Psammodynastes pulverulentus	-	+	+
	Ahaetulla prasina	-	+	+
	Ahaetulla fronticincta	-	+	+
Elapidae	*Ophiophagus hannah*	+	+	+
	Naja kaouthia	+	+	+
	Bungarus fasciatus	-	+	+
	Bungarus bungaroides	+	+	+
	Bungarus lividus	-	+	+
	Bungarus niger	+	+	+
	Bungarus caeruleus	-	+	-
	Sinomicrurus macclellandi	-	+	+
Viperidae	*Daboia russelii*	-	+	+
	Gloydius himalayanus	-	+	-
	Trimeresurus gramineus	-	+	-
	Ovophis monticola	+	+	+
	Protobothrops jerdonii	-	+	-
	Trimeresurus popeiorum	-	+	+
	Trimeresurus erythrurus	-	+	+
	Trimeresurus albolabris	-	+	+
	Trimeresurus gumprechti	-	+	+
	Trimeresurus sp.	+	+	-
	Total number of species	42	96	88

Source: Present study (2003-2006) denotes observations along the Teesta valley; Gammie (1928); Smith (1931, 1935, 1943); Waltner (1973); Ganguli-Lachungpa (1998); Shaw *et. al.* (1999); Jha and Thapa (2002); +, recorded; –, not recorded.

Appendix II. Snout- vent length of lizard species observed in Teesta valley.

Sl. no.	Species	Sample size	Snout vent length (mm)		
			Minimum	Maximum	Mean
1	*Hemidactylus bowringii*	4	45	52	48
2	*Hemidactylus frenatus*	6	40	52	45
3	*Hemidactylus garnotii*	3	21	60	46
4	*Cosymbotus platyurus*	1	...	50	...
5	*Cyrtodactylus khasiensis*	3	60	67	64
6	*Japalura variegate*	125	33	123	91
7	*Oriotaris tricarinata*	1	...	50	...
8	*Calotes jerdoni*	...	...	...	...
9	*Calotes versicolor*	47	40	103	79
10	*Sphenomorphus maculatus*	26	30	68	52
11	*Sphenomorphus indicus*	7	45	93	67
12	*Asymblepharus sikimmensis*	83	11	57	43
13	*Takydromus sexlineatus*	7	45	60	50
14	*Varanus bengalensis*	...	...	...	...

Appendix III. Snout vent length of snake species observed in Teesta valley.

Sl. no	Species	Sample size	Snout vent length (mm)		
			Minimum	Maximum	Mean
1	*Typhlops* spp.	35	76	155	118
2	*Python molurus*	1	...	2880	...
3	*Pareas monticolus*	4	312	464	403
4	*Coelognathus radiatus*	2	482	1680	1081
5	*Orthriophis cantoris*	3	710	1180	904
6	*Oreophis porphyraceus*	2	268	480	374
7	*Ptyas korros*	9	472	1518	1097
8	*Ptyas nigromarginata*	3	1016	1740	1328
9	*Oligodon albocinctus*	1	...	821	...
10	*Oligodon juglandifer*	12	240	805	665
11	*Dendrelaphis pictus*	1	...	820	...
12	*Lycodon aulicus*	7	293	562	488
13	*Lycodon fasciatus*	4	67	700	494
14	*Sibynophis collaris*	4	388	565	462
15	*Xenochrophis* sp.	14	175	820	555
16	*Rhabdophis himalayanus*	5	322	660	549
17	*Rhabdophis subminiatus*	1	...	630	
18	*Amphiesma platyceps*	33	137	950	525
19	*Trachischium guentheri*	360	88	445	275
20	*Boiga multifasciata*	3	398	820	676
21	*Bungarus bungaroides*	1	...	1121	...
22	*Bungarus niger*	2	1013	1313	1163
23	*Naja kaouthia*	4	342	1400	806
24	*Ophiophagus hannah*	1	...	2400	...
25	*Ovophis monticola*	32	174	712	447
26	*Protobothrops* sp.	28	325	1240	997

Appendix IV. Factor loadings (Principal Component Analysis) of habitat variables of reptiles in various altitude categories of Teesta valley.

