Bird Communities and their Distribution Pattern along the Elevation Gradient of Teesta Valley, Sikkim

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by
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CERTIFICATE

This is to certify that the thesis, entitled "***Bird communities and their distribution pattern along the elevation gradient of Teesta valley, Sikkim***" submitted to the Bharathiar University, Coimbatore, in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in Zoology, is a record of original research work done by ***Mr. Bhoj Kumar Acharya*** during the period June 2003 to February 2008 of his research in the Department of Zoology at Sálim Ali Centre for Ornithology and Natural History under my supervision and guidance and the thesis has not formed the basis for the award of any Degree /Diploma /Associateship /Fellowship or other similar title of any candidate of any University.

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DECLARATION

I, *Bhoj Kumar Acharya* hereby declare that the thesis, entitled "***Bird communities and their distribution pattern along the elevation gradient of Teesta valley, Sikkim***" submitted to the Bharathiar University, Coimbatore, in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in Zoology is a record of original and independent research work done by me during June 2003 to February 2008 under the supervision and guidance of ***Dr. Lalitha Vijayan, Department of Zoology*** at Sálim Ali Centre for Ornithology and Natural History and it has not formed the basis for the award of any Degree/Diploma/Associateship/Fellowship or other similar title to any candidate of any University.

Bhoj Kumar Acharya
Signature of the candidate

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I am highly privileged to glimpse into the vast biogeographical mystery of The Himalaya – my Home land, the abode of Almighty, holding torrent streams, cladescent snow-clad peaks, tranquil lakes and virgin forests ...

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CHAPTER 1

INTRODUCTION

1.1. GENERAL

Exploration and recognition of repeated patterns are considered central themes in any scientific study (MacArthur, 1972). Once a pattern is established, it inevitably leads to several questions as to what are the causes responsible for the same. Spatial and temporal patterns of species richness are the inherent properties of ecological communities (Tokeshi, 1999; Begon *et al.*, 2006). The best-known spatial pattern is the latitudinal gradient in species richness, which states that richness peaks at tropics and declines towards the poles (Rosenzweig, 1992, 1995). According to Stevens (1992), species richness pattern along the elevation gradients mirror latitudinal patterns, and hence species richness is considered to follow monotonic decline from lower to higher elevation (Terborgh, 1971, 1977; Terborgh and Weske, 1975; Begon *et al.*, 2006). However, three general patterns, (i) a monotonic decline of species richness with increasing elevation, (ii) a hump-shaped pattern with peak at intermediate elevation, and (iii) increase in species richness with increase in elevation, have been recognized in recent years. Among these, the mid-elevation peak in species richness is reported as the most common pattern (Rahbek, 1995, 2005).

Studies on the structure of bird communities have gained considerable attention over the past five decades (MacArthur and MacArthur, 1961; Cody, 1974; Wiens, 1989) and have formed the basis for development of many fundamental principles and theories in community ecology (Perrins and Birkhead, 1983; Odum, 1996; Begon *et al.*, 2006). Several other studies are continued in various parts of the globe (Terborgh *et al.*, 1990; Thiollay, 1994; Willson and Comet, 1996a, b; Robinson *et al.*, 2000; Latta *et al.*, 2003; Blake, 2007). However, information on bird communities along an elevation gradient is scanty. Understanding the distribution, diversity and structure of bird community along the elevation gradient is crucial to delineate the importance of regional or local landscapes for avian conservation (Kattan and Franco, 2004; Raman *et al.*, 2005).

Sikkim (27° 03' to 28° 07' N and 88° 03' to 88° 57' E), a state of India with a total geographical area of 7096 km^2, is a part of Eastern Himalaya biodiversity hotspot and Endemic Bird Area (Stattersfield *et al.*, 1998; Islam and Rahmani, 2004; Mittermeier *et al.*, 2005). It is surrounded by high mountain ranges on west, east and north giving the state a horse-shoe shape (Gammie, 1928). The Teesta river is one of the major physical features of Sikkim, and flows in a north-south direction bisecting the entire state. The Teesta valley encompasses wide variation in elevation (300 to 5500 m), climate (tropical to temperate) and vegetation types (tropical forest to alpine meadows) within a distance of around 100 km. The diversity of flora and fauna with high species turnover is best represented along the elevation gradient of the Teesta valley making it an ideal site for the study of distribution pattern.

Species richness, diversity, abundance and community composition of plants vary over space and time (Sukumar *et al.*, 1992; Begon *et al.*, 2006). Understanding the diversity and distribution pattern of animals remains incomplete without the knowledge of forest structure (Wilson and Comet, 1996a, b; Cody, 2001; Matlock and Edwards, 2006). Hence, biodiversity conservation should primarily focus on understanding forest characteristics and plant distribution patterns (Vetaas and Grytnes, 2002; Grytnes, 2003b).

Biotic community refers to the assemblage of organisms living together in a prescribed area or habitat (Odum, 1996). Despite criticisms on the generality of community ecology theories (Lawton, 1999), ecological studies of local communities are very effective in understanding environmental problems and are crucial in planning area-based conservation management (Simberloff, 2004). The properties of communities such as species richness, diversity, relative abundance and guild structure emerge as a result of interaction among members of the community as well as with environment (Pianka, 2000). Such kinds of interactions result in spatial and temporal variations of community organization across habitats and regions (Karr, 1976a, b; Johnsingh and Joshua, 1994; Blake, 2007). Birds are among the highly diverse group of vertebrates and so are their communities (Gill, 1995). Local ecological factors play crucial role in determining avian diversity and abundance of a particular area (Willson and Comet, 1996a, b; Matlock and Edwards, 2006).

Reproduction is the most vital function of living organisms. Nesting is a critical stage of reproduction in birds (Martin, 1995). Nesting data give information on the ability of a species to utilize resources in that habitat (Lindell and Smith, 2003). Hence, nesting site is an important indicator of the specific habitat or ecological niche of birds. A number of biotic and abiotic factors are responsible for nest-site selection and attaining reproductive success in birds (Burke and Nol, 1998; Stephens *et al.*, 2003; Smith *et al.*, 2007). Identifying crucial factors involved in nest-site selection is essential for implementing conservation measures for bird and its habitat (Pandey and Mohan, 1993; Hoover and Brittingham, 1998; Gokula and Vijayan, 2001).

Understanding the relationship between species richness and elevational gradient is necessary as it would provide insights into the observed patterns and processes responsible for the relationship (Kattan and Franco, 2004), which aids in the biodiversity conservation (Graham, 1990; Stevens, 1992; Hunter and Yonzon, 1993; Sánchez-Cordero, 2001; Vetaas and Grytnes, 2002; Raman *et al.*, 2005). Though many studies across diverse taxa are carried out along the elevation gradient, generalized pattern has not emerged yet (Brown, 2001; Lomolino, 2001).

The distribution of biota along elevation gradients varies due to various ecological, biological and historical factors (Rosenzweig, 1995; Brown, 2001; Heaney, 2001; Lomolino, 2001; Grytnes and McCain, 2007). Recently, spatial constraints on species ranges have been considered as one of the important factors (Colwell and Hurtt, 1994; Colwell and Lees, 2000; McCain, 2003, 2004; Colwell *et al.*, 2004) and null model of mid-domain effect has been proposed to explain the observed pattern (Colwell and Hurtt, 1994; McCain, 2004). The model states that geographic hard boundaries such as ocean and mountaintop constrain the species distribution on either end of elevation gradient resulting in mid-elevation peak in species richness.

The species similarity or turnover along elevation is the consequence of vegetation types and climatic conditions (Terborgh, 1977; Terborgh and Weske, 1975; Rahbek, 1995, 1997; McCain, 2007a, b). The rate of turnover either increases with elevation (Rahbek, 1997) or corresponds with the vegetation zones where transition of species occurs (Patterson *et al.*, 1996; Raman *et al.*, 2005). Spatial turnover of species is important for understanding species composition and regional biodiversity (Gaston, 1996; Harte *et al.*, 1999; Condit *et al.*, 2002). Elevational range size varies among species and depends on various factors such as habitat availability, dispersal and establishment abilities, competition, predation, local abundance, and climate (Gaston, 1996; McCain, 2006).

The immediate environment in which the animal lives plays a major role in its distribution and survival (Freifeld, 1999; Kristan, 2007). Any alteration to the habitat will directly affect diversity and community structure of animals (Baillie, 1991; Pardini, 2004; O'Dea and Whittaker, 2007). The positive relation between habitat characteristics and bird species diversity has been demonstrated by many studies (Wiens, 1989; Wilson and Comet, 1996a, b; Raman *et al.*, 1998; Cody, 2001; Matlock and Edwards, 2006; Vijayan and Gokula, 2006). Habitat segregation through vertical distribution is important for maintaining bird species diversity (Pearson, 1971; Roth, 1976; Vijayan *et al.*, 1998a). Use of different vertical strata may reduce competition among co-existing species by partitioning available resources (Gutzwiller *et al.*, 1998; Vieira and Monteiro-Filho, 2003; Sushma and Singh, 2006). An assesment of the association of birds with habitat can have significant implications for assigning conservation priorities and management (Gillespie and Walter, 2001; Jayson and Mathew, 2003; Johnson, 2007).

1.2. PAST STUDIES

Several reviews of the vast literature on ecology of bird communities are available (Cody, 1974; Perrins and Birkhead, 1983; Wiens, 1989; Keast, 1990; Morrison *et al.*, 1990). Since, major objective of the present study is to examine distribution patterns of bird communities along an elevation gradient, this review is restricted to species richness pattern and community structure along an elevation gradient. A brief account on the bird community studies in India is also provided.

Investigations of general pattern and search for a common cause of species richness along geographical gradients have engaged ecologists and biogeographers for the past few decades. Among the spatial pattern, latitudinal gradient in species richness is the most consistent and relatively well studied (Rosenzweig, 1995; Tokeshi, 1999; Rahbek and Graves, 2001; Begon *et al.*, 2006; Ding *et al.*, 2006). The elevation gradients in species richness have been described as analogous to latitudinal gradient (Stevens, 1992). Despite recent advances, controversy exists regarding the general relationship between species richness and elevation, or framing universal explanation and model formulation (Colwell and Hurtt, 1994; Rahbek, 1995, 1997, 2005; Heaney, 2001).

Several studies on species richness pattern along an elevation gradient have been undertaken in recent years. Most of the studies were focused on small mammals (Heaney *et al.*, 1989; Graham, 1990; Rickart *et al.*, 1991; Yu, 1994; Patterson *et al.*, 1996, 1998; Shepherd and Kelt, 1999; Heaney, 2001; Md Nor, 2001; Rickart, 2001; Sánchez-Cordero, 2001; Li *et al.*, 2003; McCain, 2003, 2004, 2005, 2006, 2007a, b) and plants (Beals, 1969; Bhandari *et al.*, 1997; Kessler *et al.*, 2001; Grytnes and Vetaas, 2002; Vetaas and Grytnes, 2002; Bhattarai and Vetaas, 2003, 2006; Grytnes, 2003b; Bhattarai *et al.*, 2004; Carpenter, 2005; Sánchez-González and López-Mata, 2005; Oommen and Shanker, 2005; Yu and Saprunoff, 2005; Cardelus *et al.*, 2006; Grytnes *et al.*, 2006; Kluge *et al.*, 2006; Grau *et al.*, 2007). A few studies have also been conducted in herpetofauna (Scott, 1976; Hofer *et al.*, 1999; Vasudevan *et al.*, 2006; Fu *et al.*, 2007; Naniwadekar and Vasudevan, 2007) and invertebrates (McCoy, 1990; Sfenthourakis, 1992; Olson, 1994; Samson *et al.*, 1997; Sanders, 2002; Sanders *et al.*, 2003).

1.2.1. Bird communities along an elevation gradient

Terborgh (1971) and Terborgh and Weske (1975) observed monotonic decline of bird species richness with increasing elevation on an Andean elevation gradient. Competition was the major determinant of distribution pattern, whereas ecotone and factors varying in parallel with elevation also had significant role. Terborgh (1977) continued his study on the same mountain and observed shift from monotonic decline in species richness to hump-shaped pattern when sampling methods and efforts were standardized. The author tested the universality of pattern in avian subgroups of different diet categories and found 5.2 and 2.3 fold decrease respectively in the insectivores and frugivores richness from bottom to the top of the gradient, whereas no change was observed in nectarivore population. The role of competition in elevational distribution and habitat selection on birds was supported by Noon (1981) in the study on ground foraging insectivorous birds (genus *Catharus*) of Mount Mansfield. Schluter (1982) found variation in food supply as more important determinant than competition for the elevational distribution of ground finches in the Galapagos.

Graham (1990) compared distribution of birds and bats along an elevation gradient of Peru and found decline in species richness with elevation in both the faunal groups. The decline was more rapid in bats than in birds. Similarly, Patterson *et al.* (1998) conducted comparative study on bats, mice and birds in the Andes of southeastern Peru. Species richness declined in birds and bats but no distinct pattern was observed in mice along the elevation. Loiselle and Blake (1991) simultaneously monitored changes in bird populations and fruit abundance along an elevation gradient in Costa Rica and concluded that bird abundance as well as community composition varied with resource availability.

Navarro (1992) documented the elevational pattern in birds of Sierra Madre Del Sur, Mexico and observed a monotonic decline of resident bird species with elevation. The study concluded that zonation of vegetation is responsible for structuring avian community composition along an elevation gradient. Thiollay (1996) studied distribution patterns of raptors along three mountains in the northwestern South America. The overall species richness and abundance of raptors steeply declined with elevation in all the three mountains.

Rahbek (1997) analyzed South American tropical land birds to examine four graphic models for species richness and elevation: monotonic decline, mid-elevation peak, Rapoport's rule and null models. Species declined monotonically when effect of area was ignored but changed into hump-shaped relationship when area was considered. Hump-shaped pattern emerged due to geometric constraints imposed by hard boundaries of the elevation gradient. Hawkins (1999) in a study on Malagasy forest bird communities found relatively constant species richness up to 1300 m but strong decline above this elevation. The distribution of birds was in accordance with major vegetation types in the Malagasy. Similar results were reported from Costa Rica with constant richness of birds from 50 to 1000 m elevation and significant decline thereafter (Blake and Loiselle, 2000).

Species richness of nectarivorous birds in two different locations (Sailapata and Cocapata) in the Bolivian Andes showed different patterns: maximum richness at higher elevation in Saila Pata and mid-elevation peak at Cocapata, whereas total birds, insectivores and frugivores followed unimodal hump-shaped pattern in both the locations (Kessler *et al.*, 2001). Ecological requirements of various taxonomic group determined distribution pattern of species along an elevation gradient in the Bolivian Andes. Kessler *et al.* (2001) observed the shift of species richness towards higher elevation in dry areas as compared to wet regions within the same geographical locations. The shift in bird species richness was concomitant with an upward shift of vegetation zones in the drier parts. Poulsen and Lambert (2000) also observed striking difference between the elevational distribution of resident forest birds on two islands in Indonesia. Size of forest was the major determinant of bird species distribution pattern in their study.

Latta *et al.* (2003) quantified avian diversity in four habitats along an elevation gradient in Hispaniola. Species richness and diversity were the highest in mid-elevation dry forest and pine forest but abundance was the highest in low elevation desert thorn scrub. Kattan and Franco (2004) reported a monotonic decline in bird species richness with elevation in the slopes that spanned over complete elevation gradients from lowlands to mountain peaks in Columbian Andes. In contrast, a mid-elevation peak was obtained in slopes where the lower part of the elevation gradient was truncated. Most of the variation in diversity was determined by area of the elevational transects. The authors also observed contrasting patterns between widely distributed and range restricted birds; the former declined with elevation, whereas the latter showed high richness at mid-elevation.

A few reports on elevational pattern of birds of Asian region have become available recently, mostly from Taiwan. Shiu and Lee (2003) compiled existing dataset on birds of Taiwan and explored the seasonal variation in species richness and community composition along an elevation gradient. The study found that elevational patterns vary among seasons. Lee *et al.* (2004) observed a hump-shaped relationship between bird species richness and elevation. Bird species richness increased with primary productivity (surrogated by normalized difference vegetation index [NDVI]) and decreased with urbanization (surrogated by road density and built up area). Ding *et al.* (2005) examined the pattern of distribution of breeding birds in Taiwan and found energy availability as the primary factor influencing bird species richness along the elevation gradient. Koh *et al.* (2006) found weak support for mid-domain effect on species elevational ranges and concluded that combinations of several factors are responsible for the distribution pattern.

Manel *et al.* (2000) evaluated the effects of land use on 17 species of river birds along an elevation gradient Nepal and found that river bird occurrence was explained by elevation and habitat structure. Raman *et al.* (2005) studied bird community structure along an elevation gradient in the Western Ghats, India. Bird species richness did not show significant variation along the elevation but community composition did. The authors argued that constancy in species richness is due to lack of elevational trend in vegetation structure.

With a few exceptions, the studies referred to above are restricted to either low, mid or high elevation covering only part of the gradient or on a smaller mountain with narrow elevational width. The data spanning the entire gradient, as that of Himalaya, covering wide elevation is necessary to figure out the variation of species richness with elevation (Rahbek, 1995; Carpenter, 2005). Körner (1999, 2000) and Heaney (2001) stressed the importance of Himalaya for the study of elevational pattern of species richness. Manel *et al.* (2000) documented elevational pattern of a few species of river birds in Nepal. Elevational pattern of flora was studied in central Himalaya in Nepal (Grytnes and Vetaas, 2002; Vetaas and Grytnes, 2002; Bhattarai and Vetaas, 2003, 2006; Bhattarai *et al.*, 2004; Carpenter, 2005; Grau *et al.*, 2007) and Western and Eastern Himalaya in India (Bhandari *et al.*, 1997; Oommen and Shanker, 2005; Behera and Kushwaha, 2007). Studies on elevational pattern of plants (Yu and Saprunoff, 2005), reptiles (Fu *et al.*, 2007) and mammals (Li *et al.*, 2003) are also available from different mountains in China.

1.2.2. Studies in India

Systematic studies on birds of Indian sub-continent dates back to the 19th century and most of these studies were concerning taxonomy, distribution and natural history (Jerdon, 1982; Ali and Ripley, 2001). However, ecological information at community level is scanty (Daniels *et al.*, 1990, 1992; Bhupathy, 1991; Sundaramoorthy, 1991; Johnsingh and Joshua, 1994; Pramod, 1995; Pramod *et al.*, 1997; Gokula, 1998; Vijayan *et al* 1998a; Raman, 2001; Jayson and Mathew, 2000, 2002; Nirmala, 2002; Vijayan and Gokula, 2006; Gokula and Vijayan, 2007) and most of these studies were restricted to the Western Ghats in South India. A few literatures on bird communities are available from the Himalayan region in India (Khan *et al.*, 1993; Javed, 1996; Safiq *et al.*, 1997; Raman *et al.*, 1998; Sultana and Khan, 1999; Chettri *et al.*, 2001, 2005; Price *et al.*, 2003; Sultana *et al.*, 2007).

Eastern Himalaya is probably the most diverse and least studied region of India (Crosby, 1996; Islam and Rahmani, 2004). Sikkim forms a part of Eastern Himalaya endemic bird area and global biodiversity hotspot (Stattersfield *et al.*, 1998; Myers *et al.*, 2000; Islam and Rahmani, 2004; Mittermeier *et al.*, 2005). Due to the location, topography, elevational variation and marked zonation of vegetation, Sikkim harbors high avifaunal diversity compared to its small geographical area.

Despite this high diversity, there is a severe dearth of information on birds of Sikkim. Most of the past studies were based on surveys that focused mostly on taxonomy and systematics. Ali (1962) extensively reviewed the past studies substantiated by field surveys and provided a comprehensive list of species distributed in Sikkim. The basic information on ecology of some species is also provided. He has given a list of 98 species separately, which was reported to occur long time back but were not observed by him or his contemporary ornithologists, totaling the list to 524. Ganguli-Lachungpa (1990a, c, 1992, 1998a, b, d) added six new records for the state. Chettri (2000) and Chettri *et al.* (2001, 2005) from the studies in Yuksom Dzongri Corridor, Khanchendzonga Biosphere Reserve has reported around 10 new records for Sikkim. Total avifaunal wealth of Sikkim is thus 548 species, including eight new additions by Islam and Rahmani (2004).

Although species inventory and taxonomy has been dealt fairly well, very little ecological information is available on community structure, habitat utilization and diversity patterns of avifauna in Sikkim (Ali, 1962; Chettri, 2000; Chettri *et al.*, 2001, 2005). The study by Chettri (2000) and Chettri *et al.* (2001, 2005) deals with the impact of human disturbance on forest and bird communities in Yuksom, West Sikkim. The present study examined the community structure and distribution pattern of birds along the elevation gradient (390 - 4600 m) of the Teesta valley in Sikkim.

1.3. OBJECTIVES

The major goal of this study is to examine the distribution pattern of bird communities along an elevation gradient with following specific objectives:

1. Determine the structure of bird communities in different elevation zones along the Teesta valley,
2. Understand the distribution pattern and turnover of birds, and the factors determining the same along an elevation gradient,
3. Assess the habitat use of birds along the elevation gradient.

1.4. THESIS ORGANIZATION

The thesis is organized in seven chapters. Chapter 1 gives an outline of the chapters discussed in the thesis, narrates major objectives and presents a review of literature on the elevational pattern of bird communities, with a brief account on bird community studies in India. Chapter 2 describes the study area and major vegetation types at different elevation zones selected for this research. Chapter 3 illustrates the vegetation structure along the elevation gradient of Teesta valley. A detailed account of bird community structure together with aspects of nesting is given in Chapter 4. Chapter 5 discusses the distribution pattern of birds along the elevation gradient of Teesta valley. Chapter 6 deals with habitat use and vertical stratification of birds. Chapter 7 summarizes the broad findings of the study and highlights the conservation implications.

CHAPTER 2

STUDY AREA

2.1. INTRODUCTION

Sikkim is a state of India, situated in the Himalayan Mountains. The Himalaya, which stretches about 3500 km in length, is one of the youngest mountain chains on the Earth, and is believed to have originated due to the collision between peninsular Indian and Eurasian continental tectonic plates (Ganser, 1964; Mani, 1974). This chain comprises a series of parallel and converging ranges forming the world's highest mountain region (Mani, 1974). The Indian Himalayan region extends from Jammu and Kashmir in the west to Arunachal Pradesh in the east covering an area of about 5,33,604 km^2 (Nandy *et al.*, 2006). Broadly divided into Western, Central and Eastern Himalaya, each range has its unique and rich biological diversity.

Sikkim (27° 03' to 28° 07' N and 88° 03' to 88° 57' E) lies at the convergence of the Central and Eastern Himalayas (Figure 2.1). In the Biogeographical classification of India (Rodgers and Panwar, 1988), Sikkim has been placed under the bio-unit Central Himalaya (2C), which extends from Gandak river in Nepal to the Sankosh river in Bhutan. However, the state has often been considered as a part of Eastern Himalaya (Ali, 1962; Mani, 1974; Islam and Rahmani, 2004; Nandy *et al.*, 2006).

The rugged mountain state in Indian Union, Sikkim is geographically isolated from the rest of the country. It is encircled by mountain ranges on three sides i.e. Singalila and Kanchanjunga ridge on the west, Rishipangola on the east and the Himalaya on the northern part giving the state a horse-shoe shape (Bose, 1928; Ali, 1962). The state extends about 115 km from north to south and 65 km from west to east with a total geographical area of 7096 km^2 (Anon, 2005). It is bounded by vast stretches of Tibetan plateau in the north, the Tibetan Autonomous Republic Council (TARC) and Bhutan in the east, Nepal in the west and Darjeeling district of Indian state of West Bengal in the

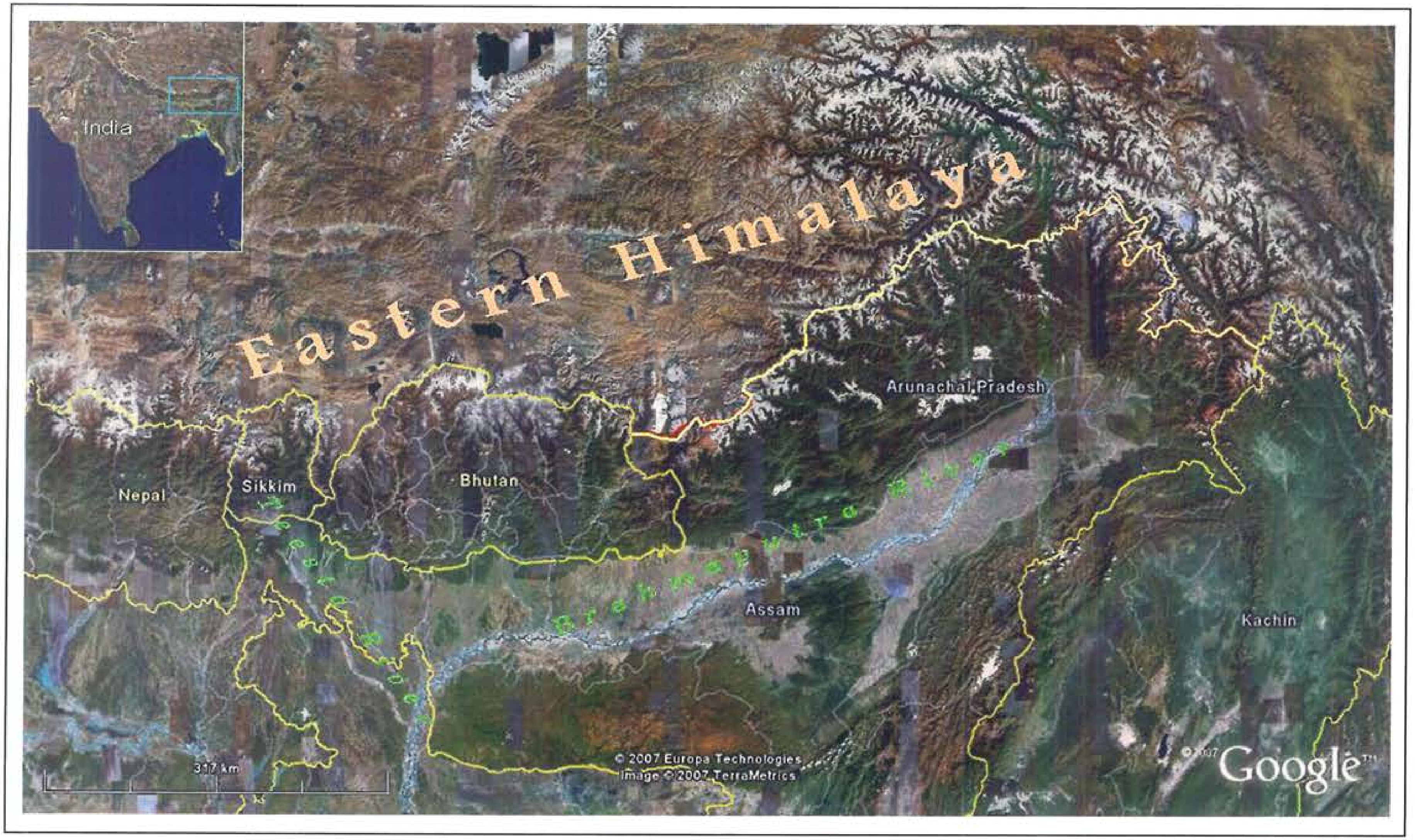

Figure 2.1. The Eastern Himalaya showing Sikkim and adjoining areas.

south. Sikkim is the catchment area of the river Teesta (Risley, 1928; Ali, 1962). River Teesta, one of the major physical features of the state originates at Chho Lhamo Lake (4800 m elevation) and flows in a north-south direction dividing the state into two halves. Along its course, the river descends abruptly encompassing deep valleys and gorges and enters West Bengal at Rangpo (300 m). The present study was conducted in the valley along the Teesta River.

2.2. TEESTA VALLEY

Teesta valley represents continuums of natural habitats encompassing wide variations in elevation (300 - 5500 m), climate (tropical to temperate) and vegetation types (tropical forest to alpine meadows). The above variations make the site important for studying distribution patterns of species along an elevation gradient.

2.2.1. Physical features

Sikkim, being a part of the mountain ranges of Himalaya, has an entirely hilly terrain. Physiographically, starting from the foothills of south and east, Teesta valley merges with Tibetan plateau on the north representing trans-Himalaya (CISMHE, 2006). Perpetual snow cover exists around 5200 m and high serrated snow-capped peaks surround the valley on all sides except on the southern part. Glaciers are the permanent source of many lakes such as Chho Lhamo, Gurudongmar and Greenlake. Teesta originates from Chho Lhamo lake in North Sikkim and is fed on its course by several tributaries such as Zemu, Lachung, Rangyong, Dikchu, Rongli and Rangpo. Rangeet river flowing through west Sikkim confluences with Teesta near Melli and finally discharges into Brahmaputra (Figure 2.1).

2.2.2. Geomorphology

Due to ongoing evolution process, the Himalaya has not attained geological and geomorphological stability (Mani, 1974). The mountain ridge of Sikkim runs more or less in north-south direction despite the general east-west trend of Himalayan mountain system, which may be due to the original southern slope of the Himalaya (Bose, 1928). The rocks fall into two major groups, Gneissic and Daling. Gneiss, oldest among the two, constitutes the main body of the Himalaya and frequently passes into mica schists in lower elevation but is comparatively less micaceous in higher elevation of the Teesta valley (Bose, 1928). Dailings are group of sub-metamorphic rocks consisting predominantly of phyllites and constitute the major portion of Teesta valley. The texture of the soil is sandy loam to clayey loam.

2.2.3. Climate

The climate, which is determined chiefly by geographical location and elevation, varies from hot tropical in the south to arctic cold in the north of the Teesta valley. Due to its proximity to the Bay of Bengal, the unobstructed inflow of moisture laden currents of south-west monsoon make Sikkim the most humid region in the entire Himalayan range (Mani, 1974) with relative humidity of 70-80% throughout the year (Hooker, 1854). Southwest monsoon normally sets around early June and withdraws by the end of September. Low altitude region along the foothills is humid which gets heavy rains exceeding 3000 mm in most parts with distinctly less rainfall beyond 1600 m elevation (CISMHE, 2006). In high altitude region precipitation is in the form of snow and most of the alpine region remains under snow for almost 7-8 months a year. The lower and middle valleys in south and east are hot and humid, while high elevation areas in north are comparatively drier and colder. The average temperature and rainfall decrease towards higher elevation (Figure 2.2). Temperature shows strong negative correlation with elevation ($r = -0.99$, $p = 0.01$) but correlation between rainfall and elevation is marginally significant ($r = -0.84$, $p = 0.07$).

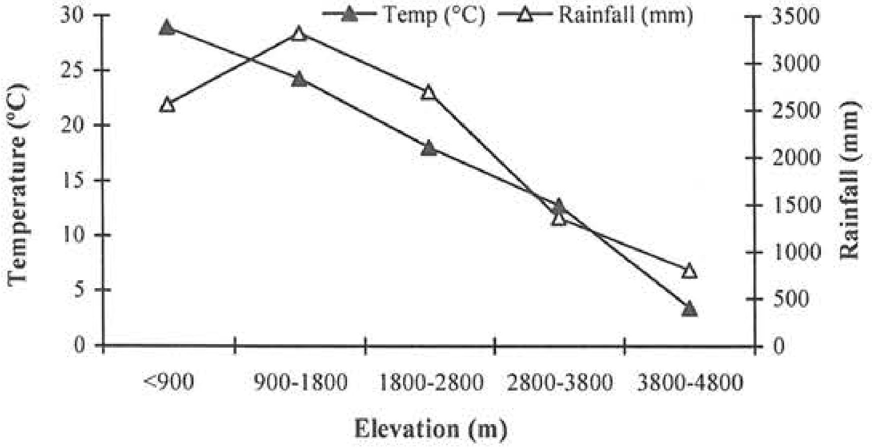

Figure 2.2 Mean annual temperature and rainfall recorded in various elevations along the Teesta valley, Sikkim (Source: Indian Meteorological Department; Indian Army).

2.2.4. Population

Sikkim is a land of ethnic diversity with more than 30 tribes and subtribes, majority of them have distinct dialect, customs and traditions. These tribes belong to three major ethnic groups, namely Nepalis, Bhutias and Lepchas. According to 2001 census, the population of Sikkim is 540,493 (2, 88,217 male and 2, 52,276 female), which account for only 0.05 percent of the country's total population (Lama, 2001). The mountainous state is sparsely populated with an average density of 76 persons per km^2. The human habitation is mostly concentrated below 2500 m except for a few nomadic tribes and yak herders who live as high as 4600 m. Towards northern side populations become very sparse with a few hamlets of Lachenpa and Lachungpa tribes. The livelihood option for the people at low and mid-elevation is small-scale agriculture and government service, whereas the major occupation at higher elevation is tourism and livestock rearing. Due to increasing demands of tourists visiting the area, most people are involved in tourism activities and many households run lodges and hotels. In recent years slash and burn agriculture, as practiced in other northeastern states of India (Raman *et al*., 1998), are expanding rapidly at steep terrains of Lachen and Lachung valleys.

2.2.5. Livestock

Live stock rearing is one of the major occupations in Sikkim and is the only livelihood option for nomadic tribes who live in high elevation areas of north and west districts. The population of pigs, poultry and goats is rapidly increasing with more than 45% increment from 1997 to 2003 (Anon, 2005). Poultry, cattle, goats, pigs, sheep, yaks and horses are reared in the Teesta valley.

2.2.6. Biogeography

The eastern Himalaya, including Sikkim, is located at the convergence of two biogeographical realms (Palearctic and Oriental) and three regions (Indian, Indo-Malayan and Indo-Chinese). The timberline and snowline are two extremely important ecological and biogeographical transition zones on the Himalaya (Körner, 1999). The fauna of the tropical belt in Teesta valley has similarity with Indo-Chinese and Malayan sub-regions of the Oriental region, whereas high elevation fauna shows close similarity with

Manchurian sub-region of the Palaearctic region (Mani, 1974; Islam and Rahmani, 2004). Apart from Palaearctic and Oriental, Ethiopian fauna are also represented (Waddell, 1928).

The varied ecological conditions of Sikkim have favored a wide variety of floristic elements (Singh and Chauhan, 1997). The flora of Teesta valley shows affinities with Sino-Japanese and Western China elements, which is probably due to close vicinity of the countries sharing almost similar climatic conditions. The high altitude flowering herbs such as *Ranunculus* sp., *Gentiana* sp., *Swertia* sp. and *Artemisia* sp. shows European and Mediterranean affinity. Contrary to flora having affinity with far-off lands, there are a few species restricted to these areas thus making Sikkim an important location for bio-diversity conservation (Singh and Chauhan, 1997, 1998).

2.2.7. Forests and wildlife

The forest area in Sikkim is 3129 km^2 or about 44.10% of the total geographical area of the state, of which 2260 km^2 are protected or reserve forests. There has been considerable increase (6.75%) in forest cover since 1993 (Anon, 2003). Out of the total forested area, 33% is under dense forest cover (crown density > 40%), whereas area under open forest cover (crown density 10 - 40%) is 67% (CISMHE, 2006).

Eastern Himalaya, which includes Sikkim, represents a global biodiversity hotspot (Mittermeier *et al.*, 2005), one of the 200 globally most important ecoregions (Olson and Dinerstein, 1998), and an Endemic bird area (Stattersfield *et al.*, 1998; Islam and Rahmani, 2004). Among all Indian states, Sikkim displays probably the highest biological diversity compared to its small geographical area (Islam and Rahmani, 2004). It is estimated that around 5,000 species of flowering plants (Orchids and Rhododendrons comprise 450 and 36 species respectively), 350 species of pteridophytes and 15 species of Gymnosperms occur in this region (Singh and Chauhan, 1997). Although Sikkim occupies only 0.02% of the geographical area of India, it possesses almost 50% of total faunal wealth of the country with species of several groups such as 156 mammals, 550 birds, 78 reptiles, 21 amphibians, 48 fishes and 689 butterflies (Ali, 1962; Haribal, 1992; Tamang, 1993; Ganguli-Lachungpa, 1998c; Avasthe and Jha, 1999; Chettri *et al.*, 2001; Jha and Thapa, 2002; Vijayan *et al.*, 2006; Chettri and

Bhupathy, 2007). In addition, numerous varieties of insects such as moths, beetles, grasshoppers and ants, and other invertebrates such as crabs, spiders, flies, snails and leeches are also found.

2.2.8. Vegetation

Hooker (1854) documented the rich and diverse floristic wealth of Sikkim and categorized the vegetation into three major types- Tropical, Temperate and Alpine. Several authors followed this classification of vegetation (Gammie, 1928; Ali, 1962; Mani, 1974; Hajra and Verma, 1996; Singh and Chauhan, 1998; Sudhakar *et al*., 1998; Islam and Rahmani, 2004).

Depending on the elevation, characteristics of vegetation and various physical and ecological factors, the following five major vegetation zones (Figure 2.3) are recognized along the Teesta valley, Sikkim (Haribal, 1992).

Tropical semi-deciduous forest includes low elevation area up to 900 m, which covers Rangpo, Singtam, Dikchu in East Sikkim, Dalep and Namphing in South Sikkim and Sangkalang in North Sikkim. These low elevation forests are largely altered for agriculture and teak plantation. However, remnant patches of original forest exist in some areas, represented chiefly by trees such as *Ceiba malabarica, Shorea robusta, Ailanthus grandis, Terminalia myriocarpa, Duabanga sonnerotoides, Schima wallichi, Ostodes paniculatus, Gynocardia odorata, Amora rohituka, Bischofia javanica, Pandanus furcatus, Cedrela toona, Castanopsis indica, Celtis tetranda, Cinnammomum tamala* and various undergrowth species such as *Strobilanthes*, *Polygonum* and *Eupatorium*.

Tropical moist and broad-leaved forest extends from Mangan and Dzongu up to Chungthang valley in North Sikkim within an elevational range of 900 -1800 m. Majority of forest areas in this vegetation type are partially disturbed by cardamom plantation. The major tree species are *Engelhardtia spicata, Alnus nepalensis, Schima wallichii, Eugenia* sp., *Litsaea citrata, Acer campbelli, Castanopsis tribuloides, Macaranga peltata, Juglans regia, Symingtonia populnea, Michelia cathcartii* and *Betula alnoides*. Shrub and undergrowth are represented by various species of *Maesa, Melostoma* and *Edgeworthia*. Tree ferns, orchids and *Rhapidophora* sp. in abundance characterize this forest type.

Temperate broad-leaved forest extends beyond Chungthang towards Lachen and Lachung valley of North Sikkim within an elevational range of 1800 - 2800 m. This forest represents the major forest cover of the Teesta valley. Closed canopy of broadleaved trees covered by mosses and other epiphytes are characteristics of this forest. The dominant trees are *Quercus lamellosa, Quercus pachyphylla, Magnolia campbelli, Machilus edulis, Castanopsis hystrix, Juglans regia, Symplocos theifolia, Michelia exelsa, Rhododendron graffithianum, Cinnamomum obtusifolium* and *Taxus wallichiana*. Most of the forest is covered by dense undergrowth of dwarf bamboo (*Arundinaria* sp.) and Rhododendrons.

Temperate coniferous and broad-leaved forest represents valleys (2800 - 3800 m) between Lachen and Thangu, and Lachung and Yumthang. The vegetation is represented by mixed conifer forest comprising of species such as silver fir (*Abies webbiana*), hemlock (*Tsuga dumosa*), spruce (*Picea spinulosa*) interspersed with blue pine (*Pinus excelsa*) and junipers. Species such as *Larix griffithiana, Taxus wallichiana, Acer caudatum, Rhododendron arboreum, R. campanulatum, R. grande* and *Betula utilis* are also found. Numerous undergrowth species such as *Berberis, Ilex, Pyrus, Ribes, Rubus, Spiraea*, *Vibernum* and herbaceous *Arisaema* sp. are common in this forest.

Sub-alpine and Alpine vegetation include areas above Thangu and Yumthang (>3800 m), where the valley becomes broader and wider finally merging with the Tibetan plateau. The turnover of vegetation from coniferous trees to dwarf shrubs and finally to herbs is distinct. Tree line ceases around 4000 m where the evergreen coniferous forests are replaced by stunted Rhododendrons, Willows, Azaleas along with flowering herb species such as *Potentilla, Anemones, Primula, Ligularia* and *Pedicularis*. The extreme higher elevation towards the plateau is represented by seasonal herb species such as *Meconopsis grandis, Saxifraga, Saussurea, Pedicularis, Potentilla, Sedum, Waldheima, Stellaria, Mandragora, Lioydia, Iris, Corydalis, Heracleum, Primula, Androsace, Anemone, Cassiope, Picrorhiza, Poa* and so on. *Rheum nobile*, the gigantic rhubarb of Sikkim, is common at rocky mountains all along the alpine region. The mat-forming rigid *Arenaria* is the most striking feature of this vegetation.

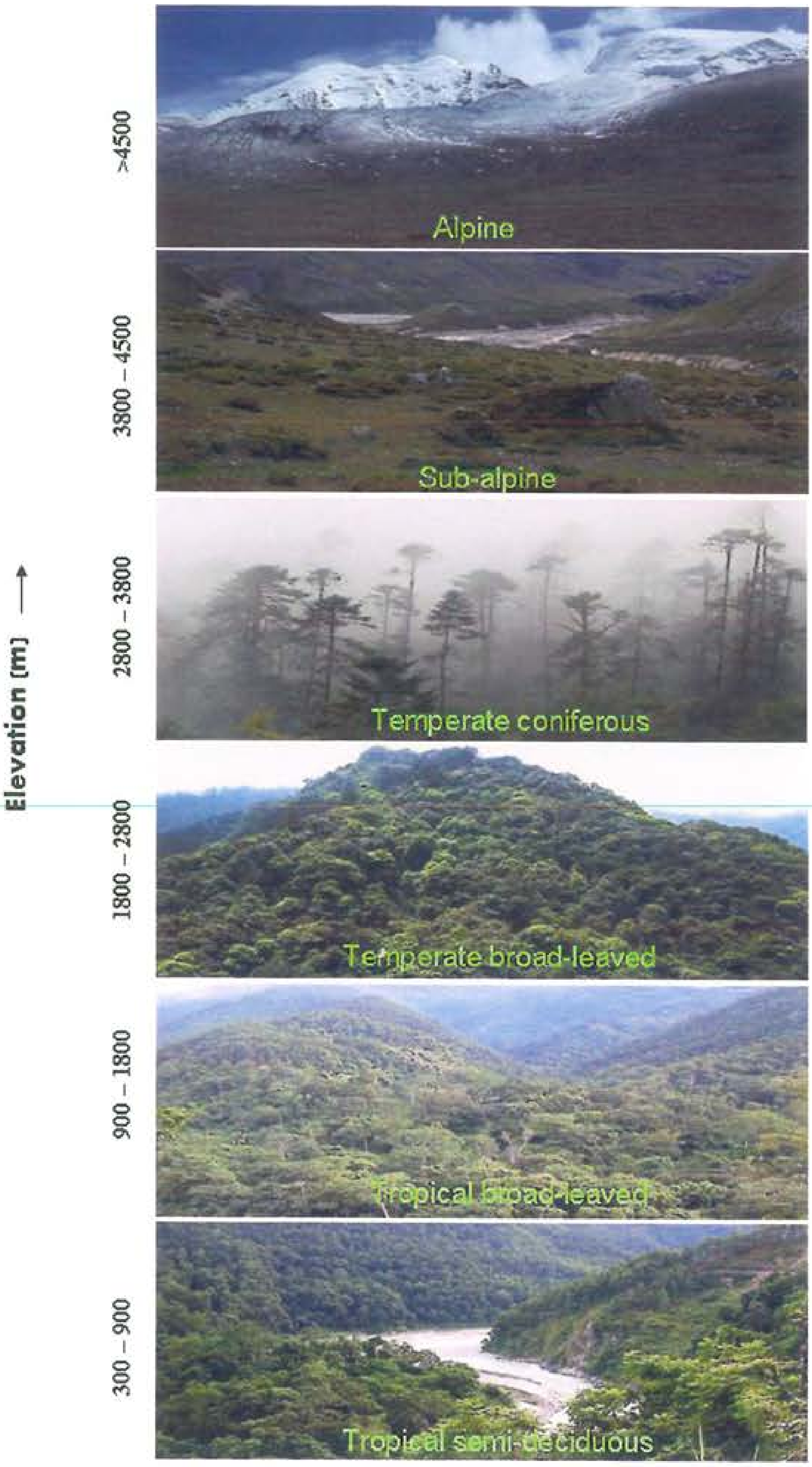

Figure 2.3 Gradation of vegetation along the elevation gradient of Teesta valley, Sikkim

For the present study, Teesta valley was divided into five zones based on elevation and major vegetation types (Figure 2.3) as discussed above. Different zones considered for the study are: Zone I (390 - 900 m) - Tropical semi-deciduous forests; Zone II (900 - 1800 m) - Tropical moist and broad-leaved forests; Zone III (1800 - 2800m) - Temperate broad-leaved forests; Zone IV (2800 - 3800m) - Temperate coniferous and broad-leaved forests; and Zone V (3800 - 4500 m and above) - Sub-alpine and alpine vegetation.

2.2.9. Sampling locations

Transects were laid covering all five zones depending upon accessibility and availability of the forest as well as altitude of the area (Figure 2.4). The same transects were regularly surveyed for bird sampling. Sampling for vegetation was carried out only once in all transects laid for birds. The details of transects (location, altitude and zones) are given in Table 2.1.

Table 2.1 Details of transects laid along the Teesta valley, Sikkim for bird and vegetation sampling.

Transects	Zone	Elevation (m)	Location	Latitude (° ′ N)	Longitude (° ′ E)
1	I	390	Bardang	27 12.1	88 28.9
2	I	550	Dalep	27 14.8	88 27.2
3	I	660	Namphing	27 14.3	88 28.4
4	I	750	Pabong	27 15.1	88 26.6
5	I	850	Sankalang	27 29.3	88 30.6
6	II	980	Sankalang Toong	27 29.4	88 30.7
7	II	1120	Barphok(Dzongu)	27 29.5	88 30.2
8	II	1290	Toong	27 33.1	88 38.5
9	II	1420	Theeng	27 34.2	88 39.2
10	II	1600	Chungthang	27 36.2	88 38.6
11	III	1850	Bop	27 37.1	88 40.1
12	III	1950	Menshithang	27 37.6	88 36.9
13	III	2140	Khedum	27 37.7	88 42.2
14	III	2310	Rabum	27 39.8	88 36.3
15	III	2550	Bitchu	27 39.5	88 43.7
16	IV	2900	Lachung	27 41.1	88 45.4
17	IV	3160	Phuni	27 45.2	88 43.8
18	IV	3350	Singba	27 46.8	88 42.5
19	IV	3500	Yumthang	27 48.4	88 42.7
20	IV	3730	Yumthang	27 49.3	88 42.5
21	V	4070	Shivmandir	27 51.4	88 41.6
22	V	4290	Yumesamdong(S)	27 52.2	88 41.7
23	V	4600	Yumesamdong (N)	27 54.8	88 41.9

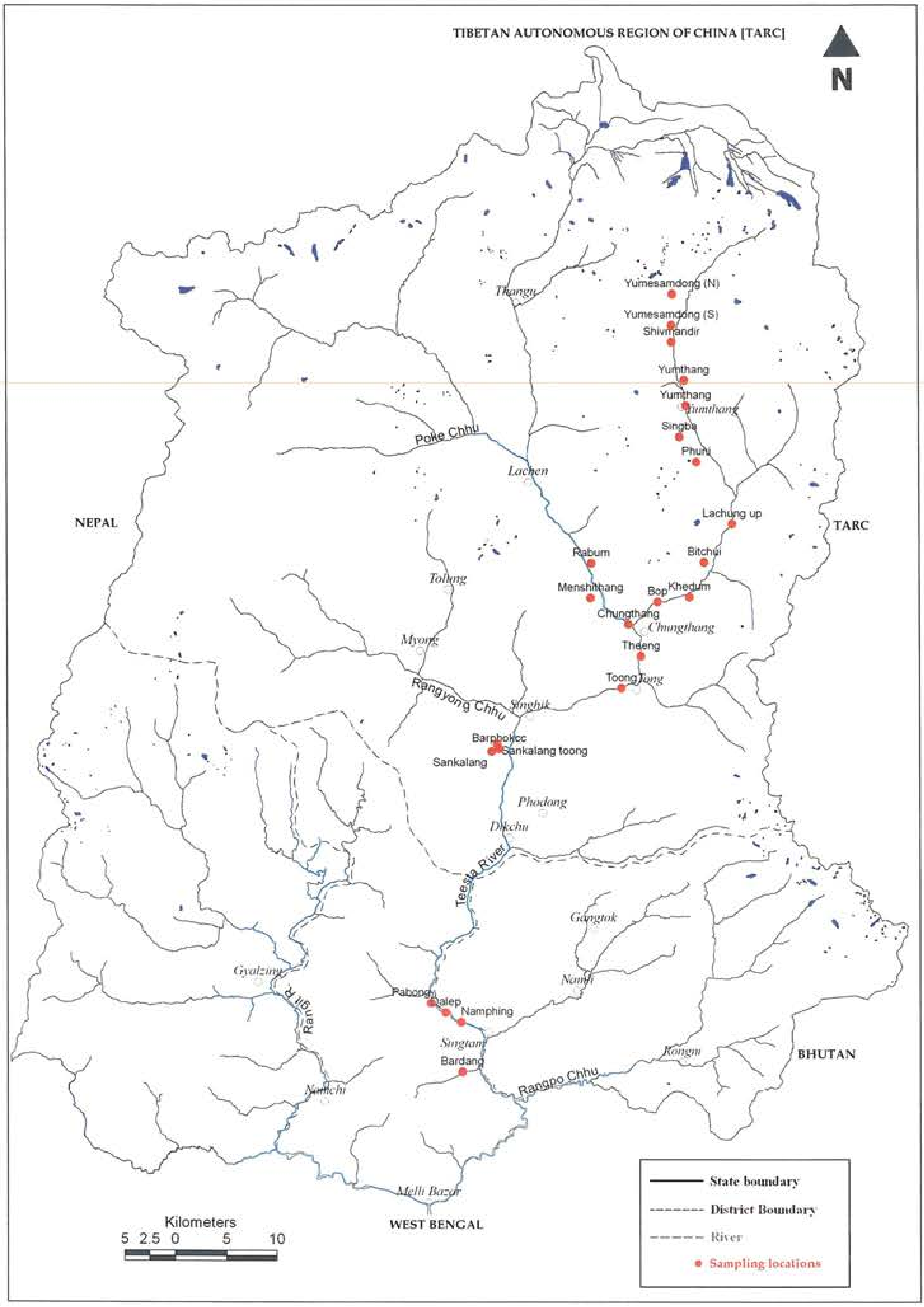

Figure 2.4 Sikkim showing sampling locations in the Teesta valley

CHAPTER 3

DIVERSITY AND STRUCTURE OF VEGETATION

3.1. INTRODUCTION

The tropical forests are regarded as one of the most diverse ecosystems (Gaston, 2000) comprising 15 of the 25 biodiversity hotspots (Myers *et al*., 2000). Information on diversity, density and distribution pattern of plants is a prerequisite for evaluating complexity and resources of the forests (Kumar *et al*., 2006). Similarly, elevational distribution pattern of species provides insight into the observed pattern and also helps in biodiversity conservation (Vetaas and Grytnes, 2002; Grytnes *et al*., 2006). The information thus obtained provides guidelines for sound ecological management at landscape level (Chettri *et al*., 2006) as vegetation is the major factor determining diversity, community composition and distribution pattern of animals (Begon *et al*., 2006). Since MacArthur and MacArthur (1961), most of the ecological studies on animals have considered vegetation as an important aspect to understand the availability of resources in the forest and utilization of these resources by animals.

The forest cover in India, including the Himalaya, is decreasing at a fast pace mostly due to anthropogenic pressure leading to various ecological cataclysms (Prasad *et al*., 1996, 1998; Jha *et al*., 2000; Chettri *et al*., 2002; Prabhakar *et al*., 2006; Pandit *et al*., 2007). Disturbance to forest has serious impacts on the distribution and diversity of animal communities (Chettri 2000; Pardini, 2004; Lee *et al*., 2006; Vijayan and Gokula, 2006). The loss of forest is considered as a major cause for extinction of birds in the Himalaya (Birdlife International, 2001; Pandit *et al*., 2007). Conservation of vegetation is prerequisite for the effective conservation of faunal communities. Hence, site-specific primary data is required for implementation of such conservation measures.

Several studies on vegetation structure and floral diversity of Indian forests are available from peninsular region, especially from the Western Ghats (Sukumar *et al.*, 1992; Pascal and Pelissier, 1996; Parthasarathy and Karthikeyan, 1997; Annaselvam and Parthasarathy, 1999; Ayyappan and Parthasarathy, 1999; Parthasarathy, 1999, 2001; Davidar *et al.*, 2005, 2007). In the Himalaya, most of the studies have been undertaken in western and central parts (Ralhan *et al.*, 1982; Saxena and Singh, 1982; Saxena *et al.*, 1984; Sundriyal and Bist, 1988; Adhikari *et al.*, 1991; Bhandari *et al.*, 1997; Metz, 1997; Grytnes and Vetaas, 2002; Vetaas and Grytnes, 2002; Bhattarai and Vetaas, 2003; Kumar *et al.*, 2004; Carpenter, 2005; Oommen and Shanker, 2005; Grau *et al.*, 2007). Efforts to study the community structure of flora in the Eastern Himalaya are a few compared to Western and Central Himalaya and other regions of India (Singh and Ramakrishnan, 1982; Jamir and Pandey, 2003; Upadhaya *et al.*, 2003, 2006; Tripathi *et al.*, 2004; Kumar *et al.*, 2006; Behera and Kushwaha, 2007).

The flora of Sikkim remained unexplored till the middle of 19th century. Hooker (1854) undertook foremost study on the rich and diverse floristic wealth of Sikkim. Subsequent studies have documented the plant communities of a few locations and highlighted their conservation importance (Sundriyal *et al.*, 1994; Sundriyal and Sharma, 1996; Chettri *et al.*, 2002, 2006; Tiwari and Chauhan, 2006). Other available literature deals with the taxonomy (Rai and Rai, 1994; Hajra and Verma, 1996). No attempt has been made to study plant communities along an elevational gradient in Sikkim including Teesta valley.

This study on vegetation was undertaken to quantify habitat of bird community of the Teesta valley. Habitat association of birds is discussed in Chapter 6. This chapter deals with the diversity, composition and structure of vegetation in different elevation zones along the Teesta valley in Sikkim.

3.2. METHODS

3.2.1. Vegetation sampling

Vegetation was studied in all the five zones of the study area (Chapter 2, Pp.20) following quadrat sampling method (Sundriyal and Sharma, 1996; Metz, 1997). Considering the steepness and topography of the study area, quadrats measuring 20 m x 10 m were laid in all the predetermined elevational transects (Table 2.1) for enumeration of trees. Ten quadrats per transect were laid on alternate side along the transect, 100 m apart. In each quadrat, all the tree species and their numbers were recorded. Plants with GBH (girth at breast height) >20 cm at 1.37 m height from the ground were considered as trees. All the trees within the quadrat were enumerated and girth measured using a measuring tape.

For estimating shrub density, two 5 m x 5 m sub-quadrats were housed diagonally within the 20 m x 10 m quadrats. Twenty such sub-quadrats per transect were established. Woody stems including saplings of trees, having girth $\leq$20 cm and height $\geq$1 m were considered as shrubs. Shrub species and their numbers in all the sub-quadrats were recorded. The quantification of herbs was not done during this study.

Trees and shrubs were identified following Polunin and Stainton (1990), Rai and Rai (1994) and Hajra and Verma (1996).

3.2.2. Data analysis

Species richness, diversity, evenness and density of trees and shrubs, and basal area of trees were calculated. Species richness was obtained as the cumulative number of species observed. Shannon-Weaver diversity (H') was calculated by the formula $H' = -\Sigma\, p_i \ln p_i$, where, p_i = proportion of i^{th} species with respect to total sample, and ln = natural logarithm. Evenness (E) was computed by the formula $E = H'/H_{max}$, where H' = Shannon-Weaver species diversity and $H_{max} = \ln S$, (S = number of species). Basal area was computed as $(GBH)^2/4\pi$, where GBH = girth at breast height, $\pi = 3.14$. One-way ANOVA was performed to ascertain the difference in species richness, diversity, evenness, density and basal area among elevation zones. The relationship between species richness and elevation was assessed using regression analysis. Since, there was no significant increase in r^2 value with cubic and higher order polynomials, quadratic curve was considered as the best fit (Zar, 1999).

Relative values of frequency, abundance, density and dominance for each tree species were determined following Mishra (1980) and Greig-Smith (1983). Importance value index (IVI) was calculated as the sum of relative frequency, relative density and relative dominance. Importance value index (IVI) for all tree species were obtained in each zones.

For the estimation of population structure, all trees in each elevation zones were categorized into the following GBH classes: 1 = 21 - 40 cm, 2 = 41 - 60 cm, 3 = 61 - 80 cm, 4 = 81 - 100 cm, 5 = 101 - 120 cm, 6 = 121 - 140 cm, 7 = 141 - 160 cm, 8 = 161 - 180 cm, 9 = 181 - 200 cm and 10 = >200 cm. The density and number of species in each GBH classes were calculated for each zones. Kruskal-Wallis test was performed to examine the variation in species richness and density in different size classes among zones.

Only 16 trees were recorded from 0.6 ha area in zone V because this zone represents >3800 m elevation and tree line in the study area ceases around 4000 m. So, tree data from only lower four zones (I, II, III and IV) were considered for analysis, whereas data from all the zones were considered for shrubs. All the analyses were performed using statistical package SPSS 10.0 and Microsoft Excel for windows.

3.3. RESULTS

In total, 230 quadrats, 50 each in zones I, II, III and IV, and 30 quadrats in zone V, were sampled for the estimation of trees. But as mentioned above, tree data from only first four zones (200 quadrats) are considered here. Total area covered was 4.6 ha (one hectare each in zones I, II, III and IV, 0.6 ha in zone V). Similarly, 460 sub-quadrats (100 each in zones I, II, III and IV and 60 in zone V) were established for shrub estimation covering 0.25 ha area each in zones I, II, III and IV, and 0.15 ha in zone V (1.15 ha in total).

A total of 216 species of woody plants belonging to 64 families were recorded from Teesta valley during the study. Of the total species observed, 170 were trees and 135 shrubs. The highest number of species (19) belonged to Ericaceae family followed by Lauraceae comprising of 14 species. Twenty-six families were represented by single species.

3.3.1. Species richness, diversity and evenness

Trees

Present study yielded 3,858 individual trees belonging to 170 species and 58 families from four elevation zones in the study area. For the pooled data from four zones (I, II, III and IV), Shannon-Weaver diversity and Evenness were 3.9 and 0.77 respectively. A maximum of 103 and minimum of 31 species were recorded in zone II and zone IV respectively. Tree species diversity was the highest in zone II, whereas evenness was maximum in zone III (Table 3.1). One-way analysis of variance (ANOVA) showed significant difference in tree species richness ($F_{3,\ 196} = 13.265$, $p = 0$), diversity ($F_{3,\ 196} = 12.769$, $p = 0$) and evenness ($F_{3,\ 196} = 11.20$, $p = 0$) among the zones.

Shrubs

A total of 15,299 shrubs representing 135 species and 46 families were observed from five elevation zones in the study area. Out of the total shrub species observed, 89 were saplings of trees. Shannon-Weaver diversity and evenness values for shrubs were 3.1 and 0.62 respectively. Shrub species richness was the highest (64) in zone II and lowest (6) in zone V. Similarly, species diversity was the highest in zone I, whereas evenness was in zone V (Table 3.2). Shrub species richness displayed significant difference among zones ($F_{4,\ 455} = 4.614$, $p = 0.001$). Species diversity ($F_{4,\ 455} = 7.384$, $p = 0.00$) and evenness ($F_{4,\ 455} = 4.053$, $p = 0.003$) also varied significantly among the elevation zones.

3.3.2. Density and basal area

Trees

Overall density of trees in the study area was 965±558 trees ha^{-1}. Tree density was the highest in zone IV and lowest in zone I. Mean tree density showed significant variation among the zones ($F_{3, 196} = 15.525$, $p = 0$). Mean basal area of trees in the study area was 72.1±69.8 (m^2/ha) with maximum value in zone III and minimum in zone II (Table 3.1). Basal area varied significantly among the elevation zones ($F_{3, 196} = 32.976$, $p = 0.001$).

Shrubs

Mean density of shrubs recorded in the Teesta valley during the study was 14,066 ha^{-1}. Highest shrub density was observed in zone III and lowest in zone V (Table 3.2). One-way analysis of variance revealed significant variation in shrub density among elevation zones ($F_{4, 455} = 271.223$, $p = 0.00$).

Table 3.1 Species richness, abundance (number of individuals), diversity (H'), evenness (E), density (D) and basal area (BA) of trees observed in different elevation zones along the Teesta valley, Sikkim.

Vegetation Zones	**Sampled area (in ha)**	**Species richness**	**H'**	**E**	**D ha^{-1} mean±SD**	**BA (m2/ha) mean±SD**
I	1	90	3.4	0.75	703±430	37.8±21.6
II	1	103	3.6	0.77	936±484	32.9±16.4
III	1	68	3.3	0.78	857±586	132.2±79.7
IV	1	31	1.8	0.52	1362±510	85.4±77.8
Total	4	170	3.9	0.77	965±558	72.1±69.8

Table 3.2 Species richness, abundance (number of individuals), diversity (H'), evenness (E) and density of shrubs observed in different elevation zones along the Teesta valley, Sikkim.

Vegetation zones	**Sampled area (in ha)**	**Species richness**	**H'**	**E**	**D ha^{-1} mean±SD**
I	0.25	53	2.74	0.67	7088±4370
II	0.25	64	1.74	0.41	9256±7397
III	0.25	43	1.64	0.42	32676±7178
IV	0.25	23	2.51	0.79	11576±7651
V	0.15	6	1.65	0.85	6846±3910
Total	1.15	135	3.1	0.62	14066±11870

3.3.3. Elevational distribution pattern

Species richness of trees followed a hump-shaped relationship with elevation showing a peak at around 1500 m. Although richness was low at both ends, decline was more towards higher elevation (Figure 3.1a). Regression drawn between species richness and elevation showed significant a quadratic relation ($r^2 = 0.688$, $p = 0.00$).

Shrub species richness showed declining trend with elevation but the relationship was nonlinear. Richness was highest between 1000 and 2000 m with a peak at around 1500 m (Figure 3.1b). Regression analysis showed significant (quadratic) correlation between shrub species and elevation ($r^2 = 0.51$, $p = 0.00$).

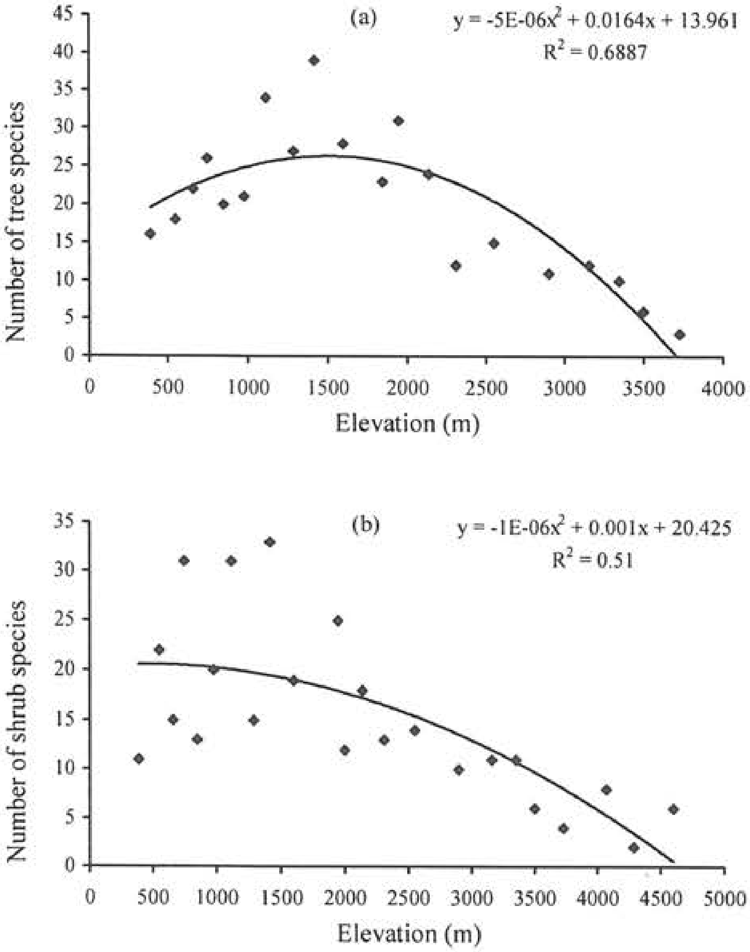

Figure 3.1 Species distribution pattern of trees (a) and shrubs (b) along the elevation gradient of Teesta valley, Sikkim.

3.3.4. Tree species composition and relative abundance

Abies webbiana was the most abundant tree species (relative abundance 19) in the study area followed by *Schima wallichi* (5.67) and *Rhododendron* sp. (4.83). Twenty-eight species were represented by single individual (relative abundance 0.026). Tree species composition and relative abundance of species varied among vegetation zones. *Schima wallichi* (20.62) was the most abundant species in zone I followed by *Ostodes paniculatus* (11.66) and *Castonopsis tribuloides* (4.97). Similarly, *Alnus nepalensis* (13.92), *Rhododendron arboreum* (15.28) and *Abies webbiana* (53) were the abundant species in zones II, III and IV respectively.

The values of relative frequency, relative density, relative dominance and importance value index (IVI) of important tree species (IVI ≥ 2) recorded in zones I, II, III and IV are presented in Tables 3.3, 3.4, 3.5 and 3.6 respectively. Forests in all the vegetation zones were dominated by a few species. For example nine species, namely *Schima wallichi* (50.82), *Shorea robusta* (20.46), *Ostodes paniculatus* (19.85), *Castanopsis tribuloides* (10.72), *Alnus nepalensis* (10.42), *Albizzia lebbeck* (10.34), *Gynocardia odorata* (9.83), *Woodfordia fruticosa* (8.68) and *Albizzia procera* (8.66) contributed 50 % IVI (149.78 out of 300) in zone I (Table 3.3). Similarly, eight species each comprised more than 50% IVI in zones II and III (Tables 3.4 and 3.5). The species with high IVI values were *Alnus nepalensis* (42.93), *Quercus lamellosa* (29.29), *Schima wallichi* (28.1), *Engelhardtia spicata* (12.2) and *Quercus* sp. (11.93) in zone II and *Quercus semicarpefolia* (29.41), *Rhododendron arboreum* (27.98), *Quercus pachyphyla* (24.25), *Prunus nepaulensis* (18.12) and *Symplocos theifolia* (17.56) in zone III. In zone IV *Abies webbiana* (161.42) scored highest IVI followed by *Rhododendron lanatum* (28.12), *Acer laevigatum* (17.79) and *Sorbus* sp. (15.55).

Table 3.3 Values of relative frequency (RF), relative density (RDN), relative dominance (RDM) and importance value index (IVI) of trees in elevation zone I in the Teesta valley, Sikkim. Species (60) with IVI <2 are considered as others.

Species	**RF**	**RDN**	**RDM**	**IVI**
Schima wallichi	11.19	20.63	19.00	50.82
Shorea robusta	2.45	4.41	13.60	20.46
Ostodes paniculatus	4.90	11.66	3.29	19.85
Castanopsis tribuloides	4.20	4.98	1.55	10.72
Alnus nepalensis	2.10	3.41	4.91	10.42
Albizzia lebbeck	3.85	2.99	3.51	10.34
Gynocardia odorata	2.45	2.42	4.97	9.83
Woodfordia fruticosa	2.80	3.98	1.90	8.68
Albizzia procera	2.10	2.70	3.86	8.66
Engelhardtia spicata	2.80	1.56	2.80	7.17
Bambusa lulda	0.35	5.97	0.73	7.05
Ailanthus grandis	3.15	1.99	1.75	6.89
Ceiba malabarica	2.10	1.28	3.34	6.72
Spondias axillaris	1.40	0.57	4.70	6.67
Terminalia myriocarpa	1.40	1.85	3.34	6.59
Unidentified (*Chamrey*)	3.15	2.84	0.37	6.36
Amoora rohituka	2.80	2.42	0.43	5.64
Acacia lenticularis	1.40	0.71	2.81	4.92
Garuga pinnata	1.40	1.00	2.44	4.83
Premna bengalensis	2.45	1.42	0.49	4.36
Taluma hodgsoni	1.05	0.43	2.55	4.03
Calicarpa arborea	1.75	1.28	0.79	3.82
Morus indica	1.75	0.71	1.26	3.72
Oroxylum indicum	1.75	1.00	0.34	3.08
Toona ciliate	1.05	0.43	1.51	2.98
Bischofia javanica	1.05	0.57	1.28	2.90
Ficus hispida	1.75	0.71	0.40	2.85
Litsaea polyantha	1.75	0.85	0.24	2.84
Macaranga denticulata	1.05	0.57	1.09	2.71
Jambosa Formosa	1.40	0.71	0.22	2.33
Others (60 species)	27.27	13.94	10.54	51.75

Table 3.4 Values of relative frequency (RF), relative density (RDN), relative dominance (RDM) and importance value index (IVI) of trees in elevation zone II in the Teesta valley, Sikkim. Others represent 72 species with IVI <2.

Species	**RF**	**RDN**	**RDM**	**IVI**
Alnus nepalensis	4.55	13.92	24.47	42.93
Quercus lamellose	4.81	10.17	14.31	29.29
Schima wallichi	6.42	7.92	13.67	28.01
Engelhardtia spicata	4.55	3.85	3.80	12.20
Quercus sp.	2.41	3.85	5.67	11.93
Brassiopsis mitis	4.01	2.68	2.97	9.66
Glochidion acuminatum	3.21	2.78	1.86	7.85
Eurya symplocina	2.67	3.75	1.20	7.62
Eurya acuminate	2.41	4.39	0.72	7.51
Betula cylindrostachys	1.87	3.43	1.95	7.25
Rhus semialatus	2.94	3.32	0.80	7.06
Macaranga denticulata	3.21	2.14	1.12	6.47
Spondias axillaris	2.41	1.39	2.23	6.03
Prunus cerasoides	2.41	2.36	0.98	5.74
Albizzia procera	2.67	2.03	1.01	5.72
Pyrularia edulis	2.67	2.03	1.00	5.71
Macaranga indica	1.87	2.36	0.68	4.91
Pandanus furcatus	2.14	1.61	0.97	4.71
Evodia fraxinifolia	1.60	0.96	1.32	3.89
Rhus insignis	1.60	1.61	0.50	3.71
Castanopsis tribuloides	1.07	1.39	0.74	3.20
Ficus cunia	1.34	0.96	0.82	3.12
Ostodes paniculatus	0.80	1.18	0.90	2.88
Toona ciliata	0.80	0.32	1.62	2.75
Viburnum cordifolium	1.34	0.86	0.51	2.71
Albizzia lebbeck	0.80	1.07	0.78	2.66
Prunus nepaulensis	0.80	0.64	0.90	2.35
Aporosa dioica	1.34	0.54	0.33	2.20
Andromeda elliptica	1.07	0.64	0.41	2.12
Nyssa javanica	0.80	0.86	0.42	2.07
Pavetta indica	1.07	0.75	0.19	2.01
Others (72 species)	28.34	14.24	11.13	53.71

Table 3.5 Values of relative frequency (RF), relative density (RDN), relative dominance (RDM) and importance value index (IVI) of trees in elevation zone III in the Teesta valley, Sikkim. Others represent 40 species with IVI <2.

Species	**RF**	**RDN**	**RDM**	**IVI**
Quercus semicarpefolia	6.09	5.36	17.96	29.41
Rhododendron arboreum	5.38	15.27	7.34	27.98
Quercus lamellosa	5.02	5.94	13.29	24.25
Prunus nepaulensis	6.09	4.55	7.49	18.12
Symplocos theifolia	5.38	9.09	3.10	17.56
Acer laevigatum	5.73	3.96	4.52	14.21
Echinocarpus dasycarpus	2.51	1.28	8.51	12.30
Andromeda elliptica	3.23	7.81	1.22	12.26
Beilschemiedia sikkimensis	4.66	2.33	5.25	12.24
Cinnamomum cinerarifolium	3.94	3.73	2.65	10.33
Machilus edulis	1.43	2.10	5.21	8.74
Elaeocarpus lanceofolius	3.23	1.98	2.93	8.13
Viburnum cordifolium	3.58	4.08	0.43	8.10
Eurya symplocina	3.58	3.26	0.97	7.81
Juglans regia	2.87	1.63	2.17	6.67
Symplocos ramisissima	2.87	3.15	0.23	6.25
Trevesia palmata	2.87	1.75	0.37	4.99
Walsura tubulata	2.51	2.21	0.09	4.81
Magnolia indica	1.08	1.05	2.63	4.75
Amoora wallichi	1.43	1.98	0.51	3.92
Rhus semialata	1.43	1.86	0.56	3.86
Pentapanax leschenaultii	1.79	0.93	0.83	3.56
Betula cylindrostachys	1.08	0.58	1.87	3.53
Rhododendron fuelgen	1.08	1.98	0.28	3.34
Unidentified	0.36	2.45	0.38	3.18
Machilus villosa	1.79	0.58	0.42	2.80
Nyssa javanica	0.72	0.23	1.75	2.70
Quercus pachyphylla	0.36	0.35	1.51	2.22
Others (40 species)	17.92	8.51	5.55	31.98

Table 3.6 Values of relative frequency (RF), relative density (RDN), relative dominance (RDM) and importance value index (IVI) of trees in elevation zone IV in the Teesta valley, Sikkim. Others represent 18 species with IVI <2.