Habitat variable	PC I	PC II	PC III
<500 m			
Tree number	0.73	0.16	0.02
Shrub number	0.20	0.02	0.73
Herb cover (%)	-0.30	0.76	0.08
Soil cover (%)	0.04	0.41	-0.42
Litter cover (%)	0.74	0.03	0.34
Other cover (gravel, stone, moss %)	-0.32	-0.83	-0.11
Number of boulders	-0.26	-0.68	0.11
Canopy cover (%)	0.79	-0.08	-0.09
Slope	0.56	0.23	-0.09
Log	-0.16	0.07	0.60
Distance to water	0.11	0.51	0.01
Eigen value	2.87	1.78	1.21
Variance explained (%)	26.11	16.15	11.00
Cumulative variance (%)	26.11	42.26	53.27
500-1000 m			
Tree number	0.51	0.29	0.38
Shrub number	-0.03	0.71	-0.04
Herb cover	0.80	-0.42	0.10
Soil cover	0.19	0.10	-0.67
Litter cover	0.16	0.71	0.02
Other cover (gravel, stone, moss)	-0.90	0.02	0.20
Number of boulders	-0.71	-0.18	0.23
Canopy cover	0.37	0.36	0.57
Slope	0.61	0.25	0.16
Log	-0.02	-0.04	-0.31
Distance to water	0.07	0.29	-0.48
Eigen value	2.91	1.51	1.37
Variance explained (%)	26.42	13.76	12.47
Cumulative variance (%)	26.42	40.18	52.65
1000-1500 m			
Tree number	-0.13	0.61	0.23
Shrub number	0.21	0.43	-0.44
Herb cover	-0.82	0.01	0.08
Soil cover	-0.10	-0.54	-0.00
Litter cover	-0.14	0.62	-0.17
Other cover (gravel, stone, moss)	0.93	-0.07	0.02
Number of boulders	0.75	-0.17	0.05
Canopy cover	-0.23	0.71	0.02
Slope	-0.04	0.15	0.63
Log	-0.09	0.03	-0.53
Distance to water	-0.02	-0.03	0.64
Eigen value	2.49	1.65	1.31
Variance explained (%)	22.72	14.98	11.87
Cumulative variance (%)	22.72	37.70	49.57
1500-2000 m			
Tree number	-0.33	0.38	0.14
Shrub number	0.08	0.13	-0.83
Herb cover	-0.95	-0.03	-0.04
Soil cover	0.53	-0.04	-0.12
Litter cover	0.02	0.85	-0.13
Other cover (gravel, stone, moss)	0.72	-0.38	0.18
Number of boulders	0.44	-0.33	0.39
Canopy cover	-0.13	0.74	0.08

Slope	0.01	0.24	0.71
Distance to water	-0.31	0.35	0.04
Eigen value	2.75	1.41	1.29
Variance explained (%)	27.49	14.15	12.88
Cumulative variance (%)	27.49	41.63	54.52
2000-2500 m			
Tree number	-0.00	0.41	0.67
Shrub number	0.00	0.76	0.13
Herb cover	-0.85	-0.21	-0.22
Soil cover	0.22	0.53	-0.55
Litter cover	0.35	0.11	0.64
Other cover (gravel, stone, moss)	0.79	-0.04	0.13
Number of boulders	0.72	-0.29	0.19
Canopy cover	-0.12	0.61	0.11
Slope	0.66	0.19	-0.23
Log	-0.69	0.20	0.03
Distance to water	0.57	0.00	0.02
Eigen value	3.36	1.69	1.22
Variance explained (%)	30.58	15.39	11.12
Cumulative variance (%)	30.58	45.97	57.08
2500-3000 m			
Tree number	0.06	0.75	0.04
Shrub number	0.49	-0.07	-0.39
Herb cover	0.80	0.35	-0.09
Soil cover	0.22	0.08	0.77
Litter cover	-0.05	0.04	0.28
Other cover (gravel, stone, moss)	-0.78	-0.37	-0.25
Number of boulders	-0.80	0.08	0.01
Canopy cover	0.09	0.80	0.25
Slope	0.49	-0.37	0.21
Log	-0.05	0.21	0.50
Distance to water	0.08	-0.26	0.65
Eigen value	2.71	1.70	1.46
Variance explained (%)	24.62	15.49	13.25
Cumulative variance (%)	24.62	40.11	53.36

Appendix V. Number of species in different niche breadth categories in three resource dimensions along the altitude zones of Teesta valley.

Altitude (m)	Niche breadth categories		
Microhabitat	**0-3.6**	**3.7-7.3**	**7.4-11**
<500	12	2	0
500-1000	12	4	0
1000-1500	8	4	0
1500-2000	10	1	0
2000-2500	3	1	0
2500-3000	3	0	0
Vertical position	**0-2.9**	**3-5.9**	**6-9**
<500	14	0	0
500-1000	16	0	0
1000-1500	12	0	0
1500-2000	11	0	0
2000-2500	4	0	0
2500-3000	3	0	0
Temporal	**0-3.9**	**4-7.9**	**8-12**
<500	10	4	0
500-1000	10	6	0
1000-1500	7	5	0
1500-2000	7	4	0
2000-2500	1	3	0
2500-3000	1	2	0

Appendix VI. Number of species in different niche overlap categories in three resource dimensions along the altitude zones Teesta valley.

Altitude (m)	Niche overlap categories					
Microhabitat	**0**	**0.01-0.33**	**0.34-0.66**	**0.67-0.99**	**1**	**Total pairs**
<500	14	21	39	17	0	91
500-1000	40	32	38	9	1	120
1000-1500	16	18	20	11	1	66
1500-2000	14	19	16	5	1	55
2000-2500	0	4	1	1	0	6
2500-3000	0	0	0	3	0	3
Vertical position						
<500	0	0	14	56	21	91
500-1000	12	3	14	62	29	120
1000-1500	0	0	0	43	23	66
1500-2000	0	0	0	19	36	55
2000-2500	0	0	0	3	3	6
2500-3000	0	0	0	0	3	3
Temporal						
<500	13	24	37	17	0	91
500-1000	20	42	40	18	0	120
000-1500	14	23	19	10	0	66
00-2000	13	14	18	7	3	55
00-2500	0	3	1	2	0	6
2500-3000	0	1	2	0	0	3