Species	RF	RDN	RDM	IVI
Abies webbiana	25.77	53.38	82.27	161.42
Rhododendron lanatum	11.34	13.66	3.12	28.12
Acer laevigatum	9.79	4.63	3.37	17.79
Sorbus sp.	8.76	5.51	1.28	15.55
Viburnum nervosum	8.76	4.33	1.34	14.43
Betula utilis	6.70	3.38	1.57	11.65
Meliosma wallichii	3.09	2.79	4.96	10.84
Rhododendron hodgsoni	4.12	1.98	0.36	6.46
Rhododendron decipens	3.09	1.98	0.20	5.28
Rhododendron barbatum	2.58	2.06	0.21	4.85
Rhododendron grande	2.06	2.06	0.29	4.41
Rhododendron thomsonii	1.55	1.10	0.19	2.84
Rhododendron sp.	1.55	0.88	0.13	2.56
Others (18 species)	10.82	2.28	0.71	13.81

3.3.5. Girth class distribution of trees

A total of 3,858 stems were measured in the four zones (I-IV) of the study area. Girth class distribution of all species recorded in four zones is presented in Figure 3.2. Tree density decreased with increasing GBH. Trees with GBH 21-40 cm dominated in all zones with declining density towards higher GBH classes. In zone III, though the maximum density was observed in 21 - 40 cm girth class, trees with >200 cm GBH were also recorded in significant numbers (Figure 3.2a). The density of trees in different size classes was not significantly different among zones (Kruskal-Wallis test, $p > 0.05$).

The number of tree species declined with increasing GBH representing maximum number of species in lower GBH classes. The number of species in each GBH classes was significantly different among zones (Kruskal-Wallis test, $H = 11.32$, $p = 0.01$). Species richness declined monotonically towards higher GBH classes in zones II and IV. In zone I, number of species decreased from 21 cm GBH to 200 cm GBH with a rise in highest GBH class (>200 cm), whereas in zone III species richness did not show much variation in different size classes (Figure 3.2b).

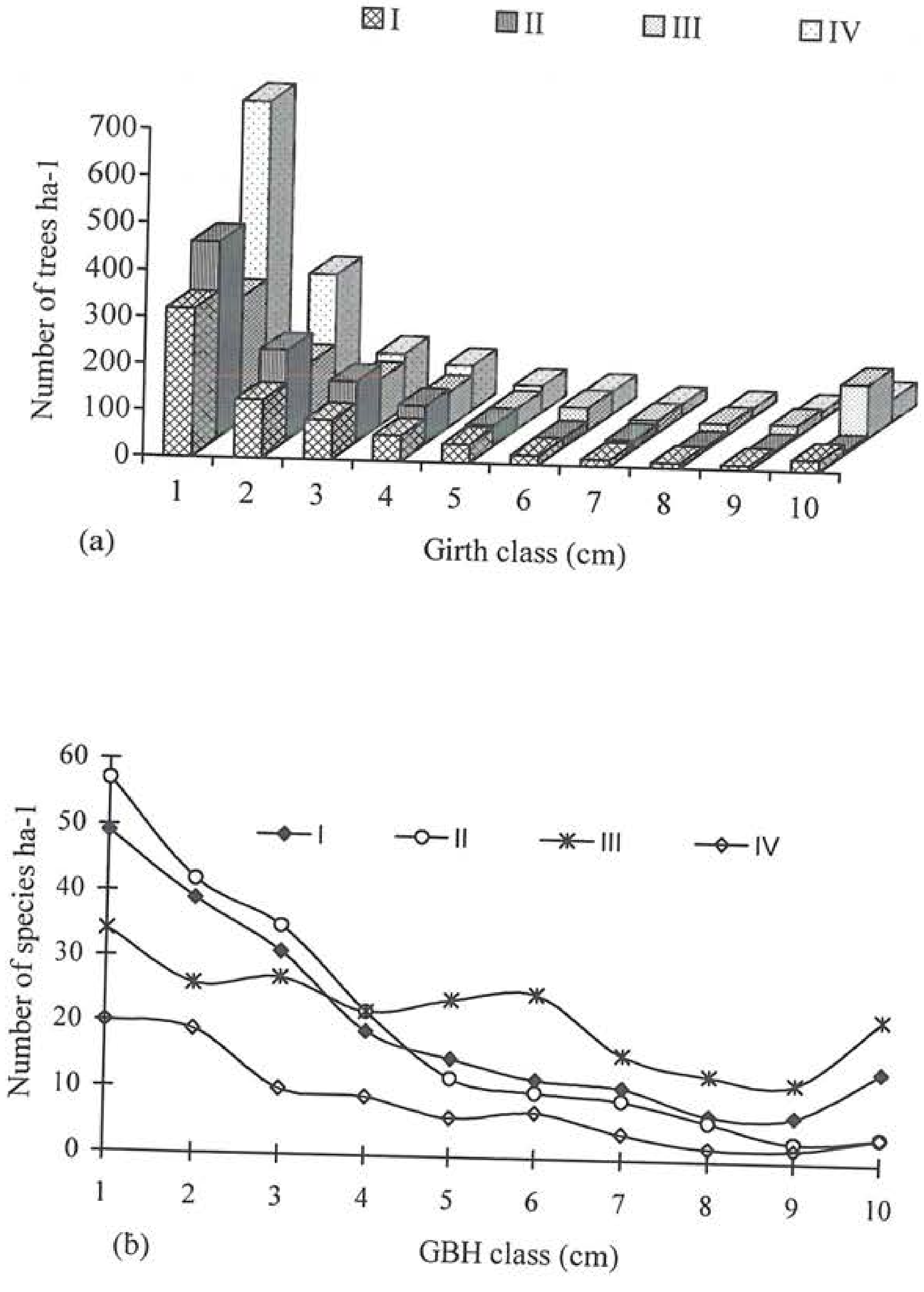

Figure 3.2 Girth class distribution of trees (> 20 cm GBH) in four elevation zones of Teesta valley, Sikkim, (a) Density ha^{-1} and (b) Number of species ha^{-1}. Numbers 1-10 in the x-axis are GBH classes (1 = 21-40 cm, 2 = 41-60 cm, 3 = 61-80 cm, 4 = 81-100 cm, 5 = 101-120 cm, 6 = 121-140 cm, 7 = 141-160 cm, 8 = 161-180 cm, 9 = 181-200 cm and 10 = >200 cm); I, II, III and IV are elevation zones in the Teesta valley.

3.4. DISCUSSION

Present study recorded 216 species of woody plants belonging to 64 families. The result indicates that Teesta valley harbors rich floral diversity. The sampling sites were located at different vegetation types and elevation. Hence, the recorded species comprise tropical, sub-tropical and temperate flora contributing to the total richness of plants in the Teesta valley. The moist climate due to high rainfall, and wide variation in elevation along the valley have resulted in a variety of habitats creating unique ecological niches for the existence of different plant species. In addition to the native flora, Sikkim including Teesta valley represent different phytogeographic elements (Singh and Chauhan, 1997), which adds to the floral wealth of the study area.

Species diversity of shrubs and trees in the Teesta valley was high (>3). The value is comparable to woody plant diversity in different parts of Sikkim (Sundriyal *et al.*, 1994; Sundriyal and Sharma, 1996; Chettri, 2000; Chettri *et al.*, 2006) as well as other Himalayan forests (Upadhaya *et al.*, 2003, 2006; Tripathi *et al.*, 2004).

Species richness and diversity of trees and shrubs were high in zones I and II (tropical and sub-tropical forests) as compared to zones III and IV (temperate forest). The lower diversity of plants in the temperate vegetation is a common trend (Begon *et al.*, 2006; Bhattarai and Vetaas, 2006) and is reported to be due to low rate of evolution and diversification of communities (Fisher, 1960), slow regeneration of component species (Chettri *et al.*, 2002, 2006) or cold climatic conditions (Carpenter, 2005; Sánchez-González and López-Mata, 2005; Begon *et al.*, 2006).

Trees and shrubs in the Teesta valley showed maximum richness in zone II (900 - 1800 m elevation). Species richness followed hump-shaped relationship with elevation showing a peak at around 1500 m. The result concurs with other studies in different parts of the Himalaya (Oommen and Shanker, 2005; Grau *et al.*, 2007). Species richness of trees in the Eastern Himalaya demonstrated two major peaks, one between 600 - 1000 m and the other between 1600 - 1800 m elevation (Behera and Kushwaha, 2007). Tripathi *et al.* (2004) observed maximum species richness, diversity and evenness of trees, shrubs and saplings at 1900 m elevation in sub-tropical forest in Meghalaya, Eastern Himalaya. A mid-elevation peak of woody plants species was observed in the Western and Central Himalayan elevation gradient (Grytnes and Vetaas, 2002; Carpenter, 2005; Oommen and Shanker, 2005; Bhattarai and Vetaas, 2006) and in China (Yu and Saprunoff, 2005). Other plant groups such as epiphytes, ferns and bryophytes are also reported to follow a mid-elevation peak in the Himalaya and elsewhere (Bhattarai and Vetaas, 2003; Cardelus *et al.*, 2006; Grau *et al.*, 2007).

Several factors have been proposed to explain high diversity at mid-elevation (Brown, 2001; Lomolini, 2001; Grytnes and McCain, 2007). Factors such as temperature, humidity and soil characteristics are considered as determinant of mid-elevation peak in plant species richness (Kessler *et al.*, 2001; Bhattarai *et al.*, 2004; Carpenter, 2005; Sánchez-González and López-Mata, 2005). Comparatively high rainfall and low variation in temperature would have resulted in high diversity at mid-elevation (900 - 1800 m) in the Teesta valley. Ongoing succession process that tends to increase species diversity in a community results in greater species richness particularly in areas represented by low fluctuation in environmental parameters (Odum, 1996). One or two factors cannot be considered as sole determinant of the distribution pattern of species, and it is impossible to evaluate the relative importance of each factor (Grytnes and Vetaas, 2002). Complex interactions of biotic and abiotic factors might result in the observed richness pattern. Oommen and Shanker (2005) suggested that multiple correlated factors could cause unimodal patterns in overall species richness.

Comparatively, tree evenness was low in zone IV. It is because of unequal distribution of individuals per species. *Abies webbiana* was a very dominant species representing more than 50% of trees in this zone. Other species were represented by only a few individuals (< 10 in most cases).

Tree density, in total as well as in all the zones, was higher than reported from similar forest and elevation sites in West Sikkim (Chettri, 2000; Chettri *et al.*, 2002) but within the range reported from the Himalayan and other tropical forests in India (Saxena and

Singh, 1982; Sundriyal and Sharma, 1996; Metz, 1997; Parthasarathy, 2001; Tripathi *et al.*, 2004; Kumar *et al.*, 2006). Lower tree density in West Sikkim might be due to high anthropogenic pressures as the study was conducted at forest corridor facing several disturbances.

Tree density in the Teesta valley differed among vegetation zones. Variation in tree density is attributed to forest community type, forest age class, tree species and size class, site history and site condition (Parthasarathy, 2001; Kumar *et al.*, 2006). Tree density in zone IV (temperate coniferous forest) was significantly higher than other zones (tropical, sub-tropical and broad-leaved forests). This might be due to higher anthropogenic pressures in low elevation areas. The present study augments the study of Chettri (2000) showing high tree density in forest at high elevation in comparison to mid-elevation forests. Density of trees is determined by complex interaction of biotic and abiotic factors as well as the regenerating potential of seedlings and saplings (Tripathi *et al.*, 2004; Davidar *et al.*, 2007).

The high density of shrubs in the Teesta valley shows that undergrowth vegetation is dense and is comparable with the regenerating seedlings and saplings in Khanchendzonga Biosphere Reserve, Sikkim (Chettri, 2000). Since 89 species of shrubs were saplings of trees, present data indicates high regeneration of most tree species. The density of shrubs was lowest in zone V compared to other zones. This is due to reduction in vegetation in colder climatic conditions of sub-alpine and alpine region of the Teesta valley. The low density of shrub in the tropical forest (zones I and II) compared to temperate ones (zone III and IV) might be due to anthropogenic pressures as discussed above for trees.

Basal area of trees in zones I, II and IV of Teesta valley is comparable to Mamley Watershed (Sundriyal and Sharma, 1996) and Khanchendzonga Biosphere Reserve (Chettri, 2000) in Sikkim and in other parts of the Himalaya (Saxena and Singh, 1982; Bhandari *et al.*, 1997; Metz, 1997; Tripathi *et al.*, 2004), and India (Kumar *et al.*, 2006) but in zone III it is higher than reported by these studies. Although trees with smaller GBH dominate in zone III as in all other zones, the numbers in highest GBH class were comparatively higher in this zone (Figure 3.2a) contributing to high basal area. High annual precipitation and low disturbance in zone III might have led to the persistence of higher number of large sized trees. Tree basal area increased nearly fivefold from 1500 m to 2500 m in a forest in Mexico (Vàzquez and Givnish, 1998). It is hypothesized that the low basal area at lower altitudes is due to drought or sporadic human disturbance or higher rate of mortality relative to tree growth (Vàzquez and Givnish, 1998). Based on the density and basal area, it can be concluded that the Teesta valley still has good forest cover that is comparable with some of the undisturbed forests in Asia and other continents (Pascal and Pelissier, 1996; Kumar *et al.*, 2006).

Species composition of trees differed among the zones. The result is as expected because the sampled vegetation zones were located at different elevations and exposed to different environmental conditions and degrees of disturbance. Similar results were reported by other studies undertaken in different elevation sites in Sikkim and elsewhere (Chettri, 2000; Parthasarathy, 2001; Tripathi *et al.*, 2004; Carpenter, 2005; Cardelus *et al.*, 2006). The forest of Teesta valley faces anthropogenic pressures that vary in type and degree among different zones. Such pressure also has a strong influence on community composition and vegetation structure (Tripathi *et al.*, 2004). The floristic composition of a vegetation community is also determined by climate, geology, soil, drainage conditions and nutritional status (Small *et al.*, 2004).

Girth class distribution of trees showed L-shaped or left skewed pattern having higher number of trees with small GBH. This result indicates healthy regeneration of forest. This pattern is a common feature in undisturbed forests and has been reported by many other studies (Sukumar *et al.*, 1992; Pascal and Pelissier, 1996; Chettri, 2000; Jayson and Mathew, 2002; Small *et al.*, 2004; Sagar and Singh, 2005; Davidar *et al.*, 2007). The size distribution curve for tree species differed among different zones, especially zone III. Although most of the species belong to smaller GBH category, significant numbers were observed in high GBH class. The difference in curve might be due to difference in anthropogenic disturbance and species composition at different locations (Jayson and Mathew, 2002; Sagar and Singh, 2005).

Many factors such as temperature, rainfall, evaporation and transpiration rate, productivity, past history and man-made disturbance should be assessed regularly to understand distribution of plant communities along the elevation gradient. Establishment and repeated monitoring of permanent plots aids in understanding habitat composition, structure and dynamics which would help in evaluating current management practices and impact of disturbance to the forest ecosystems (Sukumar *et al.*, 1992; Ayyappan and Parthasarathy, 2004; Small *et al.*, 2004).

3.5. SUMMARY

Woody plant diversity and vegetation structure was studied at different elevation zones along the Teesta valley in Sikkim following quadrat sampling method along predetermined transects. A total of 216 species of woody plants belonging to 64 families were recorded during the study. In total, 3,858 individuals belonging to 170 species were trees and 15,299 individuals representing 135 species were shrubs including saplings of trees. Shannon-Weaver diversity and evenness of trees were 3.9 and 0.77 respectively. These values for shrubs were 3.1 and 0.62. Tree and shrub species richness was the highest in zone II. Species richness and elevation followed hump-shaped relationship with a peak at around 1500 m. Tree diversity was maximum in zone II, evenness and basal area in zone III and density in zone IV. Similarly, shrub diversity was the highest in zone I, shrub density in zone III, whereas evenness was maximum in zone V. Girth class distribution of trees showed L-shaped or left skewed pattern, showing decrease in species richness and density with increasing GBH classes. The number and species of small sized trees (21-60 cm GBH) were more abundant than the large trees indicating healthy regeneration of forests.

CHAPTER 4

BIRD COMMUNITIES

4.1. INTRODUCTION

Biotic community refers to the assemblage of organisms living together in a prescribed area or habitat (Odum, 1996; Begon *et al.*, 2006). The abundance and distribution pattern of organisms are shaped by various biotic, abiotic and historical factors, which vary at different spatial and temporal scales (Tokeshi, 1999). Although the observed pattern repeats at many forms and scales, the generalizations across regions and taxa is doubtful (Lawton, 1999).

The structure of bird communities has been focused by many studies in different parts of the world (MacArthur *et al.*, 1966; Cody, 1974, 2001; Perrins and Birkhead, 1983; Wiens, 1989; Keast, 1990; Terborgh *et al.*, 1990; Willson and Comet, 1996a, b; Latta *et al.*, 2003). Most of the published literature deals with the bird communities of temperate forests and comparatively less information is available on tropical bird communities (Terborgh *et al.*, 1990; Thiollay, 1994; Robinson *et al.*, 2000; Jayson and Mathew, 2002; Vijayan and Gokula, 2006; Blake, 2007).

Bird species richness, diversity and community composition vary among the regions (Karr, 1976a; Wiens, 1989) as well as among different habitats within the same region (Johnsingh and Joshua, 1994; Cody, 2001; Sultana *et al.*, 2007). Several studies have attempted to identify the factors responsible for patterns and processes in avian diversity and their variation across regions and habitats (MacArthur and MacArthur, 1961; Wilson, 1974; Roth, 1976; Gillespie and Walter, 2001; Blake, 2007).

Biotic community differs in species richness and their abundance forming definite pattern across habitats or elevation zones (Wiens, 1989). The distribution pattern of individuals per species provides basis for the examination of species diversity and stability of the community (Magurran, 1988). Although simple presence-absence data is adequate for the study of distribution and biogeography of birds, indices of abundance are important for evaluating the trend in population change over habitat succession (Verner, 1985). Several models were formulated but only four, namely geometric series, logarithmic series, lognormal distribution and MacArthur's broken stick model have generally been used for examining diversity based on species-abundance data (Magurran, 1988; Krebs, 1989; Southwood and Henderson, 2000). Lognormal distribution is the most general pattern obtained for bird species-abundance data. Although, many ecologists claim the pattern as mere mathematical phenomenon, it has its own biological significance (Magurran, 1988; Weins, 1989).

Temporal and spatial variations in species richness and abundances are characteristic of most bird communities. Short-term temporal changes occur among seasons due to changes in weather condition (Vijayan, 1984; Kwok and Corlett, 1999; Kai and Corlett, 2002) or fluctuations in food resources, productivity and habitat quality (Loiselle and Blake, 1991; Malizia, 2001; Hulbert and Haskell, 2003; Norris and Marra, 2007). The diversity and abundance reaches peak when food resources such as insect and fruit become abundant (Gokula, 1998; Kwok and Corlett, 1999; Blake and Loiselle, 2000; Nirmala, 2002). Seasonal fluctuation of birds among different habitats is caused by movements of birds within and between habitats due to variations in biological and environmental factors among seasons (Poulin *et al.*, 1993; Norris and Marra, 2007). Population of birds in tropical forests is found to be more stable in all seasons compared to temperate forests (Gill, 1995).

Endemic and threatened species draws considerable attention from ecologists and conservationists compared to others. These species are more sensitive to disturbance and invites immediate conservation concern (BirdLife International, 2001; Wijesinghe and Brooke, 2005; Lei *et al.*, 2003, 2007; Pandit *et al.*, 2007). Information on status and distribution of threatened and endemic birds, therefore, aids in prediction of disturbance level and execution of conservation effort at all potential sites of their occurrence (Stattersfield *et al.*, 1998; Riley, 2002; Robin and Sukumar, 2002).

Reproduction is energy costing process and is considered to have negative effects on survival and future fertility of birds (Newton, 1989; Partridge, 1989). The success or faliure of reproduction decides the overall fitness of birds (Walsberg, 1978, 1983). The reproductive success depends on timing and rate of reproduction, and the nest-site selection (Perrins and Birkhead, 1983; Holway, 1991). The time of reproduction is determined by food availability, predation pressure and environmental factors (Lack, 1968; Perrins and Birkhead, 1983; Martin, 1987; Perrins, 1996; Lloyd, 1999; Conway and Martin, 2000; Simmons *et al.*, 2004; Valentina *et al.*, 2005). Production of reproductively viable offspring is the ultimate goal of reproduction.

Nesting is the most critical stage of life cycle in birds (Martin, 1995) and is directly related to reproductive success (Rader *et al.*, 2007). The presence absence data of birds provides information only on the occurrence of birds in a particular habitat, whereas nesting data gives information on its ability to utilize the resources in that habitat (Lindell and Smith, 2003). Hence, presence of suitable nesting site play major role in the choice of breeding habitat (Bosch and Sol, 1998).

Nest-site selection has strong effects on production and fitness of offspring (Martin and Roper, 1988). Availability of potential nesting sites and nest plants determine the nest-site selection in birds (Kozma and Mathews, 1997; Burke and Nol, 1998). Vegetation around the nests and area of the forest patch influence the probability of success or failure in breeding (Burke and Nol, 1998; Stephens *et al.*, 2003; Smith *et al.*, 2007) because breeding birds depend on resources associated with vegetation (Mills *et al.*, 1991). Selection of unsuitable site jeopardizes reproductive investment as well as survival of the parents (Holway, 1991). Therefore, potential nesting sites must provide concealment from predators (Martin and Roper, 1988, Holway, 1991; Gokula and Vijayan, 2001), surplus and easy access to food (Lenington, 1980; Orians and Beletsky, 1989; Burke and Nol, 1998) and protection from unsuitable weather conditions (Walsberg, 1985; Rader *et al.*, 2007). Identifying crucial factors involved in nest-site selection is essential for implementing conservation measures for bird and its habitat (Pandey and Mohan, 1993; Vijayan *et al.*, 1998b, 2000; Gokula and Vijayan, 2001).

Systematic study on birds of the Indian sub-continent initiated during 19th century and the aspects such as taxonomy, distribution and natural history has been fairly covered (Jerdon, 1982; Ali and Ripley, 2001). However, bird community study in this region gained considerable attention only during recent years. Among the available literatures, most are from peninsular India and relatively a few from the Himalayan region (Chapter 1 Pp.9). Eastern Himalaya, which includes Sikkim, is probably the most diverse and least studied region of India (Crosby, 1996; Islam and Rahmani, 2004). After the exhaustive work on taxonomy and systematics by Ali (1962), the birds of Sikkim remained out of scientific focus for almost 40 years except some casual observations (Ganguli-Lachungpa, 1990a, b, c, 1992, 1998a, b, c, d). Recently, Chettri *et al.* (2001, 2005) studied the impact of human disturbance on bird communities in Khanchendzonga Biosphere Reserve, West Sikkim. Further, most of the studies on birds in India as well as in Sikkim were undertaken within the protected areas. Forest outside protected area network, although equally important for biodiversity and landscape conservation, has not been given due attention (Prasad *et al.,* 1998; Nirmala, 2002).

Baseline information on breeding of most bird species of the Indian subcontinent is available (Ali & Ripley, 2001). Breeding ecology of some of the terrestrial species or groups has been thoroughly covered (Grub, 1974; Vijayan, 1975, 1980, 1984; Khan, 1978; Shukkur and Joseph, 1980; Becking, 1981; Price and Jamdar, 1991; Islam, 1994; Natarajan 1997; Mudappa, 2000; Somasundaram, 2006; Vinod, 2007). A few studies are also available on breeding bird community or nesting of some groups or species at different parts of India (Price and Jamdar 1990; Sundaramoorthy, 1991; Pandey and Mohan, 1993; Mudappa and Kannan, 1997; Gokula, 1998; Vijayan *et al.*, 1998b, 2000; Gokula and Vijayan, 2001; Nirmala, 2002). Besides breeding records and basic characteristics of nesting provided by Ali (1962), no attempt has been made to study nesting and nest-site characteristics of birds of Sikkim.

This Chapter deals with community structure of birds in terms of species richness, diversity, evenness, density, and abundance in five vegetation zones located at different elevations along the Teesta valley in Sikkim. Effort has also been made to investigate seasonal variation of bird community in the study area. Breeding bird community and nest and nest-site characteristics of some selected species are also discussed.

4.2. METHODS

4.2.1. Bird sampling

Point count method (Bibby *et al.*, 2000; Javed and Kaul, 2002) was used along the predetermined transects. This method is effective for rapid assessment of bird community, especially when large areas are involved (Verner, 1985; Bibby *et al.*, 2000; Haselmayer and Quinn, 2000; Sorace *et al.*, 2000). Point count method was selected considering the steepness and poor visibility in the study area, the efficiency of the method and also the objective of the study (Bibby *et al.*, 2000; Raman, 2001). In difficult terrain, transects need more attention on the path being walked missing more birds unlike the case with point counts where full attention could be given for counting. The study area being large, more points could be completed per unit time than transects increasing sampling size and covering greater variety of sites as was necessary for the present study (Fletcher *et al.*, 2000; Javed and Kaul, 2002). Description of the site is quicker with point counts than line transects or territory mapping (Bibby *et al.*, 2000) since area sampled with point counts increases geometrically with distance from the observer but only linearly with transects (Verner, 1985). Point counts are suitable for use throughout the year and for counting all categories of individuals (Baillie, 1991). The point count method has been widely used for the study of bird communities in India and elsewhere (Jimenez, 2000; Sorace *et al.*, 2000; Zimmerling and Ankey, 2000; Gillespie and Walter, 2001; Raman, 2003; Raman *et al.*, 2005).

Depending upon the vegetation and elevation of the study area, sampling sites were divided into five zones and a total of 23 transects were laid covering all the zones (Chapter 2, Pp.20). The permanent points, located at minimum 100 m apart from each other, were established in each transect. Totally there were 188 regular points comprising 37, 41, 39, 43 and 28 in zones I, II, III, IV and V respectively. Each point was replicated 1-3 times in each of the four seasons viz. summer, monsoon, post monsoon and winter during June 2003 to March 2006. All five zones were covered during all the seasons except zone V, which could not be sampled during winter due to harsh weather conditions and road blockage due to heavy snow. Overall, 2,616 points were covered after 328 transect replication during the study period.

Count in each point distributed along predetermined transects was conducted for five minutes (Bibby *et al.*, 2000; Raman, 2003; Raman *et al.*, 2005) and all the birds seen or heard were recorded. On encountering a bird, details such as species, number of individuals and the distance from the observer when first sighted were noted. The regular sampling was conducted between 0600 hrs to 0900 hrs in the morning (Poulsen and Krabbe, 1998; Bibby *et al.*, 2000) and occasionally in the evening in higher elevations. Each individual was identified to species using field guide, Grimmet *et al.* (2001). Nomenclature of birds follows Inskipp *et al.* (1996).

4.2.2. Breeding bird sampling

Study on breeding of birds was conducted in four zones (I, II, III and IV) of the study area (Chapter 2, Pp.20). Nest searches were done in transects used for bird census. Overall 16 transects were selected, four in each zones. Searches were made within 10 m on either side of the transects and nests were located following breeding activities of birds. Since, no nesting activity was observed from September to February, nest search was restricted from March to August. Each transect was sampled once in every month covering five times a year (March to July in zones I, II and III, and April to August in zone IV) during 2004 and 2005. In addition, opportunistic and casual observations made during the study period were also considered.

Once the nest is located, details such as species, location, date, presence of eggs/juveniles, clutch size and activities of birds were noted. Variables characterizing the nest-site of birds were measured within 5 m radius from the nest covering 0.0078 ha area at each nest following Titus and Mosher (1981), and Gokula and Vijayan (2001). The list of variables of nest and nest-site measured are given in Table 4.1.

Nest variables include the morphology such as length, width and breadth, and also the vertical height and horizontal position (inner, middle and edge) at which the nest is located. Nest concealment was estimated by viewing the nest at a distance of 5 m in each of four cardinal directions. The method was used following Holway (1991) with modifications considering difficult hilly terrain of the study area. Concealment was measured in percentage (nest not visible at any direction = 100%, visible at one direction

= 75%, visible at two directions = 50%, visible at three directions = 25% and visible at all four directions = 0%). Canopy cover, shrub cover, and ground vegetation and leaf litter cover were visually estimated. Data on disturbance factors such as distance to road or human settlement, number of logs and cut stumps were also collected.

Table 4.1 Nest, nest tree and nest patch variables measured for breeding birds in the Teesta valley, Sikkim.

S. No.	Nest and nest tree variables	S. No.	Nest patch variables
1	Nest width (cm)	1	Canopy cover (%)
2	Nest depth (cm)	2	Shrub cover (%)
3	Nest length (cm)	3	Ground vegetation cover (%)
4	Nest concealment (%)	4	Ground litter cover (%)
5	Nest height (m)	5	No. of trees (>20 cm GBH)
6	Nest tree species	6	Distance to water (m)
7	Nest tree height (m)	7	Distance to road/settlement (m)
8	Nest tree girth at breast height (cm)	8	Number of log and cut stump

Considering the steep terrain, unfavorable weather conditions such as heavy rain during breeding season and logistic problems, the sampling effort and area covered were unequal among elevation zones. Similarly, details on breeding biology could not be observed because the transects were located farther apart and monitoring was difficult due to time and logistical constraints.

4.2.3. Data analysis

Since, sampling efforts were unequal among years, the data from all three years were pooled for analysis. The parameters computed were-

1. Species richness: a cumulative list of species observed.
2. Species abundance: number of individual birds/point.
3. Density: number of birds/ha (Reynolds *et al.*, 1980)

$$D = n * 10000 / \pi r^2 C$$

where D = bird density (numbers/ha), n = total number of birds observed in all counts within the specific radius, r = specific radius (m), C = total number of counts conducted and л = 3.14.

4. Statistical software EstimateS version 7 (Colwell, 2004) was used to estimate the species richness (following 100 randomizations without replacement). Randomizations of sample order were done to eliminate arbitrariness in species accumulation that arises from sampling error or real heterogeneity among the points sampled (Colwell and Coddington, 1994).
    - i) Cole R: Coleman Rarefaction curves estimate richness for a sub-sample of the pooled species, based on all species actually discovered (Colwell, 2004). Rarefaction estimation assumes that all individuals in the community are randomly dispersed and is used to sample large widely spread community (Krebs, 1989).
    - ii) Chao: Chao 1 estimator computes true number of species in an assemblage based on the number of rare species in the sample. It is based on the distribution of individuals among species with singletons and doubletons. Chao 1 estimates richness including missed species in the sample through extrapolation (Colwell and Coddington, 1994; Colwell, 2004). Chao 2 estimator is based on the distribution of species among samples and requires only presence-absence data.
    - iii) Jackknife: Jackknife 1 estimator estimates species richness based on the number of species that occur in only one sample and Jackknife 2 estimator on the number of species that occur in only one sample as well as the number that occur in exactly two samples (Colwell and Coddington, 1994).

Species richness is the most commonly used measure of diversity of a biological community (Gaston, 2000). Total number of species present in an area cannot be detected during sampling, but generating comparable species richness indices are important for conservation planning (Cardelus *et al.*, 2006; Kery and Schmid, 2006; O'Dea *et al.*, 2006). Hence, estimation of species richness through extrapolation is necessary (Colwell and Coddington, 1994). In addition, the estimators allow direct comparison of species richness between sites having unequal sampling effort (Hortal *et al.*, 2006). Among the non-parametric estimators Chao 2, Jackknife 1 and Jackknife 2 were preferred because bird community of the Teesta valley was represented by many rare species (singletons and doubletons); these estimators are less sensitive to the patchiness of the species distribution and variability in the probability of encountering species (Hortal *et al.*, 2006). Since estimators have their own bias and precision, usage of more than one estimator provides better results (Walther and Martin, 2001; Walther and Moore, 2005; O'Dea *et al.*, 2006).

5. The Shannon-Weaver diversity, Evenness and relative abundance were calculated as follows:

i) Shannon-Weaver index, $H' = -\sum p_i \ln p_i$

where pi = proportion of total sample belonging to i^{th} species, ln = natural logarithm.

ii) Evenness, $E = H'/H_{max} = H'/\ln S$

where, H′ is the Shannon-Weaver Index and *S* is the number of species observed.

iii) Relative abundance = n_i*100/N

where, ni = number of Individuals of i^{th} species; N = total number of individuals of all species.

6. The four main models of species distribution, namely geometric series, log series, log normal and MacArthur's broken stick models were tested to investigate the best fit for species abundance curve. Rank abundance plots were constructed following the methods described by Magurran (1988). The expected number of species in each abundance class was calculated using statistical software Species Diversity and Richness version 2.65 (Henderson and Seaby, 2001). The difference in observed and expected number of species in each abundance category was tested using χ^2 goodness of fit test.

7. Jaccard species similarities between different elevation zones were calculated using statistical software EstimateS version 7 (Colwell, 2004).

Species richness, diversity, evenness and density of birds were calculated for total study area as well as separately for each transect, elevation zone and season. The estimation of species using non-parametric estimators and species accumulation pattern was obtained individually for five elevation zones. The richness, diversity and densities thus obtained were compared among zones. Analysis of Variance (ANOVA) was performed to test significant variation of these parameters among elevation zones during different seasons. Correlation analysis was performed to find out the association of bird community attributes with climatic factors.

Depending upon the diet of a bird, species and individuals were categorized into six trophic groups namely carnivore, frugivore, granivore, insectivore, nectarivore and omnivore based on the dietary information given by Ali (1962), Ali and Ripley (2001) and field observations. The species with mixed diet were arranged to the category based on major part of their diet. The species feeding on equal proportion of insects and fruits, insects-grains or insects-nectar was included under omnivores (Latta *et al.*, 2003).

Due to small sample size, the data on breeding birds of both years were pooled for analysis. Number of breeding species and nests observed were estimated in total as well as for each zone. The number of breeding species and nest observed in each month from April to August were also estimated. Descriptive statistics such as mean and standard deviation of nest and nest-site characteristics of the species with ≥ 10 nests were calculated. Data on nest and nest-site characteristics of individual species from all zones were pooled for analysis. Nests were classified into six types, namely Ground nest, Cavity nest, Dome nest, Pendulous nest, Platform nest, and Cup nest following Ali (1962), Pettingill (1985), and Ali and Ripley (2001). Cup nest includes statant cup and suspended cup.

All statistical analyses were performed using software SPSS version 10.0, Species Diversity and Richness version 2.65, EstimateS version 7 and Microsoft Excel for windows.

4.3. RESULTS

A total of 22,939 birds belonging to 299 species was recorded from five elevation zones of the study area during regular sampling and 30 species opportunistically. Thus 329 species representing 44 families of birds were observed in the Teesta valley during this study (Appendix I). Family Sylviidae comprised maximum number of species (82) followed by Muscicapidae (52 species) and Corvidae (26 species). Thirteen families were represented by one species each.

4.3.1. Species richness

Observed species richness (cumulative number of species) in different zones varied from 51 to 151, with the highest number of species in zone II and lowest in zone V (Table 4.2). Species accumulation curves based on number of point count indicated that most of the species were detected in zones I, IV and V but some new species were being added in zones II and III (Figure 4.1). Rarefaction curves are essentially idealized species accumulation curves that allows to compare the expected species richness of the different habitats for a constant sampling effort at each site (Colwell and Coddington, 1994; O'Dea and Whittaker, 2007). The rarefaction curves of birds in five zones of Teesta valley showed that zone II and III had higher number of species than other zones at every sampling effort (Figure 4.1).

The estimated species richness (Chao 2, Jackknife 1 and Jackknife 2) also showed highest value in zone II compared to other zones (Table 4.2). Among the three estimators, Jackknife 2 estimated higher number of species in zones II, III and V, whereas Jackknife 1 had higher values in zones I and IV. It is to be noted that Jackknife 2 had comparatively lower standard deviation than Jackknife 1 and Chao 2 in all the zones (Table 4.2).

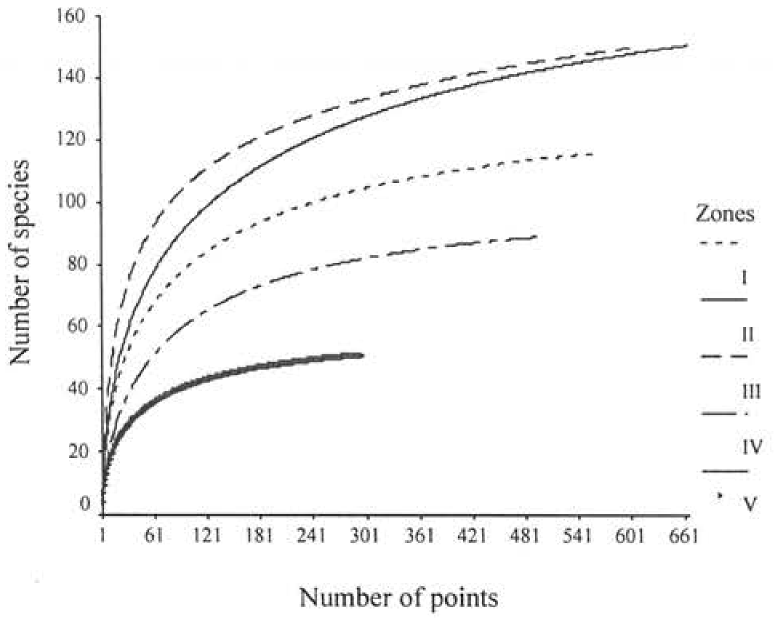

Figure 4.1 Species rarefaction curves of birds, generated with EstimateS version 7 (Colwell, 2004), based on number of point counts in five elevation zones (I, II, III, IV and V) in the Teesta valley, Sikkim.

4.3.2. Species diversity and evenness

Shannon-Weaver diversity (H′) and Evenness (E) of birds, for pooled samples from all the zones, was 4.6 and 0.78 respectively. Species diversity was >3 in all the zones which ranged from 3.27-3.97. Zone III had the highest bird species diversity and zone V had the lowest. Evenness was generally high (>0.74) and similar among the zones (range 0.74-0.78) with comparatively higher value in zone V and lower in zone I (Table 4.3).

4.3.3. Species abundance and density

Overall, density of birds was 26.2 individuals/ha with detection rate of 7.8 birds per point. Detections of birds were not equal among zones. Total number of birds observed ranged from 1,169 in zone V to 7,750 birds in zone III. Detection rate or abundance (mean number of birds detected per point count) was the highest in zone III and lowest in V. Bird density also followed similar pattern having highest density in zone III and lowest in zone V (Table 4.3).

Table 4.2 Observed and estimated (Chao 2, Jackknife 1 and Jackknife 2) bird species richness in different elevation zones of the Teesta valley, Sikkim.

Zones	Observed species	Chao 2±SD	Jackknife 1±SD	Jackknife 2±SD
I	116	122.2±4.83	130.97±3.82	130.01±1.21
II	151	176.26±14.0	178.96±5.18	192.94±1.0
III	150	164.92±9.01	172.96±4.7	179.96±1.21
IV	89	92.96±3.77	99.98±3.28	98.01±0.81
V	51	54.6±4.84	57.98±2.61	59.98±0.55

Table 4.3 Densities (birds/ha), Abundances (birds/point), Shannon-Weaver diversity (H′) and Evenness (E) of birds in different elevation zones of the Teesta valley, Sikkim.

Zones	No. of points sampled	H′	E	Density±SD	Individuals/point±SD
I	560	3.64	0.74	19.5±48.3	7.5±18.6
II	665	3.88	0.76	25.1±41.5	7.5±12.5
III	600	3.97	0.77	56.7±146.4	13.1±33
IV	495	3.5	0.76	10±14.6	4.5±6.6
V	296	3.27	0.78	6.8±16.6	4.3±10.3
Total	2616	4.6	0.78	26.2±79	7.8±20

4.3.4. Relative abundance

Out of 299 species observed during sampling, 20 dominant species comprised around 50% birds of the study area (Table 4.4). Around 45% species (133) had less than 10 individuals including 32 singletons and 25 doubletons. Black Bulbul (relative abundance 6.34) was the most abundant bird species in the Teesta valley followed by Rufous Sibia (4.59), Striated Laughingthrush (4.32) and White-throated Laughingthrush (3.22) (Table 4.4). Abundant species differed among vegetation zones. The highly abundant species in zone I were Black Bulbul (11.7), Spangled Drongo (8.99), Black-chinned Yuhina (7.33) and Grey Treepie (5.54); similarly, Striated Laughingthrush (8.29), Black Bulbul (7.63), Rufous Sibia (5.04) and Green-backed Tit (5.02) in zone II and Rufous Sibia (9.42), White-throated Laughingthrush (8.81), Chestnut-crowned Laughingthrush (5.55), and Striated Laughingthrush (5.12) in zone III. Species such as Coal Tit (14.75), Greenish Warbler (8.40), Rufous-vented Tit (8.36) and Grey-crested Tit (6.91) in zone IV and

Grandala (13.79), Snow Pigeon (10.90), Rosy Pipit (8.67) and Red-billed Chough (6.34) in zone V were the abundant species.

Table 4.4 Twenty most abundant bird species comprising 50% individuals observed in the Teesta valley, Sikkim.

Sl No.	Species	Relative abundance
1	Black Bulbul	6.34
2	Rufous Sibia	4.59
3	Striated Laughingthrush	4.32
4	White-throated Laughingthrush	3.22
5	Green-backed Tit	2.65
6	Whiskered Yuhina	2.61
7	Black-chinned Yuhina	2.44
8	Ashy Drongo	2.38
9	Great Barbet	2.37
10	Spangled Drongo	2.28
11	Yellow-bellied Fantail	2.10
12	Chestnut-crowned Laughingthrush	1.98
13	Blue Whistling Thrush	1.90
14	Scarlet Minivet	1.76
15	Coal Tit	1.59
16	Chestnut-crowned Warbler	1.57
17	Grey Treepie	1.52
18	Greenish Warbler	1.47
19	Black-throated Tit	1.44
20	Grey-hooded Warbler	1.44
	Total	49.98

4.3.5. Species abundance distribution patterns

Species abundance distribution patterns of birds of the Teesta valley showed that most of the species are rare with very few birds, whereas a few dominant species represented most individuals (Figure 4.2). Species abundance distribution pattern in different zones showed slight variation among each other and also from the total bird population. All the four models described for species-abundance data (Magurran, 1988; Krebs, 1989) were tested for best fit to the present data. The species-abundance pattern of birds followed truncated log-normal distribution for total bird population as well as for all the zones except zone II which did not fit to any models. There was no significant difference between observed and expected number of individuals among abundance categories in all the cases, except in zone II (χ^2 test; Table 4.5).

Table 4.5 Chi-square values (χ^2) between observed and expected number of individuals among abundance categories of birds in the Teesta valley, Sikkim.

Zones	χ^2	p	**Df**
I	3.64	0.82	7
II	21.36	0.006	8
III	7.32	0.5	8
IV	5.59	0.58	7
V	3.9	0.68	6
Overall	13.22	0.21	10

4.3.6. Exclusive and generalist species

Present study observed both exclusive (restricted to one elevation zone) and generalist (present in two or more zones) birds in the Teesta valley. Out of the total species observed (329), 156 (47.4%) were exclusively recorded in one specific elevation zone. Among these exclusives, 83 species (53%) were recorded only 1-2 times and remaining 73 species were relatively common to specific zones. Among zones, maximum of 41 species were restricted to zone III. Similarly, zones I, II, IV and V harbored 38, 28, 20 and 29 exclusive species respectively. However, percentage of exclusive species followed different pattern among zones. Out of 51 species observed in zone V more than 57% were exclusive species. Likewise, 33% species in zone I, 27% in zone III, 22% in zone IV and 19% in zone II were exclusives.

Generalist birds comprised 53% (173) species observed in the Teesta valley of which three species (Blue Whistling Thrush, Greenish Warbler and White-capped Water Redstart) occurred in all the five elevation zones. Out of total generalist species, 10 species occurred in four zones, 48 species in three zones and remaining 115 species were observed in only two zones. Although species richness was high in zone II, 80% birds found here were observed in other zones. Despite low species richness in zone V, 57% of the total species observed in this zone were exclusive species.

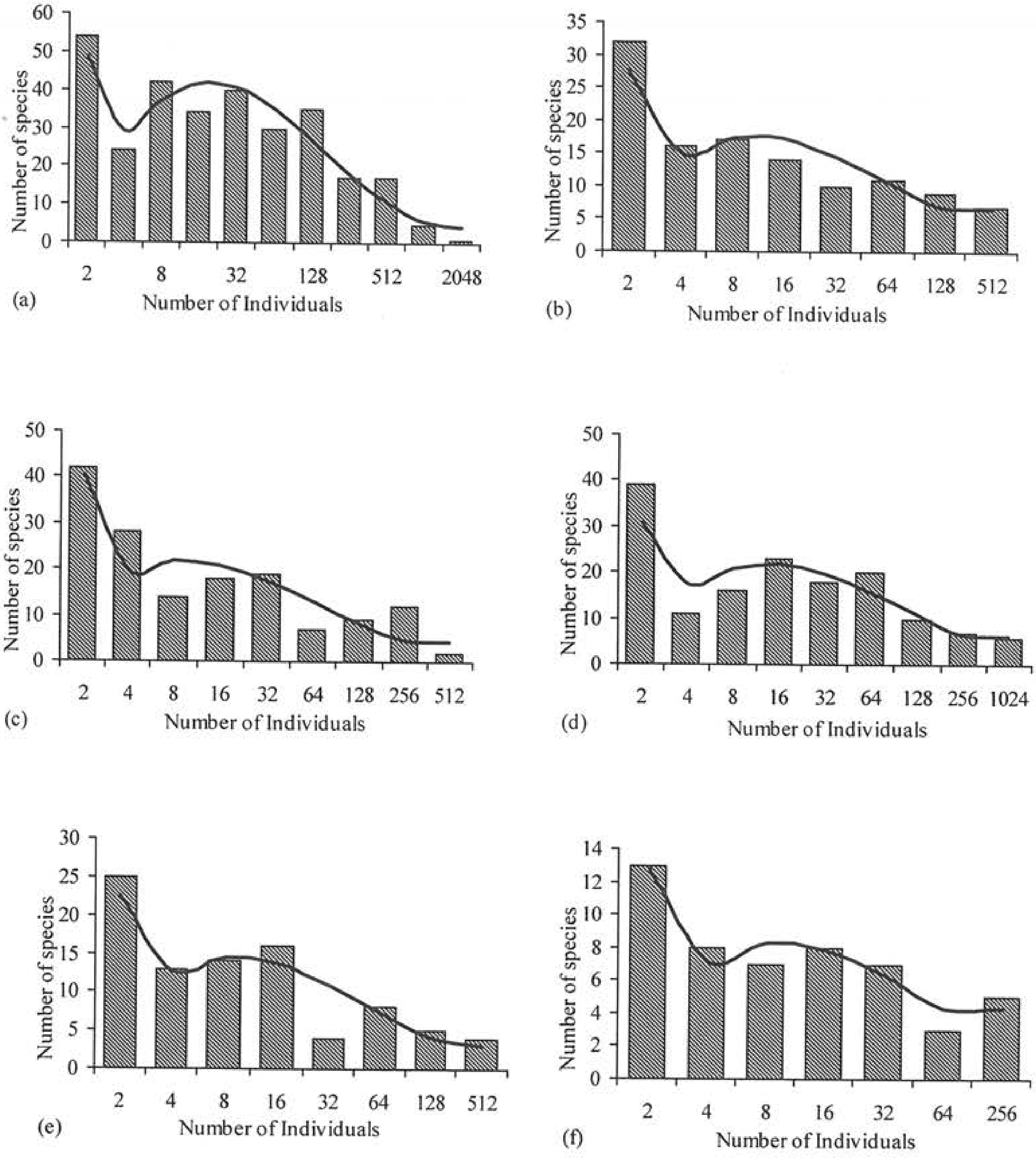

Figure 4.2 Species-abundance distribution patterns of birds in the Teesta valley, Sikkim. (a) Overall, (b) zone I, (c) zone II, (d) zone III, (e) zone IV, (f) zone V. Bar and line denotes observed and estimated species respectively. Truncated lognormal model were fitted to species abundance data (Henderson and Seaby, 2001).

4.3.7. Species similarities among elevation zones

Zones II and III shared maximum number of species (92) followed by zones I and II (87). Zone I and V had only seven species in common. Jaccard similarity index between different pairs of elevation zones is given in Table 4.6. Similarity indices were generally low, with scores of 0.04-0.4 for elevation zone pairs. Among the zone pairs, maximum similarity was observed between zones I and II (0.4) and minimum between zone I and V (0.04). Similarity was comparatively low between zones III and IV (0.24) among the adjacent zones.

Table 4.6 Species similarity matrix of birds between different elevation zones of the Teesta valley, Sikkim. Jaccard similarity index are to the left; number of species shared are to the right; total number of species observed in each zone are in the diagonal.

Zones	**I**	**II**	**III**	**IV**	**V**
I	**116**	87	54	18	7
II	0.4	**151**	92	33	10
III	0.21	0.37	**150**	53	19
IV	0.08	0.14	0.24	**89**	33
V	0.04	0.05	0.09	0.25	**51**

4.3.8. Seasonality

Species richness and density of birds observed in the Teesta valley in different seasons (winter, summer, monsoon and post-monsoon) are given in Table 4.7. Overall, species richness as well as density was high during summer and low during winter. Species richness of birds varied significantly among seasons (ANOVA, $F = 12.27$, $p< 0.001$). Similarly, bird density also showed significant variation among the seasons ($F = 13.64$, $p< 0.001$). Marked seasonal variation in bird species richness and density was observed in different elevation zones. Species richness was relatively high in zones I, II, IV and V during summer, whereas it was during monsoon in zone III. Similarly, density was high during summer in zones I and V and during monsoon in zones II, III and IV. It was observed that in all the zones species richness as well as density was maximum in summer or monsoon, minimum in winter with intermediate value during post monsoon, though seasonal fluctuations in zones IV and V is more than the lower three zones (I, II and III; Table 4.7).

Overall, diversity was the highest during monsoon (H` = 4.46) and lowest during winter (H`= 3.99). Diversity was maximum during post monsoon in zones I, II and IV and during monsoon in zones III and V. Species diversity was lowest in zone V in all the seasons. Shannon-Weaver bird species diversity also showed seasonal variation among zones (Table 4.8). Diversity was the highest in zone III during summer (H`= 3.75) and monsoon (H`= 3.81) and in zone II during post monsoon (H`= 3.64) and winter (H`= 3.39). Evenness showed very little variation among seasons; high during monsoon (0.83) and low during post monsoon (0.80). Among zones, evenness was the maximum in zone IV during winter, zone III in summer, zone V in monsoon and zone II in post monsoon.

Table 4.7 Seasonal variation in species richness (SR) and density (D) of birds in total and five elevation zones (I, II, III, IV and V) along the Teesta valley, Sikkim.

Seasons/ Zones	**I**		**II**		**III**		**IV**		**V**		**Total**	
	SR	D	SR	D	SR	D	SR	D	SR	D	SR	D
Winter	53	15.7	69	23.2	59	49.2	8	4.2	-	-	131	18.3
Summer	85	24.5	89	24.2	99	57.6	59	10.9	35	9.8	227	21.5
Monsoon	61	22.0	85	33.6	108	58.5	53	13.5	32	6.0	216	20.2
Post monsoon	79	21.5	80	31.7	73	53.0	25	8.0	20	3.4	184	19.7

Table 4.8 Seasonal variation of Shannon-Weaver species diversity (H') and Evenness (E) of birds in total and five elevation zones along the Teesta valley, Sikkim.

Seasons/ Zones	**I**		**II**		**III**		**IV**		**V**		**Total**	
	H'	E	H'	E	H'	E	H'	E	H'	E	H'	E
Winter	3.14	0.79	3.39	0.80	3.29	0.80	1.89	0.91	-	-	3.99	0.82
Summer	3.39	0.76	3.57	0.79	3.75	0.81	3.25	0.80	2.81	0.79	4.39	0.81
Monsoon	3.44	0.83	3.48	0.78	3.81	0.81	3.28	0.82	2.94	0.85	4.46	0.83
Post monsoon	3.57	0.82	3.64	0.83	3.41	0.79	2.44	0.75	2.19	0.73	4.21	0.80

4.3.9. Trophic groups

Maximum number of species (180) belonged to insectivore guild and minimum (9) to nectarivore. Omnivores, frugivores, carnivores, and granivores comprised 46, 24, 21 and 19 species respectively. Similarly, 55% birds counted during the sampling were insectivores. The other groups in hierarchical order based on abundance were omnivores (23%), frugivores (14%), nectarivores (4%), granivores (3%) and carnivores (1%) (Figure 4.3).

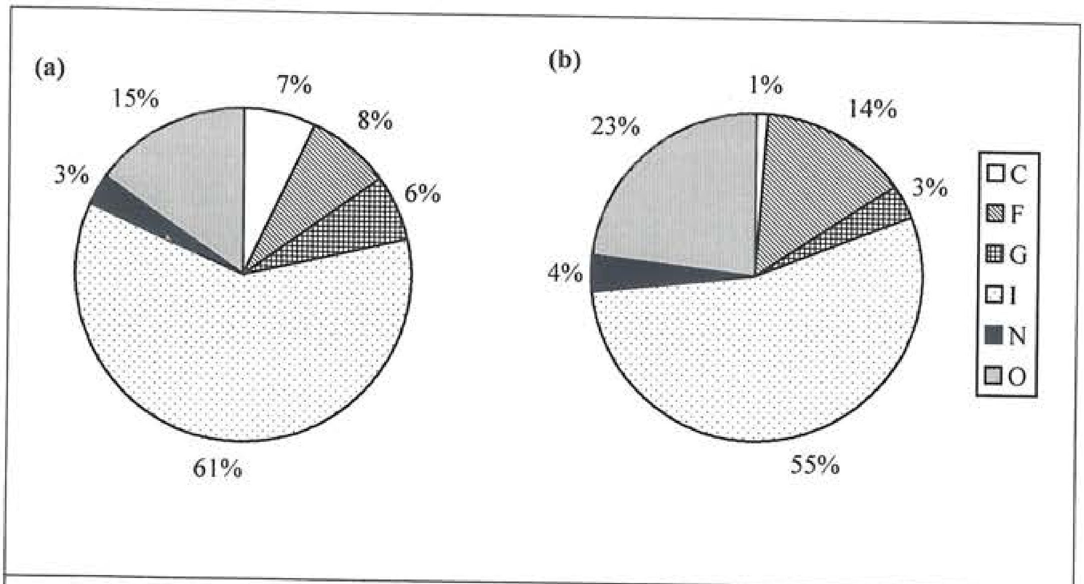

Figure 4.3 Relative percentage of species (a) and abundance (b) of birds in different trophic groups in the Teesta valley, Sikkim; C- Carnivore, F-Frugivore, I-Insectivore, N-Nectarivore, O-Omnivore and G - Granivore.

4.3.10. Birds and climatic factors

Bird species richness showed strong positive correlation with mean annual rainfall ($r = 0.937$, $p = 0.01$). Similarly, bird density also showed significant positive correlation with rainfall ($r = 0.972$, $p = 0.006$) and number of rainy days ($r = 0.886$, $p = 0.045$). There was no correlation between mean temperature and bird species richness as well as density.

4.3.11. Endemic and threatened birds

A list of threatened, near threatened and endemic (hereafter TNE) birds of Sikkim is given in Table 4.9. Of the 19 Eastern Himalayan endemic species (Stattersfield *et al.*, 1998; Rasmussen and Anderton, 2005; Jathar and Rahmani, 2006) ten are reported to occur in Sikkim (Islam and Rahmani, 2004). Similarly, 17 species are threatened (two critical and 15 vulnerable) and two are near threatened including three endemics are found in Sikkim (BirdLife International, 2001).

In total, 630 individuals belonging to six TNE species were observed from the Teesta valley during the study period. Number of species was the highest (5) in zone III, whereas abundance (357) was in zone II (Table 4.9). Out of ten endemics, only five were recorded during this study. Of these, Rusty-bellied Shortwing was rare and found only twice, once each in zone III and IV. The other four species (Broad-billed Warbler, Hoary-throated Barwing, Yellow-vented Warbler and White-naped Yuhina) were locally abundant and observed in two or three elevation zones. White-naped Yuhina and Broad-billed Warbler were recorded in three zones but the abundance of former was higher than the latter.

Among the threatened and near threatened species that occur in Sikkim, only two species (Rusty-bellied Shortwing and Satyr Tragopan) were observed in the Teesta valley. Satyr Tragopan was recorded in zone III and, as mentioned above, Rusty-bellied Shortwing was detected in zones III and IV.

4.3.12. Breeding

4.3.12.1. Breeding bird community

Altogether, 183 nests of 39 species were recorded in four vegetation zones of the study area during 2004 and 2005 (Table 4.10). The number of breeding species was the highest (16) in zones I and III and the lowest (5) in zone IV. Maximum number of nests (84) was observed in zone III and minimum (16) in zone IV. Number of nests recorded per species varied from one to twenty. Only one nest was observed in 12 species. Out of the total nests observed, 60% (111 nests) belonged to eight species, each having ≥10 nests (Table 4.10).

Table 4.9 Endemic (E), threatened (T) and near threatened (NT) birds of Sikkim (Stattersfield *et al.*, 1998; BirdLife International, 2001; Islam and Rahmani, 2004). Number indicates the individuals observed during the study in different elevation zones (I, II, III, IV and V) along the Teesta valley. (- denotes species not observed during present study).

Species	**I**	**II**	**III**	**IV**	**V**	**Total**
Baer's Pochard, *Aytha baeri*^{T}	-	-	-	-	-	-
Beautiful Nuthatch, *Sitta formosa*^{T}	-	-	-	-	-	-
Black-necked Crane, *Grus nigricolis*^{T}	-	-	-	-	-	-
Black-breasted Parrotbill, *Paradoxornis flavirostris*^{T}	-	-	-	-	-	-
Blyth's Tragopan, *Tragopan blythii*^{T}	-	-	-	-	-	-
Broad-billed Warbler, *Tickellia hodgsoni*^{E}	-	12	42	52	-	106
Chestnut-breasted Partridge, *Arborophila mandellii*^{E,T}	-	-	-	-	-	-
Giant Babax, *Babax waddelli*^{E,NT}	-	-	-	-	-	-
Greater Spotted Eagle, *Aquila clanga*^{T}	-	-	-	-	-	-
Hoary-throated Barwing, *Actinodura nipalensis*^{E}	-	10	101	-	-	111
Hodgson's Bushchat, *Saxicola insignis*^{T}	-	-	-	-	-	-
Hodgson's Prinia, *Prinia cinereocapilla*^{T}	-	-	-	-	-	-
Lesser Kestrel, *Falco naumanni*^{T}	-	-	-	-	-	-
Long-billed Vulture, *Gyps indicus*^{T}	-	-	-	-	-	-
Palla's Fish Eagle, *Haliaeetus leucoryphus*^{T}	-	-	-	-	-	-
Rufous-necked Hornbill, *Aceros nipalensis*^{T}	-	-	-	-	-	-
Rufous-throated Wrenbabbler, *Spelaeornis caudatus*^{E}						
Rusty-bellied Shortwing, *Brachypteryx hyperythra*^{E,T}	-	-	1	2	-	3
Satyr Tragopan, *Tragopan satyra*^{NT}	-	-	2	-	-	2
Slender-billed Babbler, *Turdoides longirostris*^{T}	-	-	-	-	-	-
Ward's Trogon, *Harpactes wardii*^{E}						
Wedge-billed Wrenbabbler, *Sphenocichla humei*^{E}						
White-rumped Vulture, *Gyps bengalensis*^{T}	-	-	-	-	-	-
White-naped Yuhina, *Yuhina bakeri*^{E}	37	219	13	-	-	269
Wood Snipe, *Gallinago nemoricola*^{T}	-	-	-	-	-	-
Yellow-vented Warbler, *Phylloscopus cantator*^{E}	23	116	-	-	-	139
Overall	60	357	159	54	-	630

Among all, Grey-backed Shrike had the highest number of nests (20) followed by Black Bulbul (17) and White-capped Water Redstart (16). Among the zones, maximum number of nests (11) was observed for Common Tailorbird in zone I, Black Bulbul (7) and Ashy Drongo (7) in zone II, Grey-backed Shrike (18) in zone III and White-capped Water

Redstart (6) in zone IV. Among the 16 species found nesting in zone I, 15 (with 57 nests) were exclusive; only one species (Blue Whistling Thrush) nested in other two zones. The number of species breeding exclusively in zones II, III and IV were six (10 nests), 10 (29 nests) and two (3 nests) respectively. Among the total species, Blue Whistling Thrush nested in three zones, whereas five species, namely Ashy Drongo, Black Bulbul, Grey-backed Shrike, White-capped Water Redstart and White-collared Blackbird nested in two zones (Table 4.10).

Cup-nesters dominated with 67% species and 69% nests (Figure 4.4). The numbers of ground nests were lowest as compared to other types of nests, whereas number of species using dome, pendulous and ground nests contributed 5% each. Asian Barred Owlet and Blue-throated Barbet used tree hole for nesting. White-capped Water Redstart built statant cup nest inside hole on the wall or rock cavity, hence considered here as cavity nest. Blood Pheasant and Blue-capped Rock Thrush were ground-nesters. White-rumped Munia and Hill Prinia used dome nests, while Common Tailorbird and Rufescent Prinia used pendulous nests. Platform-nesters observed in the study area were Ashy Wood Pigeon, Green-billed Malkoha, Grey Treepie and Oriental Turtle Dove. Rest of the species (refer Table 4.10) were cup-nesters of which Ashy Drongo, Spangled Drongo and Black-winged Cuckooshrike used suspended cup.

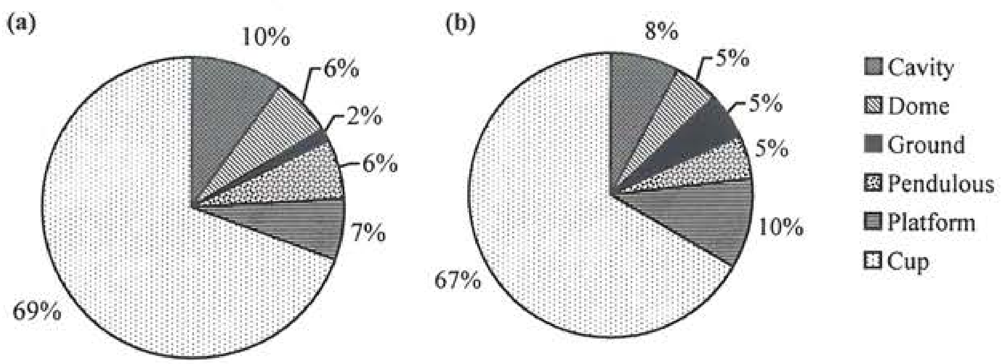

Figure 4.4 Types of nests used by birds of the Teesta valley; (a) relative percentage of number of nests and (b) percentage of species using different nest types.

Table 4.10 Breeding bird species with number of nests recorded in different elevation zones (I, II, III and IV) along the Teesta valley, Sikkim.

Species	**I**	**II**	**III**	**IV**	**Total**
Ashy Drongo		7	8		15
Ashy Wood Pigeon			1		1
Asian Barred Owlet	2				2
Black-backed Forktail	1				1
Black Bulbul		7	10		17
Black-winged Cuckooshrike		1			1
Blood Pheasant				2	2
Blue-throated Barbet	1				1
Blue Whistling Thrush	1	1	2		4
Blue-capped Rock Thrush		1			1
Chestnut-crowned Laughingthrush			10		10
Common Green Magpie	6				6
Common Tailorbird	11				11
Eurasian Jay			1		1
Greater Necklaced Laughingthrush	2				2
Green-billed Malkoha	2				2
Green-backed Tit		4			4
Greenish Warbler				1	1
Grey-backed Shrike			18	2	20
Grey Treepie	6				6
Grey-winged Blackbird			3		3
Hill Prinia		2			2
Himalayan Bulbul	3				3
Oriental Turtle Dove			4		4
Oriental White-eye	2				2
Plumbeous Water Redstart		1			1
Rufescent Prinia	1				1
Red-vented Bulbul	5				5
Rufous-bellied Niltava			2		2
Rufous Sibia			2		2
Slender-billed Scimitar Babbler			1		1
Spangled Drongo	4				4
Striated Laughingthrush		1			1
Tickel's Thrush			2		2
White-capped Water Redstart			10	6	16
White-collared Blackbird			7	5	12
White-crested Laughingthrush	1				1
White-rumped Munia	10				10
White-throated Laughingthrush			3		3
Total number of nests	58	25	84	16	183
Total number of species	16	9	16	5	39

4.3.12.2. Breeding seasonality

As mentioned in the methods, the study on breeding was undertaken during March to August. No nests were observed during March in both the years. April to August was observed as the breeding season for birds in the Teesta valley. Overall, June was the peak breeding month with highest number of breeding species (28) and the nests (85) observed (Figure 4.5). Out of 183 nests, 160 (87.4%) were observed during May and June. The breeding was at its peak during June in zones I, II and III, whereas it was in May in zone IV. Only two species, Striated Laughingthrush in zone II and Blood Pheasant in zone IV, continued breeding till August. The breeding period differed among the species. The species such as Asian Barred Owlet was an early breeder (April-May), whereas Ashy Drongo, White-throated Laughingthrush, Chestnut-crowned Laughingthrush, Oriental Turtle Dove and White-collared Blackbird were comparatively late breeders (June-July).

Breeding seasonality of eight species of birds (with ≥ 10 nests) is presented in Figure 4.6. Maximum number of nests was observed during May or June in all these species. Among eight species, only two species (Common Tailorbird and White-capped Water Redstart) nested during April while remaining six species nested May onwards. Ashy Drongo bred exclusively during May and June; maximum nests were observed during June. Species such as Black Bulbul, Chestnut-crowned Laughingthrush and Grey-backed Shrike started nesting during May and was over by the end of July with a peak during May. White-capped Water Redstart and Common Tailorbird bred during April to June. Breeding in White-collared Blackbird and White-rumped Munia was observed during May to July with highest number of nests in June (Figure 4.6).

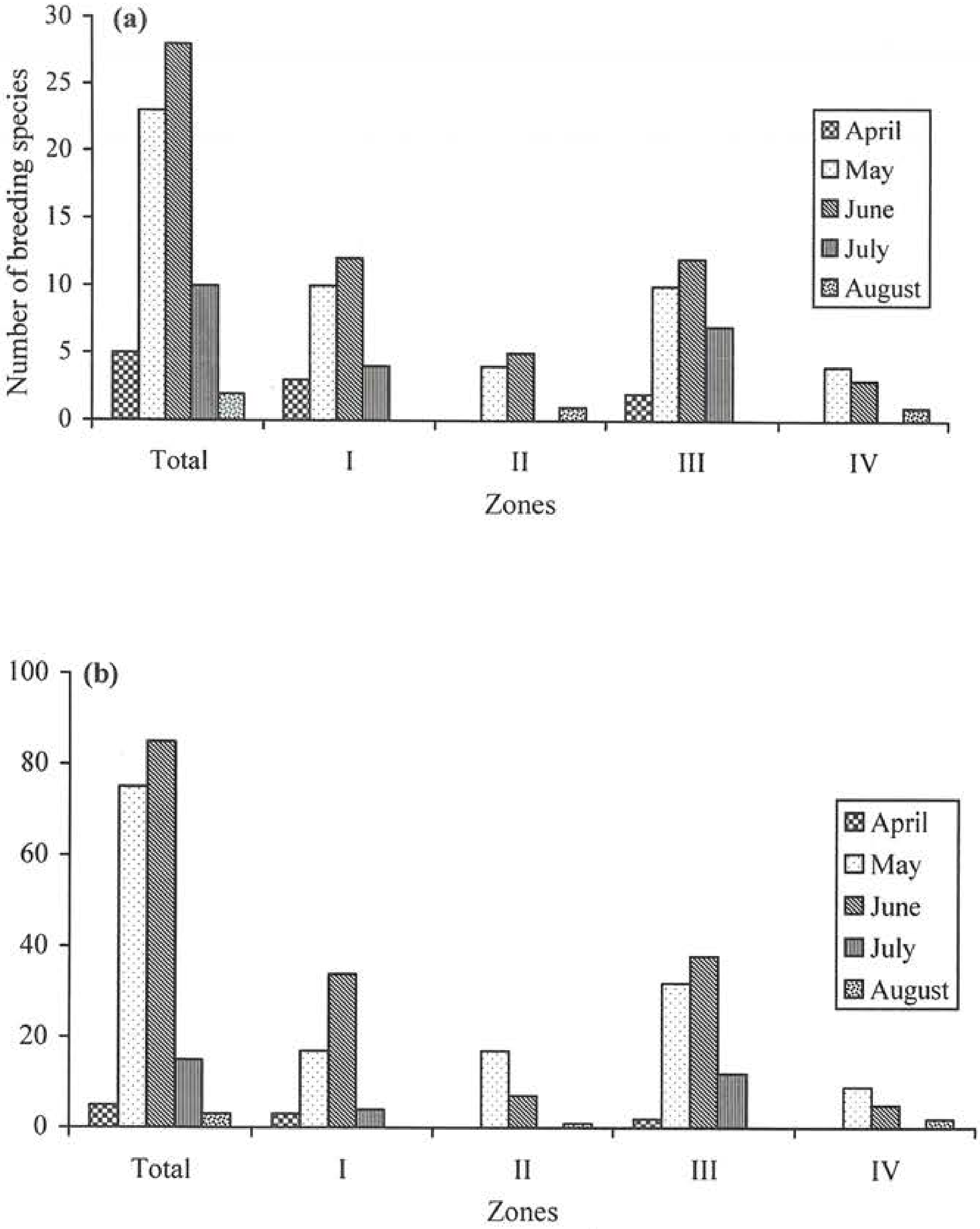

Figure 4.5 Breeding seasonality in birds of the Teesta valley, Sikkim; (a) number of breeding species and (b) number of nests observed; total as well as in different elevation zones (I, II, III and IV).

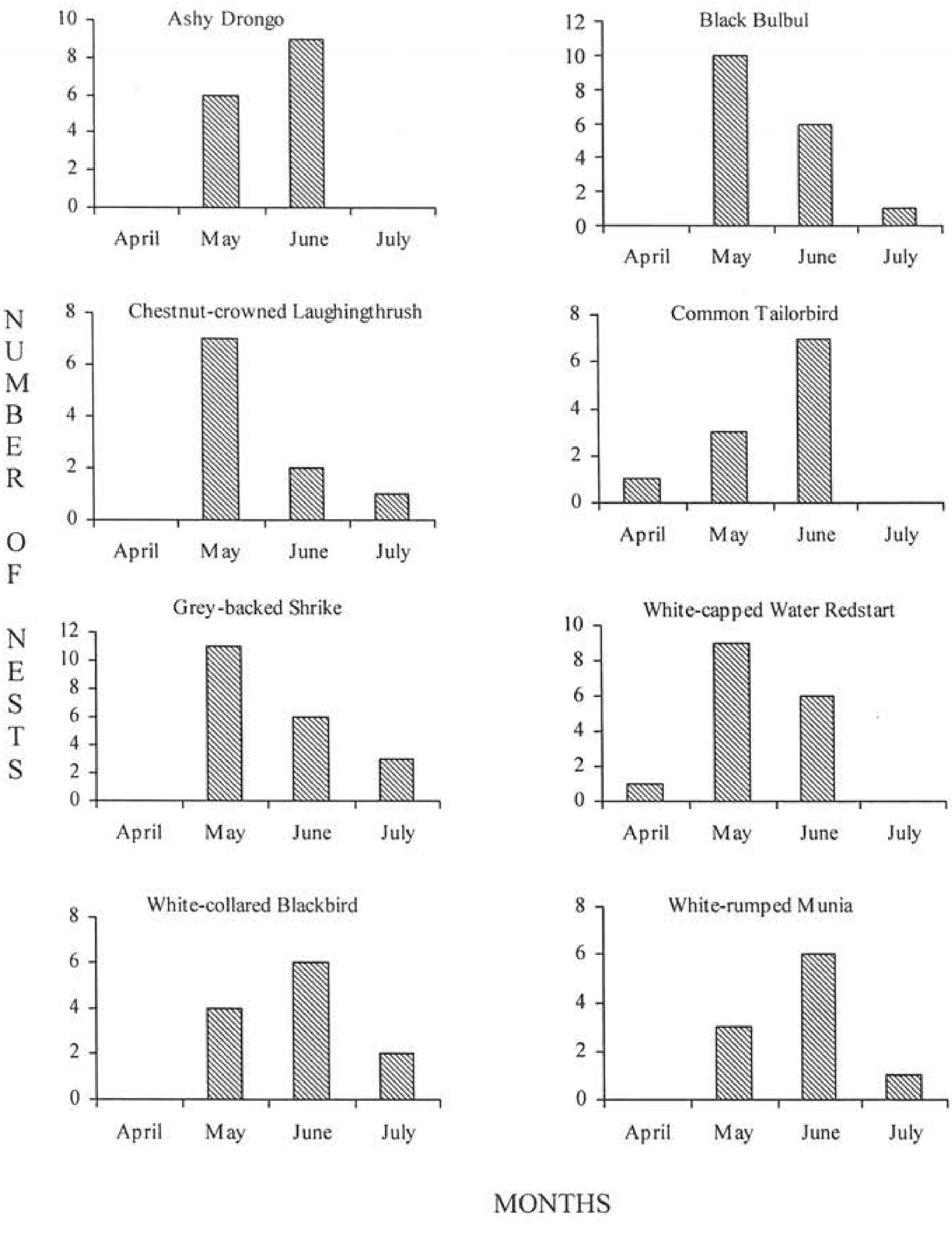

Figure 4.6 Breeding seasonality in selected species (≥10 nests) of birds of the Teesta valley, Sikkim.

4.3.12.3. Nest and nest-site characteristics

Mean and standard deviation of nest and nest-site characteristics of eight species of birds (with ≥10 nests) is given in Table 4.11.

Ashy Drongo

Ashy Drongo bred in broad-leaved forest between 1300 m and 2500 m elevation. A total of 15 nests were observed of which 12 (80%) were found in Alder tree (*Alnus nepalensis*), two on *Quercus semicarpefolia* and one on *Glochidion acuminatum*. Ashy Drongo nested in closed canopy forest (canopy cover 60 - 80%) with ground covered with leaf litter. Nests, built into a more or less horizontal fork of a slender outer branch, were placed at 3/4th height (6 - 20 m) of tall trees (8 - 25 m) having GBH greater than 60 cm (60 - 197). Clutch size varied from 2 to 4. The nest concealment at 5 m distance was generally low (0 - 25%). As the nests were located at the edge of tender branches above 8 m height from the ground, data on nest morphometry could not be taken.

Black Bulbul

Black bulbul was observed nesting in the broad-leaved forest (zones II and III) between 1600 and 2300 m elevation. Of the 17 nests observed, eight (47%) were on *Erithrina stricta*, three (17.64%) on *Ficus roxburghii*, two (11.76%) on *Prunus indica* and one (5.88%) each on *Alnus nepalensis*, *Brassiopsis* sp., *Debregesia velutina* and an unidentified plant species. Nests were placed either near the edge or at the middle of the main stem where the branches bifurcate forming suitable stand for holding the cup nest. The nests were composed of mosses, woody sticks, dry leaves and grasses neatly lined by spider-webs. Clutch size varied between two and four. Nest concealment was 25 - 75%. Concealment of the nest located in *Erithrina stricta* was low (25%) compared to nests in other species of trees. The nests were placed between 3 and 7 m height from the ground in a tree having 7 - 11 m height and 19 - 120 cm GBH.

Chestnut-crowned Laughingthrush

Chestnut-crowned Laughingthrush was nesting in scrub forest or bamboo undergrowth in temperate broad-leaved forest between 2000 m and 2600 m elevation. They built cup nest, which was placed at 0.5 to 2 m height above ground in small Rhododendron tree, *Prinsepia utilis* and bamboo. Nests were made of dead leaves and small sticks of nest plants lined with grasses or moss. The nests were generally placed within the dense undergrowth vegetation with more than 70% shrub cover. The nest concealment was high (≥ 75%). Among 10 nests observed, seven had three eggs and the remaining had two eggs.

Common Tailorbird

In all, 11 nests were observed between 300 m and 700 m elevation, mostly near the agricultural field or open area. The nest was made of a single large leaf of seasonal woody herb or *Ficus* sp., *Litsaea* sp., *polyantha* sp. sewn along the edges to form a cone with pad of dry grasses and flower of *Ceiba malabarica* at the base. Nests were placed very close to the ground totally hidden inside shrubby vegetation and were highly concealed (≥75%). Clutch size varied between four and five.

Grey-backed Shrike

Grey-backed shrike nested in scrubby vegetation at high elevation between 2300 and 3600 m. A total of 20 nests were observed during sampling. Out of the seven plant species used for nesting, 40% of the nests were found on *Ilex sikkimensis*. The other nests were found on *Prinsepia utilis* (15%), *Cryptomeria* sp. (15%), *Andromeda* sp. (10%), *Rhododendron* sp. (10%) and two unidentified species (10%). The nests were placed at 1 - 5 m above the ground at the bifurcation point of the main stem in a short tree (1 – 7 m). The nests were highly concealed within the foliage (50 - 100%). Clutch size varied from two to five, four in most of the cases.

White-collared Blackbird

A total of 12 nests of White-collared Blackbird were observed in temperate broad-leaved (seven) and coniferous (five) forests between 2500 m and 3700 m elevation. The cup nest of this species consisted of mosses, dead leaves and sticks lined with fine grasses from inside. The nests were housed in trees such as *Zanthoxylum* sp., *Ilex sikkimensis*, *Abies webbiana*, and Rhododendrons at 2 - 8 m above ground. Shrub and ground vegetation cover around the nest-site was high (Table 6.3). Nest tree height and GBH measured 2 - 15 m and 28 - 89 cm respectively. Concealment varied between 50 - 100%. Clutch size was three in all the nests observed during this study.

White-capped Water Redstart

White-capped Water Redstart nested between 2600 m and 3700 m elevation in the Teesta valley. Overall, 16 nests were found during the study. The cup nests made of mosses, leaves and grasses lined with wool or animal hair were placed in hollow of wall and rock crevice at 2 - 5 m height from the ground. White-capped Water Redstart nested near the roadside or human settlement along the streams. The clutch size ranged between 3 and 4. Nests were highly concealed (≥ 75%).

White-rumped Munia

White-rumped Munia bred in low-elevation forest between 450 m and 700 m. This species built dome-shaped nest with hay or leaf blade and flower of herbs belonging to poaceae family. The nesting trees used were *Mallotus* sp., *Schima wallichi, Premna bengalensis* and *Ficus* sp. The nests were placed at 2 - 8 m above the ground in trees having 2 - 8 m height. The birds nested in open canopy and the nests were visible at 5 m or greater distance from any direction except two nests, which were concealed at one direction. Clutch size varied from 3 to 5.

Table 4.11. Nest and nest-site characteristics of eight species of birds (with ≥10 nests) observed in the Teesta valley, Sikkim. AD - Ashy Drongo, BB - Black Bulbul, CCL - Chestnut-crowned Laughingthrush, CT - Common Tailorbird, GBS - Grey-backed Shrike, WCW - White-capped Water Redstart, WCB - White-collared Blackbird, WRM - White-rumped Munia.

Nest, nest tree and nest patch variables	**Values of different variables (mean ±SD) in select bird species**							
	AD	**BB**	**CCL**	**CT**	**GBS**	**WCB**	**WCW**	**WRM**
Nest depth (cm)	-	7.6±2.7	4.6±1.5	6.6±0.2	6.3±0.9	6.7±1.0	5.5±1.4	14.7±1.4
Nest diameter (cm)	-	10.1±1.2	6.4±3.2	4.5±1.7	8.2±0.4	10.2±1.5	7.6±1.4	8.8±1.1
Nest-tree/wall height (m)	17.7±5.2	8.4±1.1	2.7±0.9	0.4±0.13	3.05±1.2	6.6±3.5	4.1±1.3	5.1±2.3
Nest-tree GBH (cm)	136.8±39.3	62.2± 34.4	-	-	-	56.2±19.7	-	47.2±20.7
Nest height (m)	10.7±4.5	4.7±1.3	1.2±0.5	0.22±0.06	2±1.1	3.7±1.8	2.8±1.2	4.1±1.8
Nest concealment (%)	18.3±11.4	44.1±22.6	92.5±12.1	97.7±7.5	87.5±20.7	79.2±14.4	93.7±11.2	2.5±7.9
Canopy cover (%)	70.3±8.8	36.5±19.3		12.7±20.1	17±32.8	31.6±26.6	13.7±21.2	35.0±41.1
Shrub cover (%)	47.3±21.2	45.9±29.6	79±21.3	50±13.4	54.2±32.9	63.7±31.7	36.9±33.4	78.0±41.6
Ground vegetation cover (%)	65.3±22.3	61.2±12.7	58±9.2	82.7±27.9	51.5±11.8	70.0±33.6	25.6±30.1	83.0±18.9
Ground litter cover (%)	34±22.6	9.4±8.3	7±16.4	2.7±4.7	12.6±19.1	23.3±23.5	11.9±18.3	16.0±19.0
Tree density (no. per 0.0078 ha)	2.5±1.3	2.2±1.2	1.7±1.1	1.1±1.2	2.6±1.1	3.8±1.8	-	1.4±0.9
Distance to water (m)	453±474	694±752	285±191	93.2±49.9	500±424	350±254	291±266	130±142
Distance to the settlement (m)	853±528	741±680	1245±1049	127.3±46.7	1415±1348	1366±1301	1600±1800	390±335
Number of log	0.53±0.51	0.6±0.6	0.3±0.4	-	0.8±0.9	1.8±1.4	-	-
Number of cut stump	0.73±0.59	0.6±0.9	0.7±0.8	-	0.5±0.8	1.0±0.7	-	-

Plate 4.1 Chestnut-crowned Laughingthrush and its nesting microhabitat in the Teesta valley, Sikkim. They nest on short bushes in the dense undergrowth of temperate broad-leaved forest.

Plate 4.2 Grey-backed Shrike and its bulky cup nest containing eggs observed at 2600 m elevation in the Teesta valley, Sikkim.

Plate 4.3 The nest of Blue Whistling Thrush placed in the pole of a bridge, enlarged view is shown in the inset. They build nests on rocky ledges or man made structures near the stream.

4.4. DISCUSSION

The total species (329) observed in the Teesta valley during three years of this study represents 60% of the 550 bird species reported to occur in Sikkim (Vijayan *et al.*, 2006). Inskipp *et al.* (1996) have reported 1295 bird species from the Indian subcontinent of which Teesta valley harbors more than 25%. The result indicates that Teesta valley is very rich in avifauna. Abundance data also suggest that habitats along the Teesta valley support large number of birds.

The bird fauna of Eastern Himalaya, especially land birds, is enriched compared to the rest of the Indian subcontinent of similar or even larger area (Ali, 1962; Daniels *et al.*, 1992; Ali and Ripley, 2001; Price *et al.*, 2003). The diversity of vegetation along the Teesta valley, with abrupt elevation and climatic variation, created diverse habitats allowing many species of birds to co-exist. Vegetation changes (with concomitant change in profile and physiognomy) from hot tropical deciduous forest in zone I to sub-tropical and temperate broadleaved in zones II and III having dense undergrowth, to temperate conifers in zone IV and finally merging with Tibetan plateau as typical cold desert alpine meadows in zone V. The climatic and other environmental factors also change in a similar fashion. Teesta river, with a number of streams flowing through the area (Figure 2.4) keep the riverine forests moist and productive all round the year (Ali, 1962). In addition, the forest in Sikkim, especially lower and middle valleys, is a part of the continuous larger tract of evergreen vegetation of Eastern Himalaya that harbor rich avifauna of evergreen forest. Species such as laughingthrushes, babblers, bulbuls, warblers, pigeons, doves, woodpeckers and flycatchers have high diversity in the study area. Apart from these species, the coniferous forest and alpine meadows at higher elevation support the fauna of temperate and Palearctic affinity (Ali, 1962; Islam and Rahmani, 2004). All these factors contribute to the rich and diverse birdlife of the region.

Species accumulation curves in all the elevation zones almost approached asymptote, which indicates the completeness of the sampling (Colwell and Coddington, 1994). However, the addition of new species cannot completely be ruled out due to the hyper-diverse characteristics of tropics (Longino *et al.*, 2002; Cardelus *et al.*, 2006). Species accumulation curve showed that most of the species were encountered during early sampling and a few were added later with additional sampling.

Due to the inconsistency in the accuracy of species richness estimators, selection of more than one estimator is preferred (Walther and Martin, 2001; O'Dea and Whittaker, 2007). Three species richness estimators (Chao 2, Jackknife 1 and Jackknife 2) were selected to estimate the richness of birds in each elevation zones in the study area. These estimators showed relatively less standard deviation compared to other estimators. The estimators with less variance are considered as efficient estimators (Walther and Moore, 2005). Walther and Moore (2005) and Hortal *et al.* (2006) concluded that Chao and Jackknife performs better though the efficiency might vary with sample size. Estimated species richness (Chao 2, Jackknife 1 and Jackknife 2) did not differ much from the observed one in zones I, IV and V but showed slightly higher than the observed richness in zones II and III. This indicates that most of the species are detected during sampling in all the zones and a few species might be added with additional sampling in zones II and III.

Zones II and III showed higher bird species richness, abundance, density and diversity in comparison with other three zones. These zones are located at middle elevations and are bounded by zone I at lower and zones IV and V at higher elevations. The higher diversity of organisms at middle elevation is the most general trend observed across taxa and regions (Rahbek, 1995, 2005; Kessler *et al.*, 2001; Kattan and Franco, 2004; Ding *et al.*, 2005). Range extensions from lower and upper zones contribute to the higher avian diversity at mid-elevations (Rahbek, 1997; Sanders, 2002). Other factors such as vegetation complexity, tree species richness, diversity and environmental factors, separately or in combination with each other, might be responsible for high avian diversity at middle elevation. The distribution pattern of birds along the elevation gradient is discussed in detail in Chapter 5.

The results showed that the species composition and relative abundance of species among elevation zones was different. The differences in patterns of relative abundance among assemblages suggest that different factors or mechanisms are involved in governing the abundances of species in these assemblages (Tokeshi, 1999). The community composition is shaped by various factors such as food, breeding habitat, competition among co-existing species, climate and vegetation. The type and quantity of resources as well as their distribution patterns are the major factors that determine the community structure of any particular region (MacArthur, 1972; Wiens, 1989). The combination of ecological and evolutionary forces acting upon organisms determines their relative abundances in a community (Tokeshi, 1999).

The species abundance distribution patterns signify the equitability and stability of the community (MacArthur, 1960). MacArthur (1960) has discussed two assumptions regarding abundances of different species in a community. According to the first assumption, the total number of individuals in a community remains constant so that increase in numbers of population in some species result in decrease in others, whereas the second assumption states that the abundance of different species are independent and does not necessarily affect each other. He concluded that the first assumption holds true at least for birds because avian community comprises equilibrium species.

Among the four models (geometric series, logarithmic series, lognormal distribution and MacArthur's broken stick model) formulated to describe distribution of individuals among species in a community (Magurran, 1988; Krebs, 1989; Southwood and Henderson, 2000), present data (total birds as well as of different vegetation zones) fits into truncated lognormal distribution model. The close fit to lognormal distribution shows that the bird communities comprise very few rare and common species; instead contains large array of species with moderate abundance (Krebs, 1989; Wiens, 1989). The lognormal pattern of species abundance is displayed by biological communities comprising many species, especially birds (Magurran, 1988; Wiens, 1989; Tokeshi, 1999). Lognormal distribution pattern have been observed in recent studies in tropical forest bird communities in India and elsewhere (Terborgh *et al.*, 1990; Jayson and Mathew, 2000). If many independent factors are involved in determining the community structure, species abundance follows lognormal distribution (John, 1986; Krebs, 1989). Wiens (1989) reported that lognormal distribution fits well when the community is at equilibrium or free from disturbances. The observed lognormal distribution pattern of birds of the Teesta valley reflects the stability of avian community. The species-abundance distribution of birds in zone II deviated from the models mentioned above which might be because of more disturbance and habitat alterations with cardamom plantations.

Marked zonation of vegetation exists along the Teesta valley with simultaneous changes in climate, aspect and topography. Similarity in vegetation structure and forest types could explain maximum sharing between zones I and II, and zones II and III. In contrast, similarity was less between zones III (1800-2800 m) and IV (2800-3800 m) among adjacent zones, which might be because of wide differences in vegetation and environmental factors. At around 3000 m elevation, vegetation changes from temperate broad-leaved to temperate coniferous forest resulting in high bird species dissimilarity between zones III and IV. The region around 3000 m elevation is observed as transition zone for birds of the Teesta valley (Chapter 5, Pp.99). Such turnover in avifauna with transition in vegetation is also reported from the Western Himalaya (Price *et al.*, 2003) and other parts of the world (Navarro, 1992; Hawkins, 1999). The distinct species assemblages of zones IV and V could be due to the isolation mechanism of high mountains constraining the dispersal of species (Lomolino, 2001).

The birds of the Teesta valley displayed marked seasonal variation. Overall, bird species richness and density was high during summer, whereas diversity was maximum during monsoon. Seasonal changes in richness and abundance of birds occur due to changes in weather condition or fluctuations in food productivity and habitat quality (Loiselle and Blake, 1991; Kai and Corlett, 2002; Hulbert and Haskell, 2003; Norris and Marra, 2007). Rainfall showed significant positive correlation with birds. Rainfall is found to be closely associated with food abundance (Wiens, 1989). The initial rain during summer cause the emergence of new leaves. Studies have shown the correlation between emergence of new leaves with invertebrate abundance (Kai and Corlett, 2002). Hence, increase in food abundance during summer, especially insects, would have caused high species richness and density of birds during this season as reported by other studies (Wiens, 1989; Gokula, 1998; Kwok and Corlett, 1999; Nirmala, 2002). Temperature may have strong influence on seasonality of birds. Mean average temperature causes increase in energy availability due to increase in primary productivity, which in turn increases local species diversity (Lennon *et al.*, 2000; Hurlbert and Haskell, 2003). Due to maximum mean temperature during summer and monsoon, the total energy available to birds might be high during these seasons causing high diversity.

The local altitudinal movements of birds along the valley cause the seasonal fluctuations among zones as observed in other parts of the Himalaya (Price and Jamdar, 1990; Ali and Ripley, 2001; Price *et al.*, 2003; Sultana *et al.*, 2007). At the onset of cold weather during October - November, the birds start moving from higher to lower elevation. Once the winter is over, they again show upward movement mostly for breeding. This behavior was observed in species such as Black Bulbul, White-capped Water Redstart, Blue Whistling Thrush, Rufous Sibia, and Ashy Drongo. These species were abundant in zone I during January-February but migrate to zones II and III during breeding season. Similar movement was noticed in Snow Pigeon, Ashy Wood Pigeon, Grey-backed Shrike and Oriental Turtle Dove. These birds generally breed in higher elevation (mostly in Temperate coniferous forest and alpine zone) but come down to middle or lower elevations at the onset of winter.

Seasonal movements of birds within and between habitats is regulated by variations in availability of food resources and fluctuations in environmental factors (Perrins and Birkhead, 1983; Loiselle and Blake, 1991; Norris and Marra, 2007). In tropics, the impact of rainfall on invertebrate seasonality is more than temperature (Wolda, 1978; Kai and Corlett, 2002; Nirmala, 2002) and the invertebrate population is found to increase with increase in precipitation and rates of decomposition (Frith and Frith, 1990). Temperature and intensity of rain differ among zones (Chapter 2, Pp.14) and also among seasons in different zones. Such variation is more in temperate regions or higher elevations (Karr, 1976b; Terborgh, 1977; Vàzquez and Givnish, 1998) and causes high seasonal fluctuations in birds.

The maximum number of species and abundance belonged to insectivore trophic group. The domination of bird community by insectivores is consistent with many other studies in India and outside (Khan *et al.*, 1993; Kwok and Corlett, 1999; Latta *et al.*, 2003; O'Dea and Whittaker, 2007; Sultana *et al.*, 2007). Nectarivores and carnivores are generally less represented in an avian community (Wiens, 1989; Naka, 2004). The trophic structure of a community in a particular habitat is determined by available resources such as food, vegetation structure, suitable microhabitat and foraging substrates (Terborg, 1977; Naka, 2004; Arriaga-Weiss *et al.*, 2008).

Out of the 22 restricted range species of the Eastern Himalaya, 19 are confined to Eastern Himalaya Endemic Bird Area (Stattersfield *et al.*, 1998; Rasmussen and Anderton, 2005; Jathar and Rahmani, 2006). Sikkim lies within this Endemic Bird Area (Islam & Rahmani, 2004). Of these 19 endemics, ten are reported to occur in Sikkim (Islam & Rahmani, 2004). Out of the ten endemics, present study recorded only five species (Table 4.9). The remaining five endemic species, namely Chestnut-breasted Partridge *Arborophila mandellii*, Wedge-billed Wren Babbler *Sphenocichla humei*, Rufous-throated Wren Babbler *Spelaeornis caudatus*, Ward's Trogon *Harpactes wardii* and Giant Babax *Babax waddelli* were not observed during the course of this study. Among these species, Chestnut-breasted Partridge was reported to occur in habitats similar to zones I, II and III (Ali, 1962; Ali and Ripley, 2001) but the distribution of the rest four is not known.

Similarly, out of 17 threatened and two near threatened birds of Sikkim (BirdLife International, 2001), only two species (Rusty-bellied Shortwing and Satyr Tragopan) were observed in the Teesta valley during this study. Species such as Palla's Fish Eagle *Haliaeetus leucoryphus,* Black-breasted Parrotbill *Paradoxornis flavirostris,* Beautiful Nuthatch *Sitta formosa* and Satyr Tragopan *Tragopan satyra* are reported to have wider distribution range but other species such as White-rumped Vulture *Gyps bengalensis*, Long-billed Vulture *Gyps indicus*, Baer's Pochard, *Aytha baeri*, Greater Spotted Eagle *Aquila clanga*, Lesser Kestrel *Falco naumanni*, Blyth's Tragopan *Tragopan blythii*, Black-necked Crane *Grus nigricolis*, Giant Babax *Babax waddelli* have merely presence-absence records in Sikkim (Ali, 1962; Ganguli-Lachungpa, 1998a; Ali and Ripley, 2001; Islam and Rahmani, 2004).

The result indicates that the population of these birds in Sikkim is very low. Habitat loss and fragmentation is considered as the major factor for decline in population of threatened and endemic birds in the Himalaya and other parts of the world (Crosby, 1996; Mauro and Vercruysse, 2000; BirdLife International, 2001; Chettri *et al.*, 2001; Riley, 2002; Robin and Sukumar, 2002; Pandit *et al.*, 2007). It is reported that endemic species of birds are unable to utilize non-forest habitats resulted from deforestation and conversion of land to other forms (Lei *et al.*, 2003; Wijesinghe and Brooke, 2005; Vijayan and Gokula, 2006). The study by Pandit *et al.* (2007) predicts that by the end of this century, a quarter of the endemic species will be extinct due to habitat loss. Hence, the information available in literature and present study on the current status of these birds suggests detailed study on the ecological aspects and habitat requirements for the execution of immediate conservation measures.

A total of 229 species of birds have been reported to breed within Sikkim (Ali, 1962). Hence, 39 species observed in the Teesta valley during the study period represents 17% of breeding birds of Sikkim and 12% of the total number of birds (329 species) recorded from the study area. This is mainly because of less intense observations on breeding as a result of logistical problems and constraints in time as major focus was on general bird community studies in different vegetation types and elevation. However, of the 39 species, breeding of seven species, namely Ashy Wood Pigeon, Black-winged Cuckooshrike, Blood Pheasant, Eurasian Jay, Greenish Warbler, Rufescent Prinia and Tickel's Thrush have not been reported earlier from Sikkim.

Out of 39 species, 33 bred exclusively in one elevation zone. Some of the species, although seen in all the zones, bred only in one or two zones. Common and wide ranged species such as Black Bulbul, Ashy Drongo, Blue Whistling Thrush, and White-capped Water Redstart were observed only from one or two zones during breeding season. The result suggests that even the common species has specific habitat requirements for breeding though extend their ranges to other habitat or elevation during non-breeding season.

As reported by Pettingill (1985) and observed in other studies (Gokula, 1998; Nirmala, 2002), cup nesters dominated the breeding bird community. Ground nesters were low compared to other groups.

The birds of Teesta valley bred during summer and monsoon (April to August). Although, nest search was restricted to the main breeding season i.e. March to August, no signs of breeding or nesting were observed during September to March. Spring season (April to June) is primarily the breeding season in the north temperate region (Gill, 1995). Since, climatic condition of most of the study transects is temperate type, breeding in birds during the mentioned months is as expected. May and June are considered as the peak breeding months for more than 80% Indian passerines (Pramod and Yorn-Tov, 2000). The breeding season for birds of Kashmir was also from March to July (Bates and Lowther, 1952; Price and Jamdar, 1990). The length of the breeding season is reported to depend on various factors such as food availability, rainfall, temperature and length of the growing season of vegetation (Lloyd, 1999).

Gaston (1981) in a study on breeding birds of Delhi observed main breeding peak during the onset of rains. Rainfall stimulated breeding in South African birds and the clutch size increased following rainfall events (Lloyd, 1999; Simmons *et al*., 2004). Abundance of caterpillar increases with the emergence of new leaves on trees after the first rain (Gaston, 1981; Price and Jamdar, 1991). In order to meet high energy demand during breeding and for healthy growth of juveniles, bird feeds on caterpillars (Vijayan, 1975, 1980). Peak breeding season of birds in the Teesta valley coincided with the rain but ended before heavy monsoon as documented by many studies (Martin, 1987; Hsu and Lin, 1997; Lloyd, 1999; Simmons *et al*., 2004).

The breeding season, which lasted only for four months (April to July), was very short compared to other parts of India (Vijayan, 1980; Gaston, 1981; Vijayan, 1984; Gokula, 1998; Vijayan *et al.*, 1998b; Nirmala, 2002) and many tropical countries (Lack, 1968; Perrins and Birkhead, 1983). Food availability is one of the major factors that determine time of reproduction (Lack, 1968; Martin, 1987; Perrins and Birkhead, 1983; Perrins, 1996; Conway and Martin, 2000) although there are some other factors which interplay

(Chamberlain *et al.*, 1999; Lloyd, 1999; Valentina *et al.*, 2005). Due to cold weather conditions and decline in food availability (especially insects) during pre-winter and winter months, birds bred only when conditions for reproduction were favorable (Perrins, 1996). High fluctuations of temperature and humidity among seasons affect breeding patterns (Gaston, 1981). Both latitude and altitude are considered to have strong effect on breeding seasonality of birds (Perrins and Birkhead, 1983). Summer starts relatively later at high latitude or elevation and ends early resulting in shorter favorable period than low-lying areas. Since, most of the transects in the study area were located at high elevation, birds restricted breeding to the favorable summer and pre-monsoon seasons. Apart from food, availability of varieties of grasses, leaves and flowers as nesting material during rainy season (Lack, 1968; Ali and Ripley, 2001) aided birds to breed during monsoon.

Ashy Drongo generally used Alder tree (*Alnus nepalensis*) for nesting. Ali (1962) also made similar observations. Alder tree has numerous horizontal branches with forked end that provides suitable nesting site for the bird as observed by Martinsen and Whitham (1994) in hybrid cotton tree. Clutch size varied between two to four while Ali (1962) and Ali and Ripley (2001) reported three or four. Since Ashy Drongo placed nest at considerable height (8 - 25 m) from the ground, concealment might not be very significant. In addition, the closed canopy and leaves above the nest protects eggs and chicks from predators flying above the canopy and also from unfavorable weather conditions such as rain (Vijayan, 1984). Canopy cover predicts daily nest survival in some species of birds (Smith *et al.*, 2007).

Maximum nests of Black Bulbul were found on *Erithrina stricta*, which being thorny might aid in protecting nests from predators (Collias and Collias, 1984; Gokula and Vijayan, 2001). The use of short and thorny plants for nesting has been reported in Red-vented Bulbul, White-browed Bulbul, Red-whiskered Bulbul and Grey-headed Bulbul in different forests in South India (Vijayan, 1980; Kurian, 2005; Vijayan and Balakrishnan, 2005). Similar observations were made in Styan's Bulbul *Pycnonotus taivanus* in Taiwan (Hsu and Lin, 1997). Nest height use by Black Bulbul was much lower than reported by Ali (1962).

Chestnut-crowned Laughingthrush constructed nest in short bushes inside dense undergrowth vegetation with more than 70% shrub cover. Nilgiri Laughingthrush (*Garrulax cachinnans*) also placed their nests in low height bushes (1 - 2 m) in thick undergrowth vegetation (Islam, 1994). Low height nest within the dense undergrowth protects eggs or chicks from cold or windy weather conditions prevalent in the breeding habitat (Walsberg, 1985; Kumar, 1995). Although Ali (1962) and Ali and Ripley (2001) reported clutch size three as rare occurrence, this study observed three in most of the cases.

Common Tailorbird nested near the agricultural field or open canopy forest within the dense undergrowth. This kind of habitat provides concealment, favored foraging sites and microclimates for small sized species (Holway, 1991). Due to higher risk of predation and anthropogenic disturbance (Flaspohler *et al.*, 2000), nest placed near the ground was highly concealed. Ali and Ripley (2001) also reported total concealment of nests in this species. Although Common Tailorbird is reported to breed from March to December in other parts of India (Ali and Ripley, 2001), breeding was restricted to very short period (April to May) in Sikkim. The leaf of the herb and grasses used for nest building are available only during monsoon which probably restricts their breeding to this period alone (Lack, 1968; Ali and Ripley, 2001).

The breeding habitat of Grey-backed Shrike lies in the temperate scrub forest between 2300 m and 3600 m elevation. According to Ali (1962) the bird breeds between 3000 m and 4500 m, which is far above the present observation. Most used nesting plant was *Ilex sikkimensis*. The closed branching architecture with the protective thorns and high leaf density of these plants provided ideal condition for concealment of the nest from predators as well as prevention from harsh climatic conditions (Collias and Collias, 1984; Holway, 1991; Gokula, 1998; Flaspohler *et al.*, 2000; Nirmala, 2002). According to the available information (Ali, 1962; Ali and Ripley, 2001) the clutch size of Grey-backed Shrike vary between 3 and 6 but only 2 - 4 (rarely five) was recorded during the study. The variation in clutch sizes within a species is related to age, food availability, environmental fluctuations, disturbance, and individual genetic differences (Newton, 1989; Partridge, 1989; Gill, 1995; Hafner *et al.*, 2001).

White-collared Blackbird utilized dense foliage in thorny trees in undisturbed closed canopy forest for nesting. Tree density, shrub cover and ground vegetation were high at the nest-site as observed in Wood Thrushes by Hoover and Brittingham (1998). Since the nest was large, it was placed at the bifurcation of stout branches mostly along the main stem. Nest characteristics and clutch size was same as reported by Ali (1962); Ali and Ripley (2001). Mossy branches or foliage-covered nests provide protection from high wind speed and cold climatic conditions (Kumar, 1995; Flaspohler *et al.*, 2000) prevalent in breeding habitat at high elevation.

Ali (1962) reported nesting of White-capped Water Redstart between 1800 m and 4800 m. Although this species was recorded in the Teesta valley from 500 m to 4600 m during non-breeding season, breeding was restricted between 2600 m and 3700 m elevation. Concealment was high because the nests were placed in hollow of rocky wall and rock crevices. The mosses, dry leaves and wool or hair used for nesting keeps the nest warm because the nests were directly in contact with earth's surface. Since the bird nested near the stream at higher elevations, placement of nests in a hole or crevice provides insulation to cold wind thus helps in maintaining temperature required for incubation.

Nest-site characteristics of the White-rumped Munia corresponded with Spotted Munia *Lonchura punctata* of Southern India (Gokula and Vijayan, 2001). Concealment was low probably because protection was compensated by huge dome shaped nest with lateral entrance. Availability of nesting tree might be the major factor for nest site selection as nest tree used were rare except *Schima wallichi*. Nest characteristics are same as noted by Ali (1962). Clutch size observed was low compared to the report of Ali (1962).

4.5. SUMMARY

Studies on ecology of local communities are important for understanding environmental problems and planning area-based conservation management (Simberloff, 2004). Community composition, species richness and diversity of birds in five different elevation zones of Teesta valley, Sikkim were studied from June 2003 to March 2006 using point count sampling method. A total of 329 species of birds (299 during regular quantitative sampling and 30 during opportunistic observations) belonging to 44 families was recorded in the Teesta valley during the study period. The study shows that Teesta valley harbors high diversity and abundance of birds.

Broadleaved vegetation, situated at mid-elevation region, is the most diverse zone as compared to tropical, coniferous or alpine vegetation. Species accumulation curves based on number of point counts indicated that most of the species were detected in all the zones. Species richness (observed and estimated) was the maximum in zone II, whereas density, abundance and diversity were the maximum in zone III. The species-abundance pattern of birds followed truncated log-normal distribution for total bird population as well as for all the zones except zone II which did not fit to any models. Bird data showed the presence of both types of species, exclusive (restricted to one elevation zone) and generalists (present in two or more zones), in the Teesta valley. Out of the total species observed (329), 156 (47.4%) were exclusively recorded in one specific elevation zone. Only three species, namely Blue Whistling Thrush, Greenish Warbler and White-capped Water Redstart occurred in all the five zones.

Each elevation zones harbour unique species composition of birds. Zones II and III shared maximum number of species followed by zones I and II. Similarity indices were generally low, with scores of 0.04 - 0.4 for elevation zone pairs. Overall, species richness as well as density was high during summer and low during winter. Marked seasonal variation in bird species richness and density was observed in different elevation zones. Insectivores dominated the bird community in the Teesta valley comprising 61% species and 55% individuals. Nectarivore and carnivore trophic groups represented lowest species and abundance respectively.

In total, 630 individuals belonging to six TNE (threatened, near threatened and endemic) species were observed from the Teesta valley during the study period. Number of species was the highest (5) in zone III, whereas abundance was highest (357) in zone II. Out of 10 endemic species of Sikkim, only five were recorded during this study. Similarly, among the 17 threatened and two near threatened birds that occur in Sikkim only two species were observed in the Teesta valley. Study in detail on ecology of threatened and endemic species is needed for conservation action.

Breeding observations on birds of the Teesta valley, Sikkim was made during 2004 and 2005. This is the first attempt to study breeding birds in Sikkim after Ali (1962). Altogether, 183 nests of 39 species were recorded in four elevation zones of the study area. Many species had very few nests. Breeding observation of seven species, namely Ashy Wood Pigeon, Black-winged Cuckooshrike, Blood Pheasant, Eurasian Jay, Greenish Warbler, Rufescent Prinia and Tickel's Thrush were not reported earlier from Sikkim. Breeding bird community differed among zones. Most of the species breeding in zone I were exclusive to this zone which shows that they have specific habitat for breeding. In total, Grey-backed Shrike had the highest number of nests. As observed in other studies, cup-nesters dominated with 67% species and 69% nests. June was the peak breeding period with the highest number of breeding species and nests. Breeding period was short (March to August), peak being June. Similar trend was observed in all the zones. The nest and nest-site characteristics of a few select species suggest that nest concealment, immediate microhabitat and environmental variables are potential factors for nest-site selection which differed among the species studied. The result of this study indicates that Teesta valley harbors potential breeding habitats for many bird species and needs conservation attention. Detailed study focusing on habitat requirements of each species, especially the rare and endemic birds, is needed for the implementation of conservation measures.

CHAPTER 5

ELEVATIONAL DISTRIBUTION PATTERN OF BIRDS

5.1. INTRODUCTION

The elucidation of distribution pattern of organisms along environmental gradient is one of the main themes in ecology and biogeography (Gaston, 2000). Some species are narrowly distributed, whereas some others show wider distribution and the patterns are repeated at many forms and scales (Graham, 1990; Colwell and Coddington, 1994). One among such gradients that affect the distribution of organisms is elevation. However, organisms do not respond directly to the elevation gradient but do so to the factors governed by elevation such as climate or productivity (Terborgh, 1977; Brown, 2001; Lomolino, 2001; Mittelbach *et al.*, 2001; Kattan and Franco, 2004; McCain, 2007a). Owing to the complex interaction among ecological, historical, and evolutionary forces, species richness along an elevation gradient varies among taxa as well as regions or within the same region on a local scale (Rahbek, 1995; Patterson *et al.*, 1998).

In broad scale, three general patterns of species richness with elevation have been emphasized by most researchers (i) monotonic decline of species richness with increasing elevation, (ii) a hump-shaped pattern with peak in richness at some intermediate elevation and (iii) increase in species richness with increase in elevation. Unimodal or hump-shaped pattern is reported to be the most common one (Rahbek, 1995, 2005). Various underlying causes, ranging from climatic (temperature, rainfall, humidity), biological (mass effects, productivity, habitat heterogeneity), historical (isolation, speciation, extinction and immigration) and spatial (area and mid-domain effect) have been proposed to explain the elevational distribution of species (Rosenzweig, 1992, 1995; Colwell and Lees, 2000; Brown, 2001; Heaney, 2001; Lomolino, 2001; McCain, 2003, 2004; Kattan and Franco, 2004; Grytnes and McCain, 2007). Most studies concluded that instead of a single factor, various factors (biotic, abiotic and historical) interact in complex ways to generate the observed pattern of species richness (Rahbek, 1997; Heaney, 2001; Oommen and Shanker, 2005).

Among the range of hypothesis, mid-domain effect is considered as one of the plausible explanations for distribution of species along elevation gradient (Colwell and Hurtt, 1994; Colwell and Lees, 2000; Colwell *et al.*, 2004). To substantiate the elevational pattern of species richness, null models of the mid-domain effect have been proposed and empirically tested in some cases (Grytnes and Vetaas, 2002; Sanders, 2002; McCain, 2003, 2004, 2005, 2007a). According to mid-domain effect, a mid-elevation peak of species richness is obtained due to geographical constraints and is predicted where geographic hard boundaries such as mountaintops, snowline or oceans limit the extension of species so that range sizes overlap creating a peak or hump at the middle of the elevation gradient (Rahbek, 1997; Colwell and Lees, 2000). Null models show predicted richness which can be compared against empirical richness pattern. Deviation of empirical pattern from null model prediction urged the need to look for other factors besides spatial constraint for species richness (Grytnes, 2003a; McCain, 2004).

The pioneering study on elevational pattern of birds (Terborgh, 1971; Terborgh and Weske, 1975) observed monotonic decline in species richness with elevation. However, most of the recent studies on birds supported mid-elevation species richness peak (Rahbek, 1997; Kattan and Franco, 2004; Lee *et al.*, 2004; Ding *et al.*, 2005). Population of birds belonging to different diet guild categories responds in different ways with elevation (Terborgh, 1977; Kessler *et al.*, 2001; Raman, 2001; Raman *et al.*, 2005). Some groups show increase, whereas others decline, forms peak at intermediate elevation or show no definite pattern along the elevation gradient depending upon the availability of food, microhabitat and other physiological requirements (Graham, 1990).

Competition, primary productivity, ecotones and factors varying in parallel with elevation such as climate and vegetation have been considered as an important determinant for species richness patterns of birds (Terborgh, 1971, 1977; Rahbek, 1997; Kessler *et al.*, 2001; Ding *et al.*, 2005, 2006). Some studies have reported significant effects of area and isolation for elevational distribution pattern of birds (Hawkins, 1999; Kattan and Franco, 2004). The effect of geographic hard boundary for distribution has been tested mostly in plants and mammals (Grytnes and Vetaas, 2002; McCain, 2003, 2004, 2005, 2007a). In birds, the effect of geometric constraints on species distribution has been evaluated on latitudinal or continental scales and has gained equal support (Rahbek and Graves, 2000; Jetz and Rahbek, 2001, 2002; Rahbek *et al.*, 2007) and criticisms (Diniz-Filho *et al.*, 2002; Hawkins and Diniz-Filho, 2002, 2006; Rangel and Diniz-Filho, 2003) from ecologists. A few available studies on elevational pattern of birds showed significant deviation from the prediction of mid-domain effect null model (Koh *et al.*, 2006).

Similarity or species overlap allows us to see local species richness, whereas complementarity or dissimilarity of organisms can be considered as positive components of biodiversity, although both interact in complex ways (Colwell and Coddington, 1994). The faunal similarity between sites is either the consequence of similarity in vegetation types, climatic conditions or landscape. Turnover of species along an elevation gradient is expected as temperature, rainfall, humidity, vegetation, productivity and area also change accordingly (Terborgh, 1977; Rahbek, 1997; Sanders *et al.*, 2003; McCain, 2007a, b). The rate of turnover either increases with elevation (Rahbek, 1997) or corresponds with the vegetation zones where transition of species occurs (Patterson *et al.*, 1996; Raman *et al.*, 2005). Understanding the spatial turnover pattern of species is important for understanding the structure of species assemblage (Gaston, 1996). The high turnover often results in high regional biodiversity (Condit *et al.*, 2002) and it provides information for the estimation of regional species richness (Harte *et al.*, 1999; Vasudevan *et al.*, 2006).

Range size of species also varies along spatial gradient. According to the Rapoport's rule, range size increases with latitude. Since, elevation acts as proxy to latitude, elevational range of species is considered to increase with increase in elevation (Stevens, 1992; Patterson *et al.*, 1996). The factors such as habitat availability, dispersal and establishment abilities, competition, predation, local abundance, climatic or environmental tolerances and historical factors are the determinants of species range sizes (Gaston, 1996). In montane species, range size can be best used to predict the threat of extinction as most of the species has very small range size (Harris and Pimm, 2008).

In recent years, several studies on elevational distribution pattern have been conducted mostly on small plants and mammals (Chapter 1, Pp.5). A few studies on invertebrates and herpetofauna are also available (Chapter 1, Pp.5). After Terborgh (1971, 1977), considerable studies were carried out in birds but most of them are restricted to either short elevational span covering only part of the gradient or on a smaller mountain with narrow elevational width (Hawkins, 1999; Raman, 2001; Raman *et al.*, 2005). The data spanned over the entire gradient covering wide elevation is necessary to figure out the variation of species richness patterns (Rahbek, 1995; Carpenter, 2005) because the pattern changes when only part of the gradient is considered (Kattan and Franco, 2004).

A large gradient of Himalaya provides better understanding on the elevational distribution of species (Körner, 2000). Despite high variation in elevation and climate with corresponding changes in vegetation, study on elevational distribution of species in the Himalaya is scanty. A few available studies are restricted to plants, mostly in the central Himalaya (Chapter 3, Pp.23). The Eastern Himalaya, of which Sikkim forms an important part, is priority region for conservation owing to its rich and endemic flora and fauna (Islam and Rahmani, 2004). High altitudinal variation (300 - 5500 m) with apparent zonation of climate and vegetation make the Teesta valley an unique region for studying elevational distribution pattern of birds.

This Chapter deals with the distribution pattern of birds along 4200 m (390 - 4600 m) elevation gradient of the Teesta valley, Sikkim. Species similarity, turnover, range sizes and factors governing the distribution of species are also discussed.

5.2. METHODS

5.2.1. Sampling

Point count method (Bibby *et al.*, 2000) along the predetermined transects was used for sampling birds (Chapter 4, Pp.44). Transects were placed at different elevations distributed over five vegetation types. Elevational distance between two consecutive transects was 90 m to 350 m depending upon the logistics, vegetation types, availability and accessibility of suitable plots. The distance between consecutive transects were more in higher elevations mostly due to logistic problems. Within the transect, permanent points were established for bird sampling. The distance between two points within transect was 100 m. The points were replicated covering four seasons viz. winter, summer, monsoon and post monsoon. Census data from only 22 transects (Table 5.1) sampled during 2004 and 2005 are used in this chapter. Data from transect located at Bop (Table 2.1; Chapter 2, Pp.20) was not used here due to comparatively less sampling effort.

5.2.2. Data analysis

Elevational pattern of birds

Data was analyzed to calculate species richness, abundance, diversity, density, and non-parametric richness (Chao 2, Jackknife 1 and Jackknife 2) for all 22 elevational transects. The elevation of each transect was obtained as mean of all the points within transects. Species richness was also calculated for birds in different trophic groups. Details are provided in Chapter 4, Pp.46 - 49. Species accumulation curves were used to asses the completeness of sampling. The numbers of species were plotted against sampling effort (points sampled) to produce species accumulation curves at each elevational transect. If the curves attains plateau, it is assumed that species richness is estimated more or less accurately (Colwell and Coddington, 1994; O'Dea and Whittaker, 2007). Regression analysis was used to investigate relationship between observed species richness, diversity, density, and estimated non-parametric richness with elevation. Single factor analysis of variance (ANOVA) was used to test the differences in richness, density and abundance of birds in total as well as in different trophic groups along the elevation gradient. In order to meet the assumption of parametric tests, data were subjected to log transformation prior to performing ANOVA (Zar, 1999). Before transformation 0.5 was added to each data set. Relationship between species richness of each trophic group with elevation was assessed using correlation analysis. The analyses were done using statistical software EstimateS version 7 (Colwell, 2004), SPSS version 10.0 and Microsoft excel for windows.

Similarity between elevation sites

Jaccard similarity index and the number of species shared between elevational transect pairs were obtained for all 231 pairs (resulted from pairwise combination of 22 transects) using software EstimateS version 7 (Colwell, 2004). Cluster analysis was performed and a dendrogram was produced based on Jaccard similarity index illustrating similarities in bird community composition between sampled elevational transects.

Species turnover

Pattern of species turnover rate between two consecutive elevational transects was examined using Whittaker's beta index (Southwood and Henderson, 2000). Beta index (β) = S/α-1, where S is the total number of species in two consecutive transects and α is the average species richness of pair of transects. This index is applied to calculate turnover rate of birds along an elevation gradient by earlier studies (Rahbek, 1997). Pearson correlation was used to establish the relation between turnover rate and elevation of the transects.

Range sizes

Range of each species was estimated as difference between the lowest and highest elevation at which bird was recorded during the study. The species are assumed to be present at all intermediate elevations between lowest and highest elevation (Patterson *et al.*, 1998; Md Nor, 2001). Regression analyses were performed between elevational range size and lower and upper elevation limits of each species to examine the trend of range size with elevation (Patterson *et al.*, 1996).

Mid-Domain effect null model

The mid-domain effect was tested using Monte Carlo simulations programme, mid-domain effect null model (McCain, 2004). This programme uses empirical range sizes or range midpoints within the elevational range and simulates species richness curves based on analytical-stochastic models (Colwell and Hurtt, 1994; Colwell and Lees, 2000; Colwell *et al.*, 2004). To test the impact of spatial constraints on species richness, 95% prediction curves were produced based on 50,000 simulations (without replacement) using empirical range sizes and range midpoints. The empirical species richness curves were compared with the 95% prediction curves to assess the accuracy of the null model predictions. Species richness data were generated at 100 m elevational increments. Average of the predicted values was regressed on empirical values to assess fitness of the empirical richness to the null model (McCain, 2004).

5.3. RESULTS

5.3.1. Distribution pattern along the elevation

Bird species richness

The number of species observed at a single elevational transect varied from 27 to 89 (Table 5.1). There was significant variation in the observed number of species among elevational transects (ANOVA, $F_{21, 2406} = 22.18$, $p < 0.01$). Maximum number of species was observed at middle of the elevational gradient (around 2000 m) with declining trend at both the ends (Figure 5.1). There was a sharp fall in species richness at around 3000 m and no significant variation was observed beyond this elevation. Regression between elevation and the number of observed species followed quadratic model ($r^2 = 0.60$; $p = 0.00$). Since there was no significant increase in r^2 values with high order polynomials, quadratic model was selected as the best fit (Zar, 1999).

Species accumulation curve of all the 22 elevational transects is depicted in Figure 5.2. Although the accumulation curves approached plateau, a few additional species were being detected at a slower rate in some of the transects even after two years of sampling. Hence, non-parametric estimators (Chao 2, Jackknife 1 and Jackknife 2) were used to estimate the number of species. The estimated species richness tended to be higher than the observed species richness at all elevational transects (Table 5.1).

Although non-parametric estimators showed comparatively higher values than the observed species, the elevational pattern was similar in both cases (observed and estimated). The estimated species richness changed as a quadratic function of elevation for Chao 2 ($r^2 = 0.6$; $p = 0.00$), Jackknife 1 ($r^2 = 0.\ 62$; $p = 0.00$), and Jackknife 2 ($r^2 = 0.61$; $p = 0.00$) showing peak around 2000 m with declining ends (Figure 5.1).

Species diversity

Shannon-Weaver species diversity also followed unimodal or hump-shaped pattern with elevation (Figure 5.1). Regression between diversity and elevation displayed quadratic relationship and the value obtained was significant ($r^2 = 0.\ 66$; $p = 0.00$). The maximum diversity was at 2550 m and minimum at the highest elevation (4600 m) of the sampled transects (Table 5.1). The decline in diversity was sharp at high elevation transects as compared to the low elevation transects.

Abundance and density

Total number of birds encountered at a single transect varied from 260 to 1,964 and the number of individual per point ranged from 3.31 to 12.87 (Table 5.1). Species abundance (number of individuals per point) varied significantly among transects (ANOVA, $F_{21,\ 2406} = 21.68$, $p < 0.01$). Species abundance showed peak at mid-elevation but the pattern was slightly different from species richness (Figure 5.1). There were two peaks of abundances, one at 1120 m and the other one between 2000 m and 2300 m. Bird abundance was highly correlated with observed species richness (Pearson correlation: $r = 0.866$, $p < 0.001$) and diversity ($r = 0.899$, $p < 0.001$).

Bird density ranged between 5.1 birds/ha to 56.3 birds/ha with maximum density around 2300 m (Table 5.1). Density was very low above 3000 m (Figure 5.1). Significant variation in bird density was observed among different transects (ANOVA, $F_{21,\ 2406} = 17.38$, $p < 0.01$). Regression analysis revealed significant quadratic relation between bird density and elevation ($r^2 = 0.\ 51$; $p = 0.00$).

Table 5.1 Observed species richness (Sobs), estimated species richness (Chao 2, Jackknife 1 and Jackknife 2), Shannon-Weaver diversity (H'), density and abundance of birds in different elevational transects of the Teesta valley, Sikkim. Abun - Abundance (Individuals/point); D = Density (birds/ha); r^2 = regression coefficient (quadratic model) - all values are significant at $p \leq 0.001$).

Transect	**Elevation (m)**	**Sobs**	**Abun**	**H'**	**D**	**Chao 2**	**Jackknife 1**	**Jackknife 2**
T1	390	64	6.2	3.41	16.3	66.89	72.94	68.11
T2	550	48	6.63	3.3	17.3	54.53	57.88	61.86
T3	660	54	8.08	3.01	22.5	71.71	68.83	78.67
T4	750	57	9.33	3.54	22.7	62.7	66.88	69.89
T5	850	58	8.64	3.15	22.5	71.18	70.91	78.83
T6	980	59	6.63	3.49	22.1	66.41	70.88	74.87
T7	1120	55	11.15	3.46	37	57.58	62.89	61.1
T8	1290	64	7.42	3.35	24.7	77.24	78.88	86.81
T9	1420	71	8.14	3.37	26.9	76.38	84.91	83.04
T10	1600	68	10	3.48	35.7	94.72	80.92	91.8
T11	1950	89	11.86	3.65	52	98.58	102.9	108.9
T12	2140	89	11.65	3.68	51.1	96.03	103.9	104.9
T13	2310	69	12.87	3.47	56.3	75.05	80.87	82.93
T14	2550	72	10.86	3.7	47	73.7	77.94	76.06
T15	2900	39	5.45	3.1	12.1	41.14	45.9	44.08
T16	3160	32	5.3	2.87	11.8	33.28	35.94	36
T17	3350	32	4.28	2.77	9.6	35.61	36.95	39.92
T18	3500	33	4.34	2.95	9.7	34.17	35.97	36.97
T19	3730	32	4.42	2.68	9.7	35.6	38.93	40.94
T20	4070	28	3.31	2.86	5.2	28.14	29.97	25.21
T21	4290	29	3.32	2.9	5.1	29.66	31.98	31.02
T22	4600	27	5.29	2.49	8.3	34.39	33.94	38.86
r^2		**0.60**	**0.51**	**0.66**	**0.51**	**0.60**	**0.62**	**0.61**

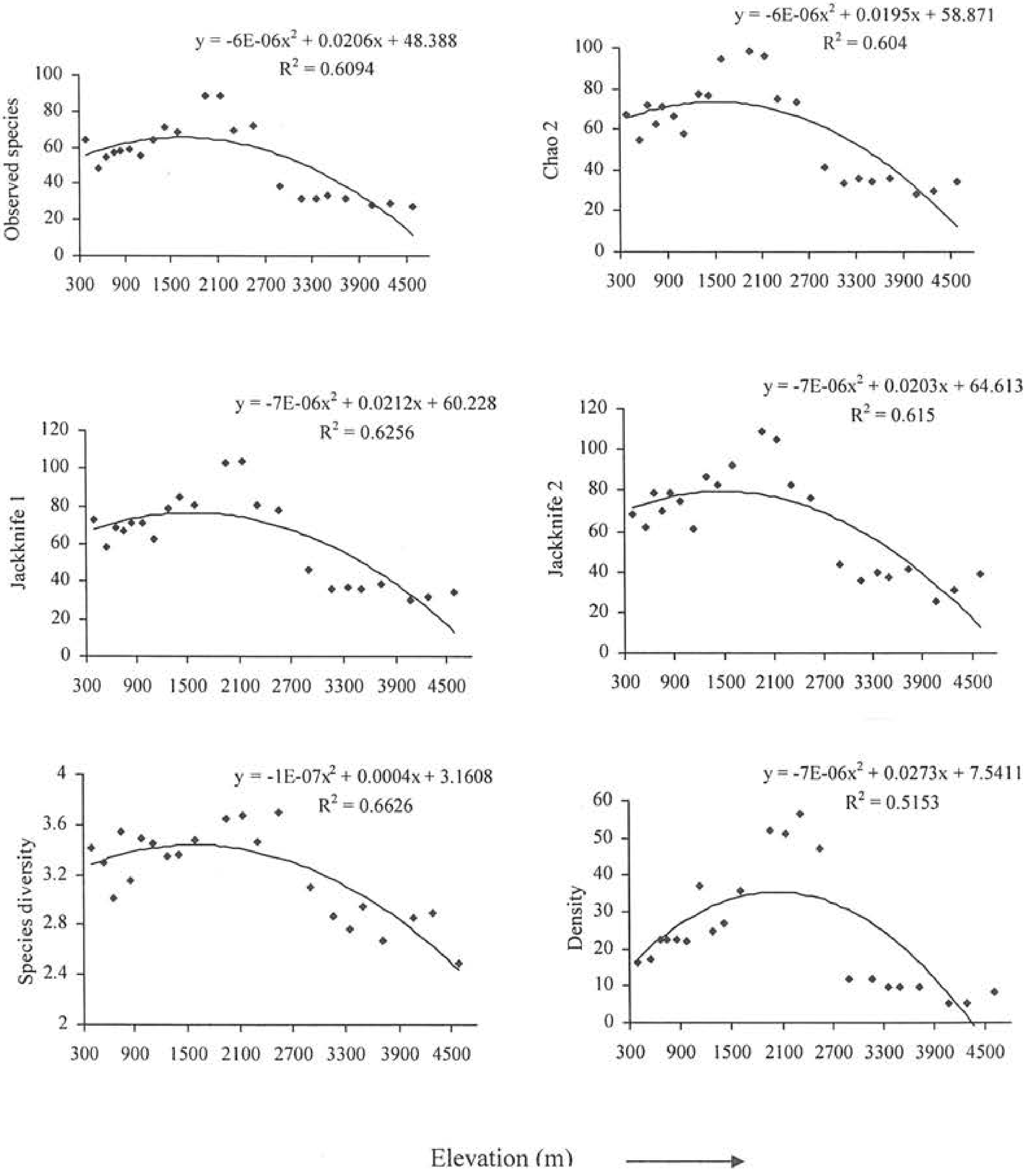

Figure 5.1 Elevational variation of bird species richness (observed, Chao 2, Jackknife 1 and Jackknife 2), diversity (Shannon-Weaver) and density (birds/ha) along the Teesta valley, Sikkim.

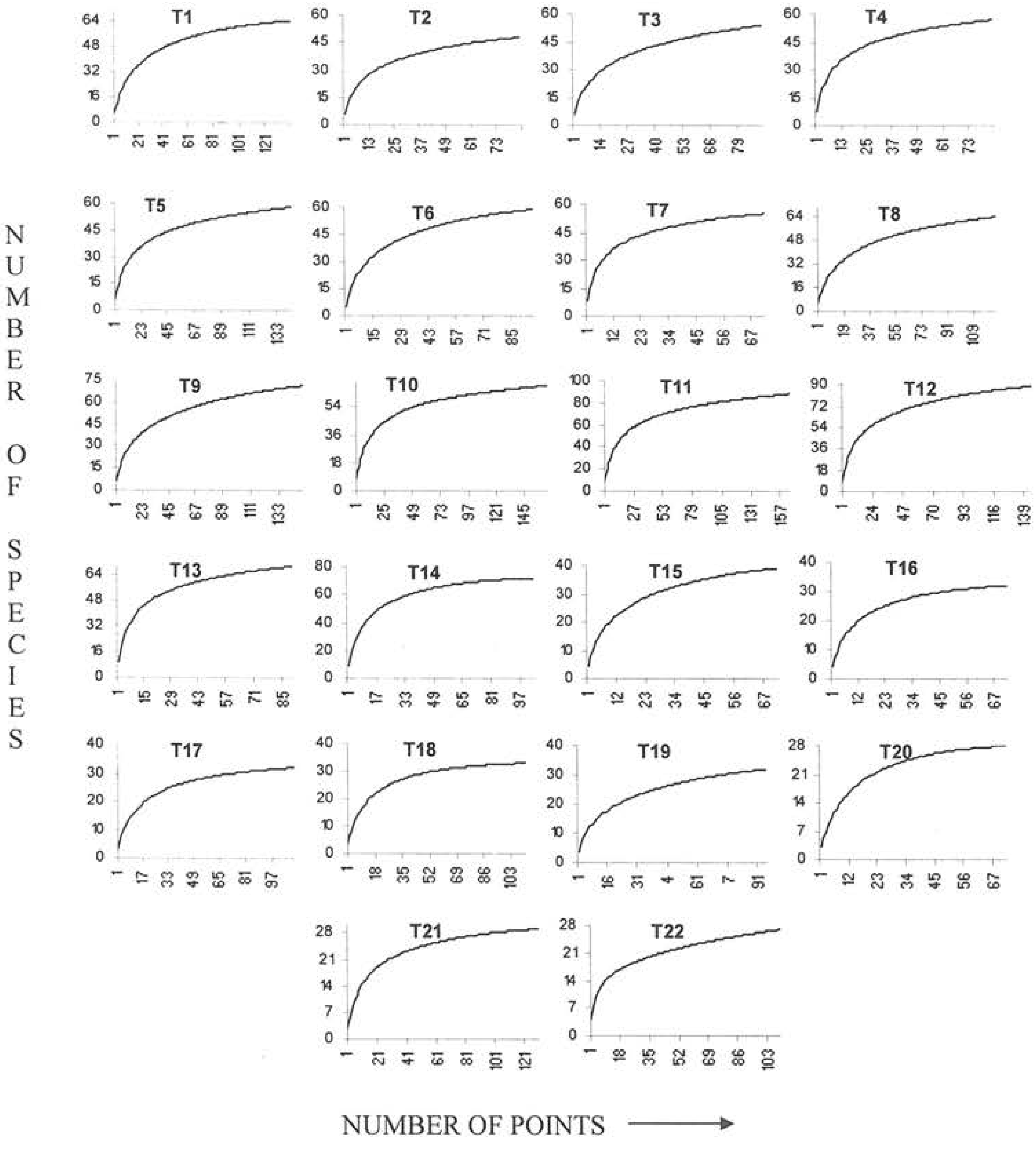

Figure 5.2 Species accumulation curves of birds in different elevational transects located along the Teesta valley, Sikkim. T1-T22 are transect numbers with increasing elevation (Refer Table 5.1).

Individual species and elevation

Out of the total bird species, only 25 occurred in ≥ 10 elevational transects. Although these species displayed relatively wider elevational distribution, their densities varied along the elevation gradient. The densities of seven species showed significant negative correlation with elevation, whereas three showed positive relation (Table 5.2). Eleven species had maximum density at mid-elevation (1600 - 2500 m). No such clear pattern was observed in remaining four species.

Table 5.2 Relationship between density of selected bird species (recorded in ≥ 10 transects) and elevation in the Teesta valley. r = correlation coefficient; values in bold are significant (** $p \leq 0.01$; * $p \leq 0.05$). The italicized species showed maximum density at mid-elevation.

Species	**Total transects of occurrence**	**r**
Blue Whistling Thrush	19	**-0.63****
Yellow-bellied Fantail	17	-0.24
White-capped Water Redstart	15	**0.58****
Ashy Drongo	14	-0.32
Green-backed Tit	14	**-0.44***
Grey-headed Canary Flycatcher	14	**-0.69****
Whiskered Yuhina	14	-0.38
Black-throated Sunbird	13	-0.37
Greenish Warbler	13	**0.56****
White-spectacled Warbler	13	-0.42
Black Bulbul	12	**-0.69****
Great Barbet	12	**-0.83****
Rufous-gorgeted Flycatcher	12	0.26
Striated Laughingthrush	12	-0.35
White-browed Shrike Babbler	12	**-0.47***
Rufous-bellied Niltava	11	-0.16
Verditer Flycatcher	11	-0.27
White-throated Fantail	11	-0.19
Grey-cheeked Warbler	10	-0.21
Grey-hooded Warbler	10	-0.41
Plain-backed Thrush	10	**0.43***
Rufous Sibia	10	-0.13
Scarlet Minivet	10	**-0.65****
Wedge-tailed Green Pigeon	10	-0.3
White-naped Yuhina	10	-0.41

Trophic diversity

Among the six groups of avifauna based on their diet, all were present along the entire elevation gradient except nectarivores, which were restricted below 3350 m. Species richness of birds belonging to different trophic groups showed significant variation along the elevation gradient (One way ANOVA, $F = 104.36$, $p < 0.01$). Carnivores, frugivores, insectivores and nectarivores showed significant negative correlation with elevation ($p \leq 0.01$; Table 5.3). Although the trend was declining, the relation was non-linear for frugivores, insectivores and nectarivores with a peak at around 2000 m to 2500 m, whereas carnivores declined monotonically with elevation. Omnivores and granivores showed no significant correlation with elevation and thus behaved differently; maximum richness of omnivores was observed around 2000 m, whereas granivorous species peaked at 4600 m.

Table 5.3 Species richness of birds in different trophic groups observed along the elevational transects of Teesta valley. C-Carnivore, F-Frugivore, G-Granivore, I-Insectivore, N-Nectarivore, O-Omnivore, r- Pearson correlation with elevation. Significant values ($p \leq 0.01$) are shown in bold.

Transect	**Elevation (m)**	**Number of Species**					
		C	**F**	**G**	**I**	**N**	**O**
T1	390	7	6	3	38	3	7
T2	550	4	4	3	29	2	6
T3	660	3	6	4	31	2	8
T4	750	4	4	4	34	3	8
T5	850	2	6	3	37	3	7
T6	980	3	7	1	38	4	6
T7	1120	4	5	1	36	3	6
T8	1290	1	6	1	46	4	6
T9	1420	3	5	1	48	7	7
T10	1600	0	4	1	50	2	11
T11	1950	1	9	2	57	5	15
T12	2140	4	8	5	50	7	15
T13	2310	2	5	2	45	4	11
T14	2550	0	6	4	46	5	11
T15	2900	0	1	2	29	1	6
T16	3160	0	1	3	24	1	3
T17	3350	0	3	2	23	0	4
T18	3500	1	3	1	26	0	2
T19	3730	2	3	2	21	0	4
T20	4070	1	1	3	14	0	9
T21	4290	0	2	5	14	0	8
T22	4600	0	2	8	11	0	6
R		**-0.69**	**-0.64**	0.34	**-0.62**	**-0.57**	0.17

5.3.2. Similarity between elevational sites

Out of the 297 species observed in 22 elevational transects, 216 were shared between different transects. The number of shared species between two transects varied from 0 to 61. The maximum number of common species (61) was observed between T11 (1950 m) and T12 (2140 m). Among the 231 possible pairs of 22 elevational transects, there were no common species between eight pair of sites. Jaccard similarity index calculated for pair-wise elevational transects ranged from 0 to 0.55. Similarity was relatively low particularly between transects that were farther apart. Maximum similarity (0.55) was observed between transects located at high elevation, T17 and T18 (3350 m and 3500 m; Table 5.4).

Dendrogram obtained (Figure 5.3), taking Jaccard similarity index between elevational transects formed two major clusters showing distinct species assemblages, low to mid-elevation 390 - 2550 m (T1 to T14) and high elevation 2900 - 4600 m (T15 - T22). The low elevation transects (T1 - T10) between 390 m and 1600 m showed more similar species composition and clustered together, although they formed two assemblages i.e. T1 to T6 (390 - 980 m) and T7 to T10 (1120 - 1600 m). The species composition of birds between 1950 m and 2550 m (T11 - T14) was unique among all transects forming a separate cluster. The high elevation cluster was also divided into two forming separate avifaunal assemblages, one with T15 to T19 (2900 - 3730 m) and other with T20 to T22 (4070 - 4600 m) showing relatively low similarity among T20 (4070 m), T21 (4290 m) and T22 (4600 m). High transition in bird species composition was observed at 2900 m (T15). High elevation avifauna joined their middle and lower elevation counterparts at the last (Figure 5.3).

Table 5.4. Species similarity matrix of birds between different elevational transects in the Teesta valley, Sikkim. Jaccard similarity index are above the diagonal and number of species shared are below the diagonal.

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22
T1	-	0.52	0.43	0.52	0.33	0.42	0.28	0.26	0.25	0.17	0.12	0.13	0.1	0.11	0.04	0.04	0.04	0.03	0.01	0.03	0.03	0.01
T2	38	-	0.44	0.52	0.34	0.39	0.27	0.24	0.24	0.13	0.09	0.11	0.09	0.08	0.02	0.01	0.01	0	0	0.01	0.01	0
T3	35	31	-	0.52	0.4	0.35	0.38	0.27	0.3	0.24	0.15	0.15	0.13	0.14	0.07	0.05	0.06	0.05	0.01	0.03	0.02	0.01
T4	41	36	38	-	0.37	0.4	0.38	0.3	0.36	0.23	0.17	0.18	0.14	0.14	0.04	0.03	0.03	0.02	0	0.02	0.02	0.01
T5	30	27	32	31	-	0.52	0.43	0.42	0.34	0.29	0.2	0.19	0.14	0.15	0.05	0.05	0.03	0.02	0	0.02	0.02	0.01
T6	36	30	29	33	40	-	0.43	0.37	0.31	0.22	0.16	0.14	0.11	0.13	0.04	0.05	0.03	0.02	0	0.04	0.04	0.01
T7	26	22	30	31	34	34	-	0.45	0.38	0.28	0.19	0.21	0.18	0.18	0.06	0.04	0.02	0.02	0	0.01	0.01	0
T8	26	22	25	28	36	33	37	-	0.47	0.31	0.24	0.25	0.19	0.19	0.1	0.07	0.04	0.02	0.01	0.03	0.03	0.02
T9	27	23	29	34	33	31	35	43	-	0.4	0.31	0.36	0.26	0.27	0.1	0.04	0.08	0.06	0.04	0.03	0.03	0.02
T10	19	13	24	23	28	23	27	31	40	-	0.39	0.35	0.33	0.32	0.11	0.08	0.11	0.09	0.05	0.03	0.04	0.01
T11	16	11	19	21	24	20	23	30	38	44	-	0.52	0.44	0.45	0.14	0.09	0.09	0.08	0.07	0.04	0.06	0.02
T12	17	14	19	22	23	18	25	31	42	41	61	-	0.52	0.5	0.19	0.1	0.1	0.08	0.08	0.04	0.05	0.02
T13	12	10	14	15	16	13	19	21	29	34	48	54	-	0.52	0.2	0.12	0.1	0.07	0.06	0.03	0.07	0.02
T14	13	9	15	16	17	15	19	22	30	34	50	54	48	-	0.23	0.13	0.12	0.08	0.08	0.05	0.06	0.03
T15	4	2	6	4	5	4	5	9	10	11	16	20	18	21	-	0.39	0.31	0.29	0.25	0.16	0.13	0.05
T16	4	1	4	3	4	4	3	6	4	7	10	11	11	12	20	-	0.39	0.35	0.36	0.25	0.2	0.07
T17	4	1	5	3	3	3	2	4	8	10	10	11	9	11	17	18	-	0.55	0.45	0.28	0.22	0.11
T18	3	0	4	2	2	2	2	2	6	8	9	9	7	8	16	17	23	-	0.41	0.24	0.15	0.11
T19	1	0	1	0	0	0	0	1	4	5	8	9	6	8	14	17	20	19	-	0.18	0.2	0.07
T20	3	1	2	2	2	3	1	3	3	3	4	5	3	5	9	12	13	12	9	-	0.33	0.22
T21	3	1	2	2	2	3	1	3	3	4	7	6	6	6	8	10	11	8	10	14	-	0.37
T22	1	0	1	1	1	1	0	2	2	1	2	2	2	3	3	4	6	6	4	10	15	-

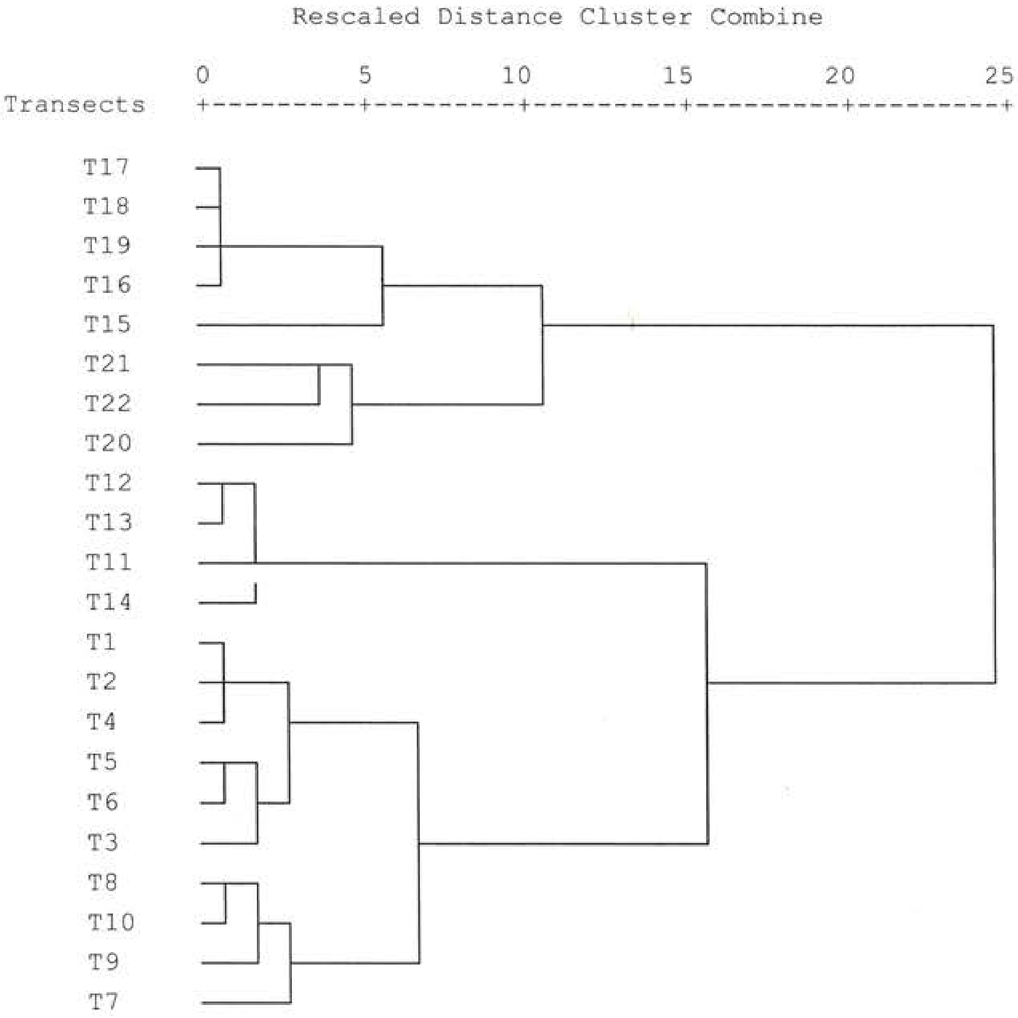

Figure 5.3 Dendrogram from a cluster analysis based on Jaccard similarity index of bird species between elevational transects along the Teesta valley, Sikkim. T1 - T22 are transect numbers with increasing elevation (elevation of the transects are given in Table 5.1).

5.3.3. Species turnover

Turnover rate of species calculated between two consecutive transects along the elevation gradient was not uniform. The rate of turnover ranged from 0.29 - 0.7 with the highest value (0.7) between T19 and T20 (3730 - 4070 m). There were two major peaks of turnover i.e. between T14 and T15 (2250 - 2900 m) and T19 and T20 (3730 - 4070 m, Figure 5.4). The rate of change in species composition was relatively higher in high elevation as compared to low elevation. Species turnover between two consecutive elevational transects showed significant positive correlation with mean elevation of the two transects ($r = 0.465$; $p = 0.05$).

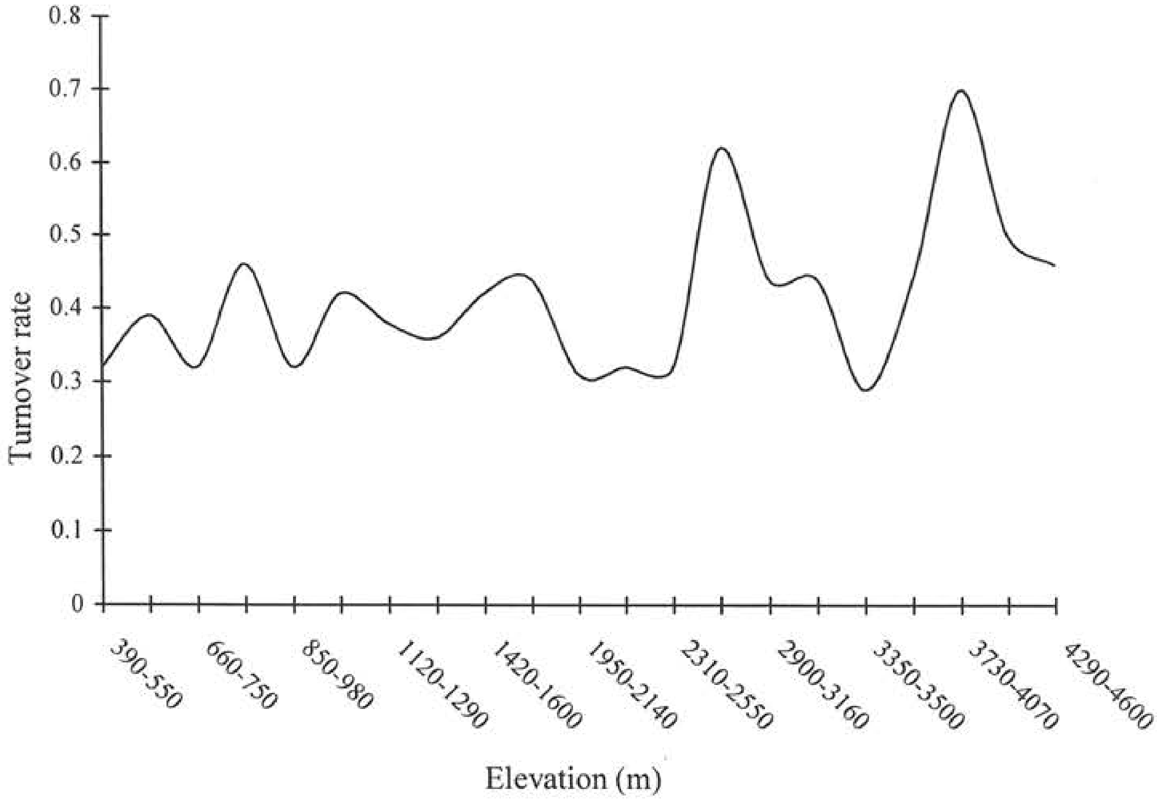

Figure 5.4 Bird species turnover rate between consecutive elevational transects in the Teesta valley, Sikkim.

5.3.4. Elevational range profile and species range size

The elevational range profile of birds of Teesta valley is illustrated in Figure 5.5. Around 90 species were restricted below 1800 m, whereas 200 species showed distribution from low to mid-elevation (<2600 m). Forty species occurred specifically above 3000 m. Maximum overlap of elevational ranges of species occurred between 1800 m and 2600 m elevation. Most of the low elevation species were restricted below 2600 m. Although, some of the high elevation species extended their range towards mid and low elevation but most species were restricted above 2600 m. It is to be noted that many species were restricted within very narrow elevational width.

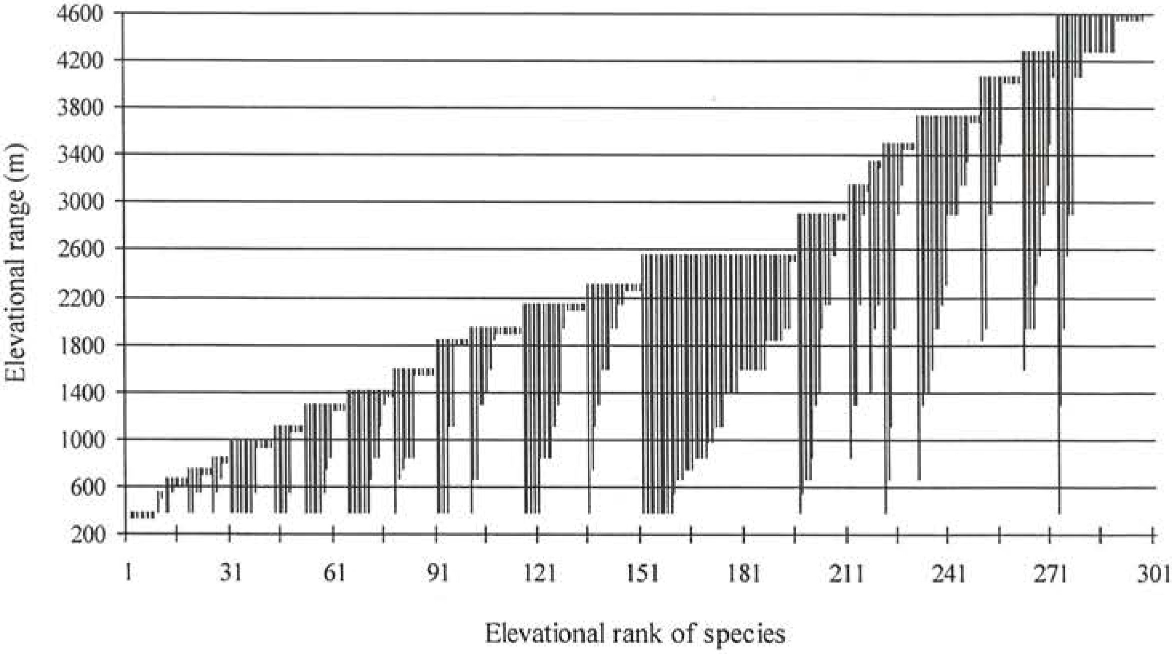

Figure 5.5 Elevational range profiles of birds of the Teesta valley, Sikkim. Vertical bars indicate maximum and minimum elevational limits of each species.

The number of species declined sharply with the increase in range size. Around 42% (125) species of birds used very narrow elevational width (<500 m) including 90 (30%) species restricted to single elevational transect. Remaining 172 species had elevation range between 500 m and 4210 m, out of which, only 35 species showed more than 2000 m range sizes (Figure 5.6). White-capped Water Redstart is the only species that occurred all along the Teesta valley and occupied the largest range (4210 m). Correlation of elevational range size with lower and upper limit of each species showed that the range size of lowland species tended to decrease with elevation ($r = -0.340$, $p = 0.00$), whereas reverse trend was obtained for highland species ($r = 0.368$, $p = 0.00$). However, the regression of range size of species with upper and lower range limits resulted in very low r^2 value.

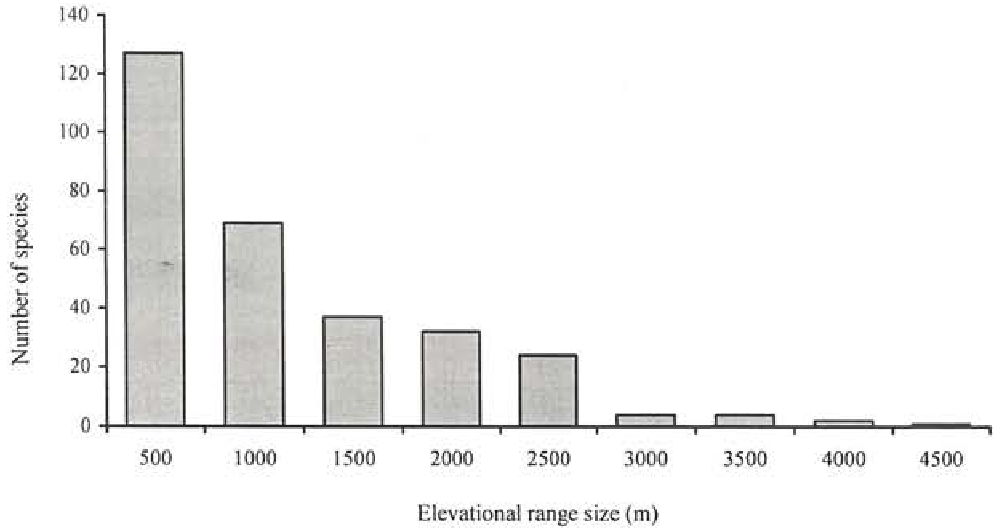

Figure 5.6 Elevational range-size distribution of birds of the Teesta valley, Sikkim.

5.3.5. Mid-Domain effect null model

Species richness pattern, including estimated species, demonstrated peak at mid-elevation at around 2000 m. To test mid-domain effect, empirical richness pattern was compared to null model predictions generated by a Monte Carlo simulation procedure (Mid-Domain Null; McCain, 2004). The curves were asymmetrical, and thus differed from mid-domain predictions (Figure 5.7). A comparison of the empirical data with the 95% prediction curves obtained from 50,000 simulations using range sizes showed that 80% (35/44) of the empirical points occurred outside the predicted range of the null model. Similarly, majority of the empirical points (32/44) occurred outside the 95% prediction curves of the null model when range mid points was used in the analysis (Figure 5.7). Regression of empirical species richness using range size with mean of the predicted richness across simulation per bin showed significant deviation ($r^2 = 0.18$; $p = 0.003$). Null models showed 20 - 25% fitness at middle and highest elevations. But the empirical species richness showed comparatively closer fit to the null model predictions obtained using range midpoints ($r^2 = 0.83$; $p < 0.001$). Randomized placement of range midpoints showed better result than range limit but midpoint simulations are too constrained by the empirical data that gives better fit to MDE null model than it should be (Christy McCain, 2007 *Pers. Comm.*). Hence, range size simulations rather than range midpoint is better for assessing fit to mid-domain effect null model for geometric constraints of species richness.

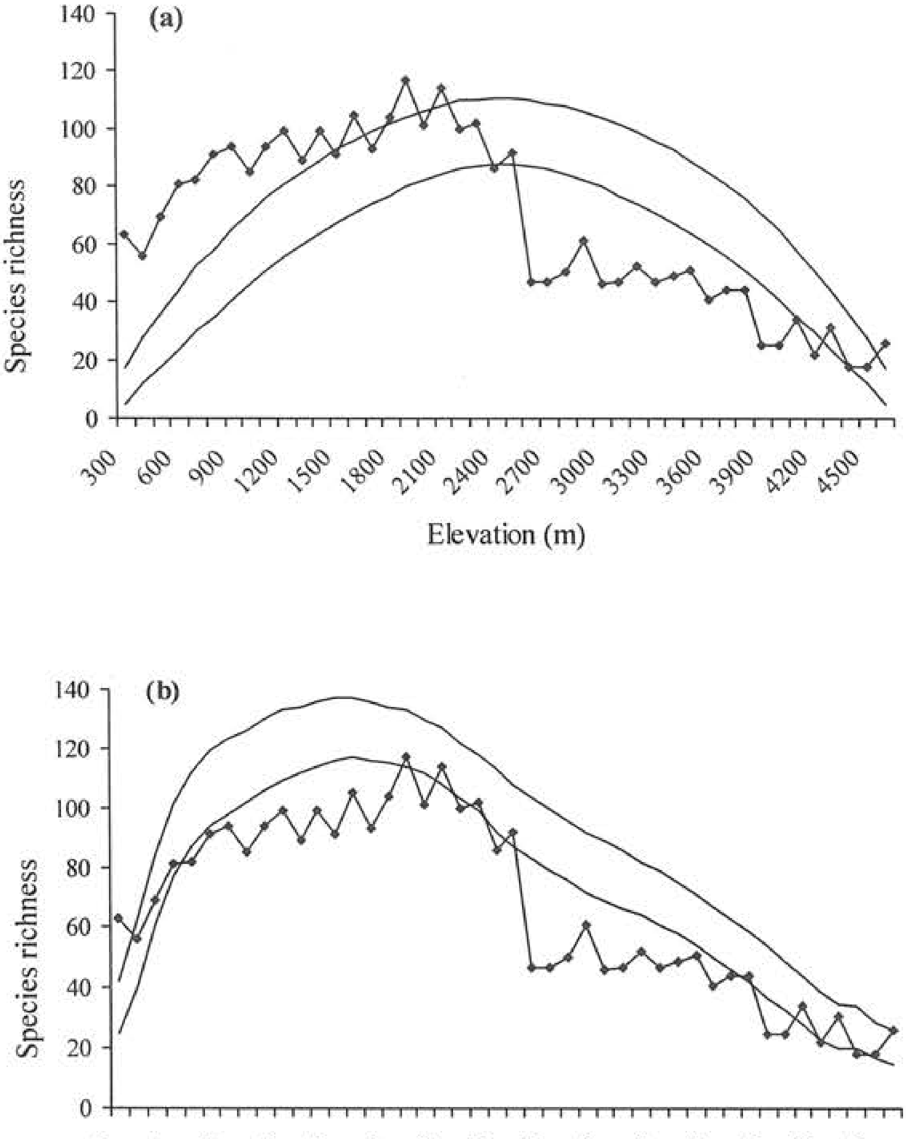

Figure 5.7 Bird species richness curve (line with squares) along the elevation gradient of the Teesta valley, Sikkim with 95% simulation curves (lines without markers) obtained using the programme mid- domain null (McCain, 2004), (a) using empirical range sizes and (b) empirical range midpoints.

5.4. DISCUSSION

The Birds of the Teesta valley showed a mid-elevation peak in species richness. Such a mid-elevation peak or hump-shaped or unimodal pattern is reported in most taxa in the studies conducted in various parts of the world; for example small mammals (Graham, 1990; Patterson *et al.*, 1998; Heaney, 2001; Li *et al.*, 2003; McCain, 2003, 2004), birds (Rahbek, 1997; Kessler *et al.*, 2001, Kattan and Franco, 2004; Lee *et al.*, 2004; Ding *et al.*, 2005; Raman *et al.*, 2005), herpetofauna (Cadle and Patton, 1988; Hofer *et al.*, 1999; Fu *et al.*, 2007), invertebrates (Olson, 1994; Sanders, 2002; Sanders *et al.*, 2003) and plants (Vàzquez and Givnish, 1998; Kessler *et al.*, 2001; Oommen and Shanker, 2005; Grau *et al.*, 2007). Hump-shaped relationship between species richness and elevation is reported to be the most general pattern (Rahbek, 2005).

Bird species richness and diversity in the Teesta valley peaked around 2000 m elevation. A few studies have obtained peak in species richness between 2000 m and 2500 m. For instance, species richness of birds in Columbian Andes was the highest at 2000 - 2500 m elevation band (Kattan and Franco, 2004). Kessler *et al.* (2001) also found similar pattern of bird species richness in Bolivian Andes with a peak around 2500 m. Breeding bird species in Taiwan gradually increased with elevation, peaked at around 2000 m, and then decreased along the elevation with lowest richness at the highest elevation i.e. around 4000 m (Lee *et al.*, 2004; Ding *et al.*, 2005). Maximum richness at this elevation was also observed in other organisms; small mammals at 2550 m in Philippines (Heaney, 2001), ants at around 2100 m in Western USA (Sanders, 2002), epiphytic pteridophytes at 2500 m in Bolivia (Kessler *et al.*, 2001), and ferns at 2000 m (Bhattarai *et al.*, 2004) and plants at 2500 m (Grytnes and Vetaas, 2002) in Central Himalaya in Nepal. Heaney (2001) concluded that if the elevation in mountains exceeds 2000 m, the species richness peaks at around 1500 - 2200 m and declines thereafter.

Rahbek (1997, 2005) proposed four models to explain the variation of species richness along an elevation gradient. The first model is based on productivity. According to this model, decrease in productivity from sea level to mountaintop causes monotonic decline in species richness along an elevation gradient since productivity correlates positively with species richness. The second model is based on Rapoport's rule which says that the mean elevational range of species increases with increasing elevation resulting in monotonic decline in species richness due to narrow tolerance of lowland species to wider climatic fluctuations at high elevations. Third model also follow species richness-productivity view but the diversity forms peak at mid-elevation and decline in species richness both at lower and higher ends. Fourth model assumes that species richness occurs due to random placement of elevational range size of species between two geographical hard boundaries beyond which species ranges do not extend.

Since birds of the Teesta valley showed high richness at mid-elevation, the first two models predicting monotonic decline in species richness are eliminated. Regression between range size of species and upper and lower range limit resulted in very low r^2 value. This result suggests that the distribution of birds in the Teesta valley is not in accordance with the Stevens (1992) rule. Hence, the observed pattern is consistent with the third and fourth models showing peak at middle of the elevation gradient.

Geometric constraint on species ranges is considered as an important explanation for mid-domain peak in species richness (Jetz and Rahbek, 2001, 2002; Rahbek and Graves, 2001; McCain, 2003, 2004; Colwell *et al.*, 2004). Mid-domain effect null model analysis showed significant deviation of empirical richness from the predicted one as very few data points (20%) fits within 95% prediction curve of the null model (Figure 5.7). Although geometric constraint explained much of species richness pattern at large spatial scales (Jetz and Rahbek, 2001, 2002), several studies have found little empirical support for mid-domain effect on birds (Diniz-Filho *et al.*, 2002; Hawkins and Diniz-Filho, 2002; Rangel and Diniz-Filho, 2003). Birds being highly mobile vertebrates, geographic boundary might not be the major hindrance for their distribution at smaller spatial scales (Dunn *et al.*, 2007; Grytnes and McCain, 2007). McCain (2005) found higher fit of null model for gamma than alpha diversity and the richness peak was shifted at higher elevation in the case of alpha diversity. Koh *et al.* (2006) observed significant deviation of empirical bird species richness from those predicted by mid-domain models along the local elevation gradient in Taiwan. Richness patterns of small ranged species are better predicted by environmental variables than by mid-domain effect null models (Rahbek, 2005; Cardelus *et al*., 2006).

The deviations from null model urge to look for other factors (climatic, ecological, biological or historical) governing the distribution pattern (McCain, 2004, 2005). Studies on alpha diversity (diversity within single mountain) pattern along an elevation gradient indicated that optimum diversity occurs at intermediate climatic conditions (e.g., Heaney, 2001; Md Nor, 2001; McCain, 2004, 2005; Grytnes and McCain, 2007). The hump-shaped relationship of species richness along elevation gradient is claimed to be due to optimal humidity condition (Kessler, 2001; Rahbek 1995) or productivity (Rosenzweig, 1995; Mittelbach *et al.*, 2001).

Primary productivity plays an important role in distribution of bird species in East Asia (Ding *et al.*, 2006). Although, primary productivity could not be measured during this study, the vegetation parameters such as tree and shrub species richness and diversity and tree height, which has direct role in productivity, were taken as a surrogate for productivity. Kessler *et al.* (2001) used bryophyte cover and canopy height as an index for humidity and ecosystem productivity respectively. Normalized difference vegetation index (NDVI) have been taken as a measure of primary productivity by many other studies (Box *et al.*, 1989; Ding *et al.*, 2005; Koh *et al.*, 2006). In the present study, vegetation parameters showed positive correlation with bird species richness (Chapter 6, Pp.119), which indicates that food resources as well as microhabitat availability for birds is maximum at mid-elevation.

Empirical bird species richness and diversity correlated well with the abundance of birds. Terborgh (1977) predicted that the most productive environment is that which harbor both highest species richness and highest abundance. Similarly, trophic diversity was maximum at mid-elevation. It is assumed that trophic habit occurs when the food is present (Terborgh, 1971). Hence, diverse habitat with complex vegetation structure at mid-elevation has relatively higher productivity, which would have played significant role to create peak in species richness and abundance of birds in the Teesta valley. The elevational pattern of species richness of the birds of Andean Peru was largely affected by habitat complexity (Terborgh, 1977). Sánchez-Cordero (2001) found peak for rodents and bats richness at an elevation with high floristic complexity and diversity as well as in wet and humid habitats.

Apart from productivity, climate is considered as major predictor of elevational pattern of species richness (Heaney, 2001; Grytnes and McCain, 2007; Rahbek *et al.*, 2007). Although climatic (rainfall and temperature) data could not be obtained for all the 22 elevational transects, rainfall was maximum between 900 m and 1800 m elevation (Chapter 2, Pp.14). Birds of the Teesta valley showed significant correlation with rainfall and number of rainy days (Chapter 4, Pp.58). It is known that temperature declines progressively with increasing elevation but rainfall and humidity reaches peak at mid-elevation (Terborgh, 1977; Hawkins, 1999; Md Nor, 2001; McCain, 2007a). Heaney (2001) observed close association between diversity of small mammals and annual rainfall. McCain (2007a) found optimum temperature and high water availability for high species diversity at mid-elevation.

Any observed patterns of species richness are not wholly explained by single factor (Heaney, 2001; Sánchez-Cordero, 2001; Oommen and Shanker, 2005). If the pattern obtained is same irrespective of taxa, then climatic factors would be considered limiting (Rahbek, 1997) but it is found that species richness along elevation gradients among taxa and regions vary (Rahbek, 2005) which might be true because biological and physiological requisites and tolerance to climatic factors differ among taxa (Graham, 1990). Due to this reason, variation within taxa also occurs as observed in the present case where different bird species showed varied response to elevation. Hence, various habitat parameters and biological diversification (Rahbek, 1995), and evolutionary and historical events (Lomolino, 2001) combine to shape the ultimate faunal assemblages and distribution. Although, habitat structure and complexity or primary productivity are the major limiting factors for distribution of birds in the Teesta valley, other factors such as ecological (humidity, temperature, rainfall), biological (food availability, competition), historical and geographical might interplay. Hofer *et al.* (1999) reported that biotic factors (competition, predation, resource availability) limit the elevational distribution of endotherms, whereas abiotic factors play major role for spatial organization of ectotherms along the elevation gradient.

Abrupt decline in species richness beyond 2500 m have been attributed to decline in forest stature and severity in climatic conditions at higher elevations, both of which cause decline in abundance and size distribution of invertebrates and scarcity of other food items for birds (Terborgh, 1971; Blake and Loiselle, 2000). The decline in forest stature causes concomitant decline in microhabitats at higher elevation and hence affect species richness and abundance of birds. Low richness in high elevation is also proposed to be due to small area because of the conical shape of the mountain, isolation mechanisms, less energy availability and low rate of speciation (Rahbek, 1997; Hawkins, 1999; Lennon *et al.*, 2000; Lomolino, 2001; Sanders *et al.*, 2003; Kattan and Franco, 2004; Grytnes and McCain, 2007; McCain, 2007b). All these factors are plausible but harsh climate might be the major constraint for species at high elevations. The hypothesis could not be tested due to the unavailability of weather data from high elevation area. Although the available area decreases with elevation (Lomolino, 2001), it might not be a limiting factor in a smaller geographical scale (McCain, 2005).

Species belonging to different diet guild showed varied pattern along the elevation, which is expected keeping in view of the different ecological requirements among different trophic groups of birds (Kessler *et al.*, 2001) or competition between trophic groups inhabiting the area (Terborgh and Weske, 1975; Noon, 1981). Species richness of insectivores showed negative correlation with elevation, with maximum diversity at mid-elevation. Similar results were reported in earlier studies on birds (Terborgh, 1977; Graham, 1990; Kessler *et al.*, 2001) and bats (McCain, 2007a). The diversity of insects is reported to peak at mid-elevation (Janzen, 1973). Habitat variables such as vegetation complexity attained peak at mid-elevation. Habitat complexity increases microhabitat availability for insects, which in turn increases their diversity and abundance ultimately increasing the diversity and population of birds (Terborgh, 1977).

Frugivore and nectarivore species showed declining trend with elevation. Terborgh (1977) observed gradual decline in frugivore species richness but no significant variation in nectarivores along an elevation gradient. The variation in species richness is probably due to fluctuation in availability of flowers and fruits along the elevation gradient (Loiselle and Blake, 1991; Blake and Loiselle, 2000). When food becomes scarce at one elevation site, birds move to resource abundant sites so that species composition and abundance at one elevation depend upon availability of resources at other elevation (Loiselle and Blake, 1991). This explanation appears reasonable because species (with wide elevation range) were detected at most sites in one or the other season during sampling. The decline in richness of these groups at high elevation is attributed to reduction in partitioning of resources in simple vegetation prevalent at this elevation (Terborgh, 1977).

Omnivorous bird species showed no significant correlation with elevation but had relatively higher richness at mid-elevation. Omnivory arises due to resource constraints and high energetic requirements so that exploitation of broader range of food items occurs to acquire enough food for maintaining energy requirements of the body (Graham, 1990). Due to higher bird density, competition for resources might be high at mid-elevation (Noon, 1981) so that exploitation of broader range of food items would be beneficial.

The slight increase in granivorous birds at high elevation is similar to the findings of Graham (1990) but partly in disagreement with those of Kessler *et al.* (2001). Higher elevations, especially sub-alpine and alpine meadows were dominated by granivores. Open grassland has large capacity of seed production (Chettri, 2000), which may be true owing to the diversity of herbs grown there. Due to cold weather, insects and other resources become very scarce at high elevation but dry seeds persist even during harsh winter supplying constant food to the birds. Monotonic decline of carnivorous birds along an elevation concur with the study of Thiollay (1996) on raptors in the Northern Andes. The decline could probably be explained by their specialized food habit and habitat preference or lower survival ability and speciation rate at higher elevation (Thiollay, 1996).

Similarity in bird species composition shows that the elevational distribution of birds of Teesta valley conforms generally to the major forest types of the study area. Similar observations were reported from the studies on birds and mammals elsewhere (Navarro, 1992; Hawkins, 1999; Md Nor, 2001; Sánchez-Cordero, 2001; Latta *et al.*, 2003). The close similarity in species composition between 390 m and 850 m is that all the transects were in low elevation tropical deciduous forest. Similarly, similarity between 980 - 1600 m, 1950 - 2550 m, 2900 - 3730 m and 4070 - 4600 m is explained by the fact that the regions are represented respectively by tropical broad-leaved forest, temperate broad-leaved forest, temperate coniferous forest, and alpine and sub-alpine vegetation (Chapter 2, Pp.20). This finding also supports the fact that habitat variability is the major factor for elevational distribution of birds in the Teesta valley. Species similarity is high between the transects located nearer to each other along the gradient than the one located farther apart. Species composition in localities separated by a few hundred meters of elevation was found to be different in other studies (Terborgh and Weske, 1975; Rahbek, 1997). The habitat having similar floristic diversity, vegetation structure and climatic factors support similar avifauna since available resources influence bird assemblages and affect distribution pattern (Loiselle and Blake, 1991; Blake and Loiselle, 2000).

Turnover rate of bird species along the elevation gradient was generally high (0.29 - 0.7). Distinct zonation of vegetation along the Teesta valley might have caused high species turnover of birds. The turnover rate was high especially at vegetation transition zones. Maximum turnover was observed between 3730 m and 4070 m. Tree line ceases at this elevation and is replaced by shrubby vegetation. The other peak of turnover was observed at 2550 - 2900 m, where highly diverse and structurally complex vegetation (temperate broad-leaved forests) changes to floristically and structurally simple coniferous forests. Along with the vegetation characteristics, climatic and environmental factors show rapid changes at higher elevation creating new environment for the assembly of new set of species. Hence, species turnover rate attain sharp increase with increasing elevation. The finding of present study is concurrent with that of Navarro (1992) for Mexican birds where turnover rate was maximum at vegetation ecotones. High turnover of birds at vegetation transition was also observed along the elevation gradient in northern Taiwan (Koh *et al.*, 2006).

In the present study, turnover rate was high where the species richness was low. Earlier studies correlated spatial turnover with species richness and turnover of environment. Recently turnover was found to be high in species rich as well as species poor area (Gaston *et al.*, 2007). The high turnover in species poor area may be due to loss or gain of few species which change the species composition markedly.

According to Rapoport's rule (extended to elevation by Stevens, 1992), the range size of species should increase with increasing elevation. The range profile of birds of the Teesta valley shows that around 90 species end their range below 1800 m elevation and 200 species below 2600 m, whereas 40 species were restricted to above 3000 m. Although, range size of high elevation species tended to increase with elevation, the relation was weak as displayed by low r^2 value. Hence, birds of the Teesta valley did not fully agree with Rapoport's rule as reported in Neotropical land birds (Rahbek, 1997). The range profile of birds of the Teesta valley showed that mid-elevation species had wide elevational range creating mid-elevation peak of species richness. Results of the present study indicate that species richness as well as range size was high at mid-elevation.

Most species had very narrow elevational range. It is observed that maximum species are habitat specialists, either restricted to single elevational transect or vegetation zone. Due to the specialization to particular food habit or narrow tolerance to climatic variations, elevational width of birds might have reduced. Observation on the distribution pattern of individual species supports this result. Omnivorous species such as Blue Whistling Thrush was present all along the gradient, whereas a true frugivore Pin-tailed Green Pigeon was present at single transect. Similarly, White-capped Water Redstart, although insectivorous but often consumes other food items, occupied the largest range (4210 m) of the study area. The behavioral and physiological responses to environmental factors also affect the distribution range of birds (Graham, 1990), which are genetically determined and evolved over a long time period.

5.5. SUMMARY

Understanding the distribution of species along the elevation gradient is necessary to understand the factors responsible for patterns and for biodiversity conservation. The patterns of species richness, diversity, abundance and range size distribution of birds were examined along the elevation gradient of the Teesta valley, Sikkim. Species richness as well as abundance, diversity and density of birds showed hump-shaped relationship with elevation showing peak at around 2000 m. This finding is in accordance with many other studies conducted elsewhere. Birds belonging to different diet categories responded in different ways along the elevation gradient. Highest trophic diversity was observed at mid-elevation between 1950 m and 2300 m. It is observed that temperate broad-leaved forest located between 1800 m and 2800 m elevation harbors high avifaunal diversity. Different casual factors such as climate, productivity, area, evolutionary history and geographic constraints have been proposed to affect distribution pattern of species along the elevation gradient. Low fit to mid-domain null models suggests the minor role of geographic hard boundary for distribution pattern of birds in the Teesta valley. The vegetation structure and other habitat features caused major variation in the distribution pattern of birds in the Teesta valley. The role of climatic factors such as rainfall might be important to determine the spatial and temporal distribution of bird species. Birds of the Teesta valley segregated according to the major vegetation types of the study area and distinct community assemblage was formed at each vegetation zones. Although, richness and diversity was relatively low at higher elevation, community composition of birds was different. Most of the bird species had very narrow elevation range. Out of the 297 species, 90 species were restricted exclusively to single elevational transect. Similarity was more along transects located within similar vegetation types, whereas high turnover occurred at habitat transition zones. High diversity and unique community composition of birds at each elevational transect and narrow elevational width of most species suggests that entire gradient has crucial role for the maintenance of bird community composition and diversity, and requires conservation attention.

CHAPTER 6

HABITAT ASSOCIATION OF BIRDS

6.1. INTRODUCTION

Habitat is defined as a particular locality, site or immediate environment occupied by an organism (MacArthur, 1972). The immediate environment in which the animal lives plays a major role in its distribution and survival. Habitat shows spatial and temporal variation and significantly influences species abundance and distribution pattern (Jones, 2001; Johnson, 2007). Habitat structure has both vertical and horizontal components of which the former generally describes habitat heterogeneity, while the latter provides a measurement of habitat complexity (Brown, 1991; Kristan, 2007). Habitat characteristics vary among forest types or elevation zones (Terborgh, 1977, 1985; Raman *et al.*, 2005; Grau *et al.*, 2007). Consequently, association of different species or trophic components of birds differs among habitats and elevations (Kessler *et al.*, 2001; Matlock and Edwards, 2006; O'Dea and Whittaker, 2007). Information on habitat structure and diversity, and their relationship with birds provides insights on habitat use, which ultimately aids in the conservation of species (Cody, 2001; Gillespie and Walter, 2001; Okes *et al.*, 2008).

Diversity, density and complexity of vegetation are considered to be the major variance for avian richness (Cody, 2001; Kristan, 2007). Habitat characteristics such as habitat quality (Jones, 2001; Johnson, 2007; Kristan, 2007), plant species richness (James and Wamer, 1982; Matlock and Edwards, 2006), floristic composition (Rotenberry, 1985; Freifeld, 1999), and vegetation structure (MacArthur and MacArthur, 1961; MacArthur *et al.*, 1966; Terborgh, 1977; Erdelen, 1984; Vijayan *et al.*, 1998a; Jayson and Mathew, 2003; Matlock and Edwards, 2006) have been identified as good predictors of avian species richness. Some studies reported contrasting pattern, decrease in avian diversity with increase in tree species richness or diversity (Daniels *et al.*, 1992) or no correlation between foliage complexity and bird species richness or diversity (Wilson, 1974; Pearson, 1975). Although, floristic richness or simple measurements of vegetation structure are not only the factors affecting avian species richness in the forests (Johnson, 2007; Kristan, 2007), understanding the association of vegetation characteristics with birds has important conservation implications (Raman *et al.*, 1998; Jayson and Mathew, 2003; Blake, 2007).

In general, the vertical distribution of foliage is not uniform along the forest. Information on vertical distribution of foliage helps in understanding the distribution of resources in the forest. The foliage distribution patterns influence the vertical distribution of birds (Jayson and Mathew, 2003). Vertical segregation can determine the occurrence and density of birds and is important for maintaining species diversity (Pearson, 1971; Roth, 1976; Robin and Davidar, 2002). Spatial heterogeneity such as vertical complexity determines the distribution of animals and reduces competition among co-existing species by partitioning available resources (Vijayan, 1984; Gutzwiller *et al.*, 1998; Vieira and Monteiro-Filho, 2003).

Most species utilize specific vertical strata for their activities (Pearson, 1971; Gutzwiller *et al.*, 1998) while others utilize multiple strata because individual bird species may associate on specific structural features for foraging, predator avoidance, and nesting (Holmes and Robinson, 1981; Robin and Davidar, 2002; Gokula and Vijayan, 2007). Other activities such as maintenance, perching and roosting also occurs at specific height from the ground, which varies among species and habitat depending on the availability of suitable substrate, food, concealment from predators and rain as well as competition among co-existing species (Holmes and Robinson, 1981; Maurer and Whitmore, 1981; Wiens, 1989; Gokula and Vijayan, 2000; Robin and Davidar, 2002).

The role of vegetation structure on distribution of birds has been examined by several studies both in tropical and temperate forests (MacArthur and MacArthur, 1961; MacArthur *et al.*, 1966; Roth, 1976; Terborgh, 1985; MacNally, 1990; Cody, 2001; Gillespie and Walter, 2001; Jones, 2001; Jayson and Mathew, 2003; Matlock and Edwards, 2006; Kristan, 2007). However, the information on vertical stratification and habitat utilization along different elevation zones is scanty. This Chapter deals with the association of bird community with their habitat characteristics such as floristic diversity and physiognomy and vertical distribution of foliage along different elevation/elevation zones in the Teesta valley, Sikkim.

6.2. METHODS

6.2.1. Bird sampling

Bird sampling was done using point count method (Bibby *et al.*, 2000). The method is described in detail in Chapter 4, Pp.44. In addition to the information on species and number of individuals, vertical positions of birds from ground were also noted. Vertical height categories were 0 m, 0 - 5 m, 5 - 10 m, 10 - 15 m, 15 - 20 m, 20 - 25 m and > 25 m. Information on elevation zones and transect details are provided in Chapter 2, Pp.20.

6.2.2. Vegetation sampling

Quadrat method was used for measuring vegetation and other habitat details of the study area. Details of method used for sampling trees and shrubs are provided in Chapter 3, Pp. 24. In addition to the data on trees and shrubs, relative percentage covered by herb, grass, fern, litter, rock, soil and mosses was visually estimated using 5 m x 5 m quadrat in all transects used for bird sampling.

Foliage structure and complexity of vegetation was assessed at all transects by measuring cover values at seven different height categories: 0 m, 0 - 5 m, 5 - 10 m, 10 - 15 m, 15 - 20 m, 20 - 25 m and > 25 m. Presence and absence of vegetation within 0.5 m radius at each height category was noted at 25 points spaced 10 m apart following Erdelen (1984) and Jayson and Mathew (2003).

6.2.3. Data analysis

Data from only four elevation zones (zone I - IV) are used in this Chapter because absence of trees and reduction of vegetation in zone V does not allow comparison among zones especially vertical stratification. Bird community parameters such as species richness, Shanon-Weaver diversity and density and, species richness in each trophic group were calculated for each transect as described in Chapter 4, Pp.46 - 49. Similarly, species richness, diversity and density of trees and shrubs, and basal area of trees were obtained from Chapter 3. Mean height of trees, number of logs and cut stumps were determined for each transects. Pearson correlations were used to assess the relationships between vegetation characteristics and bird community parameters.

Multivariate statistical technique, principal component analysis (PCA) was used to simplify data on vegetation variables of the study transects. PCA reduces the large number of correlated variables to smaller set of new uncorrelated variables that account for major variation in the data set (Zar, 1999). The variables were subjected to varimax rotation that extracted principal components having eigen values more than one. Since original variables showed high correlation with factor scores resulted by PCA, they were used to correlate with bird community parameters (Zar, 1999).

Species richness, diversity and abundance (number of individuals) of birds at different height categories were calculated for all the transects as well as for each elevation zones. One-way ANOVA was performed to assess the trend in bird species richness, diversity and abundance among height categories. Jaccard similarity index and the number of species shared between different height categories was obtained using software EstimateS version 7 (Colwell, 2004). Foliage height diversity (FHD) was calculated for each transect following Pearson (1977). Presence of vegetation within 0.5 m radius at each height category was presented as one and absence as zero. Foliage abundance for each height category was obtained by adding these values from all the points in each zone following Jayson and Mathew (2003). Spearman rank correlation was performed to examine the association of bird community attributes with foliage abundance. All statistical analyses were performed using software SPSS version 10.0, and Microsoft Excel for windows.

6.3. RESULTS

6.3.1. Principal component analysis of habitat variables

Principal component analysis (PCA) of habitat characteristics extracted three components that accounted for 68.55% of the total variance in the data set (Table 6.1). PC I explained 26.14% of the variance and was positively associated with tree and shrub species richness, tree diversity and vertical stratification of the vegetation. Moss cover and disturbance factors such as number of logs and stumps were negatively associated with PC I. PC II explained 23.36% variation and was positively influenced by canopy cover, tree density, leaf litter cover, and negatively associated with herb cover. PC III explained 19.04% variation, which is negatively influenced by basal area of tree and shrub density.

Table 6.1 Factor loadings of principal component analysis (PCA) of habitat characteristics of birds of the Teesta valley, Sikkim.

Habitat variables	**PC I**	**PC II**	**PC III**
Tree species richness	0.771	0.291	0.436
Tree species diversity	0.778	0.259	0.452
Tree height	0.619	-0.056	0.350
Basal area (m^2)	0.182	0.148	-0.542
Tree Density ha^{-1}	-0.343	0.678	0.369
Number of stump	-0.810	0.440	0.122
Number of log	-0.785	0.371	0.139
Foliage height diversity	0.715	0.171	-0.409
Shrub species richness	0.719	0.411	0.368
Shrub density ha^{-1}	0.310	0.391	-0.656
Canopy cover (%)	0.085	0.858	-0.098
Herb cover (%)	0.074	-0.842	0.042
Litter cover (%)	0.373	0.559	-0.426
Moss cover (%)	-0.808	0.365	0.093
Eigen values	4.93	3.20	1.91
Variance explained (%) Cumulative	26.14	23.36	19.04
variance (%)	26.14	49.50	68.55

6.3.2. Correlations between habitat characteristics and birds

Bird community parameters (species richness, diversity and density) showed close association with habitat variables of the study area. Bird species richness correlated significantly and positively with tree species richness ($r = 0.72$, $p = 0.001$), tree diversity ($r = 0.615$, $p = 0.002$) and mean tree height ($r = 0.660$, $p = 0.001$). Similarly, bird density showed significant positive correlation with tree diversity ($r = 0.591$, $p = 0.003$) and mean tree height ($r = 0.724$, $p = 0.000$). Bird diversity also correlated positively with tree diversity (0.668, $p = 0.000$), tree richness ($r = 0.634$, $p = 0.001$) and mean tree height ($r = 0.562$, $p = 0.005$).

Similarly, bird species diversity correlated positively with PC scores II ($r = 0.464$, $p < 0.05$) and negatively with PC scores III ($r = -0.488$, $p < 0.05$). Frugivores ($r = 0.490$, $p < 0.05$) and nectarivores ($r = 0.537$, $p < 0.05$) species richness showed significant positive correlation with principal component score I. All other correlations between bird community parameters and habitat characteristics were not significant.

6.3.3. Vertical stratification

6.3.3.1. Trends in species richness, diversity and abundance

Vertical stratification of 286 species of birds was recorded from four elevation zones of the study area. Birds displayed marked stratification along the vertical plane of vegetation. The number of bird species, abundance and diversity among height categories were different. One-way ANOVA revealed significant difference in species richness among height categories ($F_{6,\,133} = 60.11$, $p = 0.00$). Similarly, abundances ($F_{6,\,133} = 29.2$, $p = 0.00$) and Shannon-Weaver diversity index ($F_{6,\,113} = 55.2$, $p = 0.00$) of birds also showed significant differences among height categories. One-way ANOVA showed significant variation in species richness, abundances and diversities at different height classes in all the zones (Table 6.2).

Overall, maximum species richness (231) was observed in 0 - 5 m height followed by 5 - 10 m, 10 - 15 m and the ground layer. Richness was high up to 15 m, beyond which there was considerable decline towards the canopy. Species abundance and diversity also followed the similar trend (Table 6.3).

Out of 286 species, 83 were restricted to only one height category, whereas 203 utilized more than single height category. Species restricted to one height category was the highest (39) in the 0 - 5 m height category where maximum species were found.

Table 6.2 F values resulted from One-way ANOVA in bird community parameters (species richness, abundance and diversity) among seven height categories in four elevation zones of the Teesta valley. All the values are significant at p = 0.00.

Zones	**F values among height categories (df = 6)**		
	Richness	Abundance	Diversity
I	47.3	13.1	27.5
II	53.3	14.98	38.4
III	32.3	16.6	34.4
IV	46.3	45.8	28.1
Overall	60.11	29.2	55.2

Table 6.3 Species richness, abundance (number of individuals) and Shannon-Weaver diversity index (H′) of birds in different height category observed in different elevation zones in the Teesta Valley, Sikkim.

Zones	Height (m)	No. of species	Abundance	H′
I	0	23	109	2.73
	0-5	88	1178	3.54
	5-10	74	1304	3.49
	10-15	62	967	3.22
	15-20	39	558	2.48
	20-25	10	62	1.79
	>25	13	129	2.2
II	0	27	74	2.82
	0-5	106	1641	3.68
	5-10	104	2183	3.73
	10-15	73	1098	3.42
	15-20	40	455	2.98
	20-25	16	107	2.21
	>25	13	158	1.59
III	0	43	437	2.93
	0-5	104	2769	3.64
	5-10	100	1692	3.69
	10-15	69	1114	3.42
	15-20	53	604	3.14
	20-25	16	67	2.42
	>25	14	183	2.35
IV	0	43	298	3.18
	0-5	73	1222	3.11
	5-10	40	503	2.97
	10-15	34	218	3.01
	15-20	13	67	1.71
	20-25	7	22	1.69
	>25	7	26	1.71
Overall	0	112	918	3.84
	0-5	231	6810	4.27
	5-10	186	5682	4.18
	10-15	148	3397	3.83
	15-20	91	1684	3.44
	20-25	35	258	3.03
	>25	24	496	2.45

6.3.3.2. Bird species composition at different vertical strata

Each height category harboured distinct species composition and assemblages. For the pooled data from four elevation zones, species such as Snow Pigeon, White-capped Water Redstart and Chestnut-crowned Laughingthrush were the most abundant at ground level. Similarly, Striated Laughingthrush, Chestnut-crowned Laughingthrush, White-throated Laughingthrush and Coal Tit at 1 - 5 m height; Striated Laughingthrush, Rufous Sibia, Whiskered Yuhina and White-throated Laughingthrush at 5 - 10 m; Black Bulbul, Rufous Sibia, Great Barbet and Striated Laughingthrush at 10 - 15 m; Black Bulbul, Rufous Sibia, Ashy Drongo and Scarlet Minivet at 15 - 20 m; Scarlet Minivet, White-spectacled Warbler, Black Bulbul and Chestnut-crowned Warbler at 20 - 25 m and Black Bulbul, Speckled Wood Pigeon and Ashy Drongo at >25 m height were the most abundantly recorded species.

The differences in species composition among height categories were observed in all the zones. In zone I, Blue Whistling Thrush was the most abundant species at ground level. Species such as White-crested Laughingthrush at 0 - 5 m, Black-chinned Yuhina at 5 - 10 m, Black Bulbul at 10 - 15 m, Wedge-tailed Green Pigeon at 15 - 20 m, Scarlet Minivet at 20 - 25 m and Grey Treepie at >25 m height were the abundant species. Hill Prinia at ground, Striated Laughingthrush at 0 - 5 m and 5 - 10 m, Black Bulbul at 10 - 20 m, White-spectacled Warbler at 20 - 25 m, and Ashy Drongo at > 25 m height were abundant species in zone II. Similarly, abundant species at different heights in zone III were Chestnut-crowned Laughingthrush, White-throated Laughingthrush, Rufous Sibia, Black Bulbul, Ashy Drongo, Speckled Wood Pigeon and Ashy Wood Pigeon respectively at 0 m, 0 - 5 m, 5 - 10 m, 10 - 15 m, 15 - 20 m, 20 - 25 m and > 25 m height categories. In zone IV, abundant species comprised of Snow Pigeon at 0 m, Coal Tit at 0 - 5 m, Grey-crested Tit at 5 - 10 m and 10 - 15 m. Species such as Ashy Wood Pigeon, Spotted Nutcracker and Red-billed Chough occupied the canopy of the forest in zone IV.

6.3.3.3. Species similarity among vertical strata

The number of species shared among pair of height categories ranged from 5 to 158. Maximum number of species (158) was shared between height categories 0 - 5 m and 5 - 10 m and minimum (5) between ground layer (0 m) and canopy (>25 m). Jaccard similarity index calculated among pairs of height categories varied from 0.08 to 0.87. Similarity was the highest between 5 - 10 m and 10 - 15 m and lowest between 0 m and 20 - 25 m height category (Table 6.4).

Table 6.4 Species similarity matrix of birds of the Teesta valley, Sikkim between different vertical strata. Jaccard similarity index is to the right and number of species shared is to the left of the diagonal. The total number of species observed in each height category is given in the diagonal.

Height	0 m	0-5 m	5-10 m	10-15 m	15-20 m	20-25 m	>25 m
0 m	**112**	0.34	0.21	0.16	0.14	0.08	0.1
0-5 m	91	**231**	0.81	0.65	0.4	0.26	0.27
5-10 m	64	158	**186**	0.87	0.62	0.42	0.33
10-15 m	52	121	121	**148**	0.85	0.56	0.46
15-20 m	30	72	79	74	**91**	0.62	0.58
20-25 m	10	28	33	29	25	**35**	0.33
>25 m	5	17	20	18	18	14	**24**

Cluster analysis based on Jaccard similarity index of birds among vertical strata showed distinct bird species assemblages at different heights. Cluster analysis revealed that species were separated into two major groups, namely ground and above-ground. The community composition of ground living birds was entirely different from the birds occupying above-ground layers. The above-ground species formed two groups, sub-canopy (0 - 20 m) and canopy (>20 m) dwelling birds. Bird assemblages were very similar between height categories 5 - 10 m and 10 - 15 m (Figure 6.1).

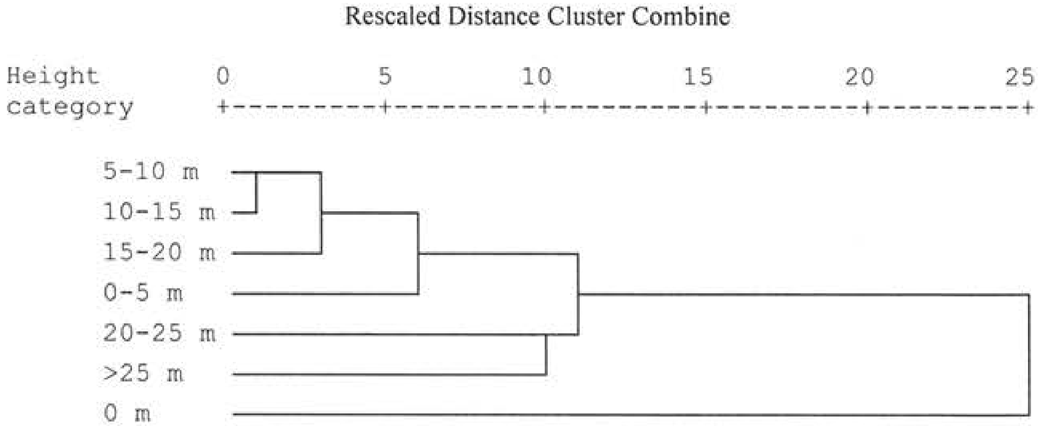

Figure 6.1 Dendrogram based on Jaccard similarity index of birds among different vertical strata in the Teesta valley, Sikkim.

6.3.3.4. Response of birds to foliage abundance

Foliage abundance at different height categories in four elevation zones is presented in Figure 6.2. The abundance varied among the height categories. Maximum foliage was concentrated between 0 - 10 m height in all the zones. In zones I, III and IV abundance was maximum at 0 - 5 m with the highest value in zone III, whereas in zone II maximum abundance was at 5 - 10 m. Abundance declined above 10 m in all the zones. Decline was more rapid in zone III compared to other zones.

Vertical distribution of birds showed close association with foliage at each height strata. Correlation analysis revealed significant positive relations between foliage abundance and species richness ($r = 0.729$, $p < 0.01$), abundance ($r = 0.680$, $p < 0.01$) and diversity ($r = 0.678$, $p < 0.01$) of birds. Similar results were obtained when the correlation analysis was performed separately for data from each zone (Table 6.5).

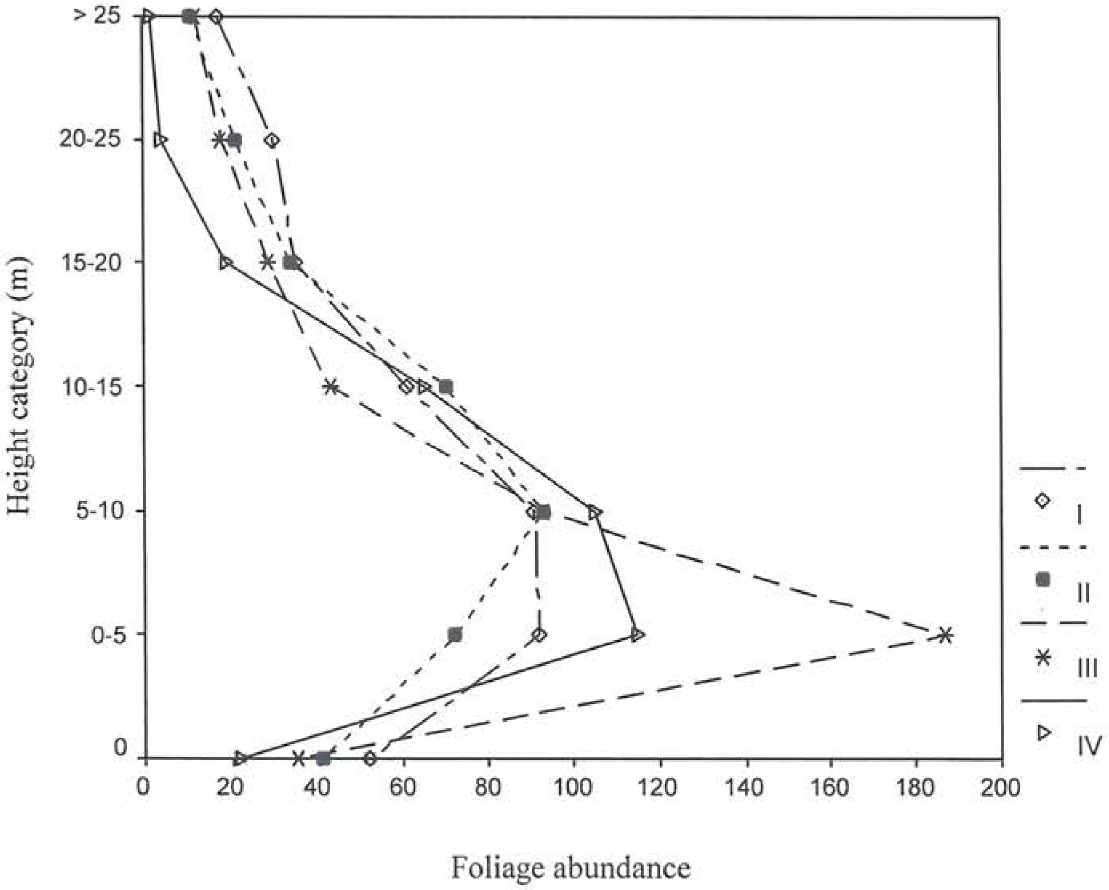

Figure 6.2 Vertical distribution of foliage at seven height categories in different elevation zones (I, II, III and IV) in the Teesta valley, Sikkim.

Table 6.5 Spearman rank correlation coefficient between foliage abundance and bird community parameters (species richness, abundance and diversity) along the Teesta valley, Sikkim. All the values are significant at $p < 0.01$.

Elevation zones	**Spearman rank correlation coefficient**		
	Species	Abundance	Diversity
Overall	0.710	0.674	0.665
Zone I	0.789	0.674	0.758
Zone II	0.652	0.498	0.675
Zone III	0.791	0.853	0.665
Zone IV	0.763	0.725	0.741

4.4. DISCUSSION

Principal component analysis extracted three components that describe three major habitat characteristics for the birds of the Teesta valley. PC I described habitat having complex physiognomic structure and well diversified vegetation with less disturbance. PC II explained habitat having closed canopy vegetation with litter covered ground and minimum herb cover. It also explained the habitat with high tree density. PC III explained floristically rich habitat having small sized trees and minimum shrub cover.

The habitat characteristics such as floristic diversity (tree and shrub species richness and diversity) and vegetation structure (tree height) were closely associated with bird species richness and diversity in the Teesta valley. Present results concurred with other studies (Snow and Snow, 1971; James and Wamer, 1982; MacNally, 1990; Gillespie and Walter, 2001; Matlock and Edwards, 2006) in that both floristic richness and physiognomy influences species richness of birds. Structural complexity, as represented by foliage height diversity, has been found to account for most of the variance in bird species diversity both in tropical and temperate forests (MacArthur and MacArthur, 1961; MacArthur *et al.*, 1966; Terborgh, 1977; Wiens, 1989; Gokula, 1998; Vijayan *et al.*, 1998a; Chettri *et al.*, 2001). It is reported that birds are influenced not only by physiognomic structure and complexity of the vegetation but also by the diversity of flora that represents the forests (James and Wamer, 1982; Terborgh, 1985; Terborgh and Petron, 1991; Sherry and Holmes, 1996; Chettri *et al.*, 2001). Vegetation diversity and complexity offers wide variety of foraging sites, which can support larger assemblages of species and thus results in higher avian richness (Latta *et al.*, 2003). With the increase in diversity or complexity of vegetation, the resource available to birds increases which ultimately leads to increase in number of species and abundance of birds (Terborgh, 1977, 1985).

The birds of Teesta valley showed positive association with mean tree height, a measure of habitat structure. Gillespie and Walter (2001) made similar observations in tropical dry forest of Central America. Kessler *et al.* (2001) found correlation between bird species richness and canopy height in the Bolivian Andes. The result suggests that with the increase in height of the trees, new strata of under-storey appear adding to the vertical complexity and total diversity of plants in the forests (Terborgh and Petren, 1991). The increase in height of plants adding vertical complexity results in increase of resources such as food, space and microhabitat for birds (Brown, 1991). Thus the forest with taller trees can support more species and individuals of birds than with short height trees (Terborgh and Petren, 1991).

Bird species diversity showed significant positive correlation with PC II. The gradient of vegetation with close canopy, high tree density and high litter cover (explained by PC II) reflects the presence of undisturbed primary mature forest and thus can harbor diverse avifauna. Birds attain highest diversity in mature undisturbed tropical forests (Terborgh, 1985; Arriaga-Weiss *et al.*, 2008) which provide habitat for many species that do not occur in successional or disturbed stands (Terborgh and Petren, 1991; Raman *et al.*, 1998; Chettri *et al.*, 2001; Raman, 2001; Vijayan and Gokula, 2006). Bird species diversity correlated negatively with PC III. PC III explained vegetation with small sized trees and minimum shrub cover reflecting disturbed habitat. Many studies have found less diversity of birds in disturbed or human modified habitats (Chettri *et al.*, 2001; Watson *et al.*, 2005; Hannon, 2006; Lee *et al.*, 2006; Vijayan and Gokula, 2006; O'Dea and Whittaker, 2007) because most species avoid such disturbances (Okes *et al.*, 2008). Species richness of frugivores and nectarivores showed close association with PC I which represents habitat with high tree species richness, diversity and tree height and, shrub species richness. Response to vegetation structure and diversity differs among different trophic groups of the community (Terborgh, 1977; Kessler *et al.*, 2001; Arriaga-Weiss *et al.*, 2008). Highly diverse vegetation harbors variety of fruits and flowers in abundance that provides appropriate food of choice to these birds and can support larger set of species and individuals (Blake and Loiselle, 2000). Terborgh (1985) found strong relationships of frugivores and nectarivores to the availability of appropriate food resources. Frugivores are reported to depend on taller trees and less disturbed forests (Somasundaram and Vijayan, 2006; Arriaga-Weiss *et al.*, 2008).

Birds of the Teesta valley displayed discernible pattern of stratification along the vertical plane of vegetation. Species richness, abundance and diversity of birds were the maximum at 0 - 5 m height with declining trend beyond 5 m. All strata cannot support equal species and individuals of birds as a result of differences in energy potential among vertical strata due to the unequal distribution of foliage (Pearson, 1975; Jayson and Mathew, 2003). Analysis revealed that birds utilized mid-story or sub-canopy layers of vegetation more often than the ground or top canopy layer. Jayson and Mathew (2003) made similar observations in their studies in tropical forests in the Western Ghats, India. Dunlavy (1935) observed higher number of bird species at low bush and high bush zone than at ground or tree zone. Most of the fruit bats utilized <10 m strata in a forest in Malaysia (Hodgkison *et al.*, 2004). Species richness and abundance of fruit-feeding butterflies in Malaysian forest was highest at 2 m height (Tangah *et al.*, 2004). The higher strata are more exposed to unfavorable physical (e.g. rain, wind, heat) or biological (e.g. predators) conditions and are energetically disadvantageous for foraging, nesting or roosting activities (Pearson, 1977; Gutzwiller *et al.*, 1998; Schultze *et al.*, 2001; Szarzynski and Anhuf, 2001; Turton and Siegenthaler, 2004). Low diversity at ground level is probably due to lower resource categories such as food and microhabitat availability. In addition, presence of non-avian competitors or cold climatic conditions of the study area might play significant role in reducing the diversity and abundances of birds at ground level.

Species assemblages of birds in different vertical strata were not similar. Changes in bird communities between habitats and vertical heights might be attributed to altered resource distributions resulting from changes in plant community composition and vegetation structure (Holmes *et al.*, 1979; Hayes and Gruver, 2000; Stork and Grimbacher, 2006). Diversity of many ecological communities is maintained through effective partitioning of resources and segregation of habitats (Schoener, 1974; Blake and Loiselle, 2000; Begon *et al.*, 2006). Differential use of vertical habitat reduces interspecific competition allowing coexistence of greater number of species (Gutzwiller *et al.*, 1998; Sushma and Singh, 2006). Differences in community composition among each height strata result from the differences in ecological requirements (Vieira and Monteiro-Filho, 2003; Sushma and Singh, 2006) based on morphology (Pearson, 1977; Hodgkison *et al.*, 2004) or behaviour (Maurer and Whitmore, 1981; Hayes and Gruver, 2000) among taxonomic units or species.

Maximum species similarity was observed between 0 - 5 m and 5 - 10 m height category. This may be because of the seasonal or diurnal movements of birds between these strata due to similarities in foliage density, structure of vegetation and available resources or movement of insect prey (Pearson, 1971; Basset *et al.*, 2001). Low species similarity between most height category pairs suggests that species are specific to vertical stratification of vegetation and each strata of vegetation has significant role for maintaining the diversity and stability of the population of birds.

Each height strata harbours distinct assemblages of species although different degrees of overlap were observed among height categories. Around 30% of species were restricted to particular height and can be considered as specialists. The differences in foliage density, food composition and availability, and predators among vegetation strata restrict birds to one or two strata. Specialization to particular resources or degree of physiological tolerance to microclimate determines the species assemblages at different vertical strata (Goldstein, 1990; Stork and Grimbacher, 2006).

The foliage abundance in different vertical strata was not uniform. Maximum foliage was concentrated within 10 m height from the ground in all the elevation zones of the study area. This pattern is reported from many other forests (Maurer and Whitmore, 1981; Terborgh and Petren, 1991; Francis, 1994; Zubaid, 1994; Jayson and Mathew, 2003). Maximum number of exclusive species was observed at 0 - 5 m followed by ground layer and 5 - 10 m height category. Highest species richness, diversity and abundance of birds were also observed within 10 m height. The result indicates that the vegetation at sub-canopy layer (<10 m) harbor high diversity of resources and allow effective partitioning, resulting in high diversity of birds. The data on insect, fruit, and flower abundances, and other factors such as competition, predators, light intensity and radiation from sun at each stratum would provide better understanding on vertical distribution of birds. Results of the present study suggest that understorey or sub-canopy vegetation is very crucial for maintaining diversity and conservation of birds.

6.5. SUMMARY

Information on vegetation structure and diversity, and their relationship with birds provides insights on habitat use, which ultimately aids in the conservation of species. Bird community parameters (species richness, abundance and diversity) showed close association with various habitat characteristics. The result suggests that the bird community in the Teesta valley is determined by both floristic diversity and vegetation structure. The findings concur with a number of earlier studies on avian communities.

The number of bird species, abundance and diversity among height categories were different. Overall, maximum species richness (231) was observed in 0 - 5 m height followed by 5 - 10 m, 10 - 15 m and the ground layer. Similar trend was observed in all the elevation zones. Each height category harboured distinct species composition and assemblages of birds. Species similarity among height categories was low which suggests that each strata of vegetation is important for maintaining the diversity and stability of the population of birds.

Maximum foliage was concentrated within 10 m height from the ground in all the zones. Correlation analysis revealed significant positive relations between foliage abundance and species richness, abundance and diversity of birds. It is obvious that structure and composition of vegetation has a major role in determining bird community structure in all the zones.

Results of this study have brought out the significance of understorey or sub-canopy vegetation with least disturbance in maintaining and conserving avifaunal diversity. A detailed study on the resources and other environmental parameters in different zones and vegetation strata could provide better understanding on the distribution of birds.

CHAPTER 7

CONCLUSION AND CONSERVATION IMPLICATIONS

Distribution and co-existence of species in an area over time is determined by various factors such as ecological, environmental and historical (Brown, 2001; Grytnes and McCain, 2007). Information on bird communities and distribution pattern along environmental gradients such as elevation provides insights to the observed pattern and aids in their conservation (Hawkins, 1999; Raman *et al.*, 2005). The studies conducted along elevational gradient covering various taxa and regions reported three major patterns of species richness - monotonic decline, mid-elevation peak and increase with elevation. However, a generalized pattern is not recognized yet (Rahbek, 2005).

Studies on the elevational distribution of species received due attention in recent years and several literatures are available mostly on small mammals and plants (Chapter 1, Pp.5). A few studies has examined distribution pattern of birds along the elevation gradient (Chapter 1, Pp.5-8) but no study has been undertaken in the Himalaya. Being the largest mountain ecosystem in the world, Himalaya offers ideal situation for examining elevational distribution of species due to wide variation in climate and elevation. Hence, the present study was initiated to (1) determine the structure of bird communities in different elevation zones, (2) understand the distribution pattern and turnover of birds along the elevation gradient and, (3) assess the habitat use of birds in the Teesta valley, Sikkim.

Sikkim, a small state of India, is characterized by rugged mountainous terrain and has a total geographical area of 7096 km^2. Part of the Eastern Himalaya, Sikkim is a priority region for conservation owing to its rich and endemic flora and fauna. It also forms part of the global biodiversity 'hotspot' as well as an endemic bird area, the Eastern Himalaya

(Stattersfield *et al.*, 1998; Myers *et al.*, 2000; Islam and Rahmani, 2004). Sikkim is considered as catchment area of the river Teesta, which is the major physical feature of the state. The Teesta valley represents continuums of natural habitat encompassing wide variation in elevation (300 to 5500m), climate (tropical to temperate) and vegetation types (tropical forest to alpine meadows) within a distance of around 100 km. For the present study, the Teesta valley was divided into the following five zones based on elevation and major vegetation types: zone I (tropical semi-deciduous forests: < 900 m), zone II (tropical moist and broad-leaved forests: 900 - 1800 m), zone III (temperate broad-leaved forests: 1800 - 2800 m), zone IV (temperate coniferous and broad-leaved forests: 2800 - 3800 m) and zone V (sub-alpine and alpine vegetation: >3800 m).

The study was conducted during June 2003 - March 2006. Point count method along the predetermined transects was employed for sampling birds. Transects were placed at different vegetation types covering five elevation zones. Each point was replicated 1 - 3 times in each of the four seasons, namely winter, summer, monsoon and post monsoon. At every point, observations were made on bird species, number of individuals of each species, distance from the observer and vertical position. Breeding birds of the Teesta valley was studied during peak breeding period (March to August). Nest searches were done in transects used for bird counts substantiated by opportunistic observation. Four zones of the study area (I - IV) were covered during 2004 and 2005. Once the nest is located, details such as species, location, date, presence of eggs/juveniles, clutch size and activity of the bird were noted. The nest-site characteristics were measured within 5 m radius from the nest.

Vegetation sampling was done following quadrat method (20 m x 10 m for trees and 5 m x 5 m for shrubs and ground cover). Species and individuals of both trees and shrubs were recorded. GBH of the trees (>20 cm) were also measured. The relative percentage covered by herb, grass, fern, litter, rock, soil and mosses was visually estimated. Abundance of foliage at seven different height categories was noted.

A total of 216 species of woody plants belonging to 64 families were recorded from the Teesta valley during the study. Among the total, 3,858 individuals belonging to 170 species were trees and 15,299 individuals of 135 species were shrubs. Tree species richness and diversity and shrub species richness were maximum in zone II (tropical broad-leaved forest), shrub diversity in zone I (Tropical semi-deciduous forest), tree basal area and shrub density in zone III (temperate broad-leaved forest), whereas tree density was the highest in zone IV (temperate coniferous forest). Tree and shrub species richness followed a hump-shaped relationship displaying peak at around 1500 m. *Abies webbiana* was the most abundant tree species in the study area. Species composition and relative abundance of plants were different among the zones. Density of small-sized trees (21 - 60 cm GBH) was more than the large trees indicating healthy regeneration of forests. Similarly maximum number of species was concentrated in lower GBH classes.

Overall, 2,616 points were covered after 328 transect replication for sampling birds during the study period. A total of 329 species (299 during regular quantitative sampling and 30 during opportunistic observations) and 22,939 individuals representing 44 families of birds were recorded from the Teesta valley during this study. Broad-leaved was the most diverse vegetation zone compared to tropical semi-deciduous, coniferous or alpine. Species accumulation curve approached an asymptote in all the elevation zones. Species richness (observed and estimated) was the highest in zone II and lowest in zone V. Bird species diversity was the maximum in zone III and minimum in zone V, whereas evenness was comparatively higher in zone V and lower in zone I. Density of birds was also maximum in zone III. Black Bulbul was the most abundant bird species in the study area. Twenty dominant species comprised around 50% birds of the study area. The species-abundance pattern of birds followed truncated log-normal distribution indicating the stability of the bird community. Out of the total species observed (329), 156 (47.4%) were exclusively recorded in one specific zone. Only three species, namely Blue Whistling Thrush, Greenish Warbler and White-capped Water Redstart occurred in all the five zones. Maximum number of species was shared between zones II and III followed by I and II.

Overall, species richness as well as density was high during summer and low during winter but diversity was the highest during monsoon. Marked seasonal variation in bird species richness, density, diversity and evenness was observed within and between elevation zones. Among the six trophic groups of birds, insectivore group was the most dominant in the Teesta valley comprising 61% species and 55% individuals. Nectarivores and carnivores trophic groups represented lowest number of species and abundance respectively. Out of the 10 Eastern Himalayan endemic species recorded from Sikkim, only five (Broad-billed Warbler, Hoary-throated Barwing, Rusty-bellied Shortwing, Yellow-vented Warbler and White-naped Yuhina) were observed during this study. Similarly, among the 17 threatened and two near threatened birds that occur in Sikkim only two species (Rusty-bellied Shortwing and Satyr Tragopan) were observed in the Teesta valley during this study.

Altogether, 183 nests of 39 species were recorded in four elevation zones (I - IV) of the study area. Breeding observations of species such as Ashy Wood Pigeon, Black-winged Cuckooshrike, Blood Pheasant, Eurasian Jay, Greenish Warbler, Rufescent Prinia and Tickel's Thrush were not reported earlier from Sikkim. The number of breeding species were 16, 9, 16 and 5 in zones I, II, III and IV respectively. Maximum of 67% species made cup nest, which accounted for 69% of the total nests observed. June was the peak breeding period with the highest number of breeding species and nests. Nest and nest-site characteristics of eight species with ≥10 nests are discussed in Chapter 4.

Observed species richness of birds changed as a quadratic function of elevation showing peak around 2000 m with declining trend at the lower and higher elevations. Estimated species richness (Chao 2, Jackknife 1 and Jackknife 2), diversity and density also peaked at mid-elevation. Birds of different trophic groups showed varied response along the elevation gradient. Species richness of frugivores, insectivores and nectarivores showed significant negative correlation with elevation but the relation was non-linear with a peak between 2000 m and 2500 m, whereas carnivores declined monotonically with elevation. Omnivores and granivores showed no significant relation with elevation. Similarly, the density of individual species varied along the elevational gradient.

The number of shared species between two elevational transects varied from 0 to 61. Similarly, Jaccard similarity index calculated for pair wise elevational transects ranged from 0 to 0.55 with the maximum similarity between 3350 m and 3500 m elevation. Cluster analysis revealed two major assemblages of birds - low to mid-elevation (390 - 2550 m) and high elevation (2900 - 4600 m). Within low and high elevation assemblages, birds displayed distinct community composition corresponding to major elevation zones of the study area. Most of the bird species had very narrow elevation range with 90 species restricted to single elevational transect. The range profile revealed that around 90 species were restricted within 1800 m, whereas 200 species showed distribution from low to mid-elevation (<2600m). Forty species occurred specifically above 3000 m. The turnover rates were relatively high at vegetation ecotones and showed increasing trend with elevation. Mid-domain effect null model (Monte Carlo simulations; McCain, 2004) was tested to see the impact of spatial constraint on species distribution. Regression of empirical species richness with mean of the predicted richness across simulation per bin showed significant deviation from mid-domain null model. The deviation indicates that apart from geographic hard boundaries, the distribution of birds in the Teesta valley is governed by biotic and abiotic factors.

Bird community attributes (species richness, diversity and abundance) showed close association with various habitat characteristics (tree, shrub and ground cover). The result suggests that species richness and diversity of birds are determined by both floristic diversity and vegetation structure. Vertical distribution of birds along vegetation profile was not uniform. Maximum species richness was observed at 0 - 5 m height category followed by 5 - 10 m. Each vertical strata of vegetation harbored distinct species composition with low species similarity among height categories. Maximum similarity was observed between 5 - 10 m and 10 - 15 m height categories. Foliage abundance was maximum at 0 -10 m height in all the zones. Vertical distribution of birds showed positive association with foliage abundance.

Conservation implications

Most of the river valley ecosystems witnessed immense anthropogenic intervention despite their biologically diverse nature. These ecosystems in the mountain are susceptible to landslides, soil erosion, and rapid loss of habitat. The loss of biodiversity in the Himalaya due to forest fragmentation and other anthropogenic pressures is alarming at present. It is predicted that 90% forest will be lost from the Himalaya by the end of this century, if the fragmentation is continued at the current rate wiping out more than 25% endemic species (Pandit *et al.*, 2007).

Sikkim occupies only 0.21% of the geographical area of India but harbours 42% (550 species) of birds that occur in the Indian subcontinent (1295 species). The record of 329 species of birds (around 60% found in Sikkim) during this study shows that the Teesta valley harbors high diversity of birds. Structure and composition of vegetation was unique among elevation zones along the Teesta valley. Consequently, high diversity and unique community composition of birds was apparent in each elevation zones representing different vegetation types. This suggests that conservation of natural habitat along the Teesta valley is essential for the conservation of birds.

Utilization of different vertical height categories suggests that birds are specific to each strata of vegetation. Since maximum diversity and exclusive species were observed between 0 - 10 m height strata, the preservation of under-storey vegetation is very crucial for maintaining and conserving the avifaunal diversity.

Mid-elevation forests around 2000 m possess the highest species richness of birds. Lower and higher elevations with lower species richness have species which are not found in the other elevational sites. Since, many species exhibited very narrow elevational width and most of them showed marked seasonal movement along the elevation, the entire gradient has crucial role for the maintenance of the unique bird community.

Most species specifically bred in one or two zones with maximum exclusive species breeding in zone I. The result indicates that the Teesta valley harbors potential breeding habitats for many bird species and needs conservation attention. Since many species depend on size of the forest for breeding (Burke and Nol, 1998), effort should involve in the preservation of larger tracts of forest to provide adequate nesting habitat for forest interior species.

Low elevation forest harbour high diversity but experience immense anthropogenic pressures everywhere in the world (Crosby, 1996; Daniels, 1996; Hawkins, 1999). Most of the low elevation forest in Sikkim is also fragmented due to agricultural practices or unplanned developmental activities such as hydropower generation, road building activities and urbanization. All existing protected areas in Sikkim are located mostly above 1500 m. The distribution of protected areas and conservation efforts should be in accordance with distribution of biota, area and human population (Hunter and Yonzon, 1993). The study revealed that altitudinal distribution of protected areas does not match with the distribution of biological hotspots in Sikkim. The protected areas cover only 27% good forests as most of the higher elevations are covered by permanent snow, moraines, alpine scrub and barren rocky slopes (CISMHE, 2006). Considering the uniqueness of species, high richness and absence of protected areas at low elevation, the study suggests the extension of conservation areas to low and mid elevation forests.

Forests below 1800 m in the Teesta valley are of much importance for small mammals, birds, herpetofauna, butterflies and plants (Vijayan *et al.*, 2006). Most of these forests (<1500 m) fall under private holdings and are exposed to several anthropogenic threats. However, protection of this diverse mosaic landscape is challenging as this zone is almost entirely inhabited by people. Hence, the protection of these areas is possible only through community participation. The current land use consists of agricultural land interspersed by small patches of original forest and is highly conducive for retaining the native fauna of Sikkim. The retention of original remnant patches of forest with native tree cover among agricultural fields should be done in consultation with various stakeholders and managed without further loss of biodiversity.

The Government of Sikkim has taken new initiatives to protect high altitude landscapes with the participation of the local communities. For the preservation of mountains and wetlands, the local communities are nominated as voluntary caretakers called *Pokhari Sanrakshan Samiti* and *Himal Rakshak* (Anon, 2006). Such conservation actions need to be extended and implemented to low elevation areas as well in Sikkim.

Plate 7.1 Construction activities (a) and firewood collection (b) - disturbances to the forests of the Teesta valley, Sikkim.

It was observed during the study that most of the local people rampantly extract bamboo, which forms dense undergrowth in broad-leaved forests. *Rhododendron nivale*, a high elevation shrub, is collected in large scale for incense. This undergrowth provides ideal microhabitat for many pheasants, babblers, laughingthrushes and other shy and skulking birds. Present study found maximum species richness and abundance of birds at 0 - 5 m height. Hence, extraction of forest resources should be monitored and managed properly in a more sustainable way so that the habitats of many rare and specialist birds remain unaltered.

The livelihood options for high elevation communities are livestock rearing and tourism, and are largely dependent on forests. The increasing tourism activity has immense pressure on the forest vegetation and birds of Khanchendzonga Biosphere Reserve (Chettri *et al.*, 2001, 2002, 2006). North Sikkim, especially Lachung and Yumthang valleys attract many domestic and international tourists all-round the year with more than 2,000 tourists per day during March to May (personal observation). The heavy influx of tourists to these valleys has increased the demand for firewood as a source of fuel for cooking and heating purposes. Livestock grazing, although officially banned (Anon 2003), is still the major conservation problem in North Sikkim. Cattle and Yaks are left freely in the forests even within the protected areas. The personnel engaged with road construction are dependent on forests for fuel and housing and are also responsible for poaching.

Conservation measures to this high elevation ecosystem need to be strengthened and practically implemented. Although, an alternative source of fuel such as LPG (liquefied petroleum gas) is provided to the local communities living on the fringes of protected areas by the government of Sikkim, refilling centres are not available nearby. Awareness programme on importance of forests and wildlife should regularly be conducted targeting villagers, students, tourist entrepreneurs, cattle herders, GREF and army personnel.

Manpower in the forest department is to be increased for deployment in the forests. Better facilities are to be provided to the forest staff to withstand the cold climatic conditions that persist in the area, especially the high elevation. Such measures would help increased protection to this unique landscape.

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APPENDICES

Appendix I. Checklist of birds recorded during the study period (2003-2006) from the Teesta valley, Sikkim. The classification follows Inskipp *et al.* (1996).

Family	Species	Scientific Name
Phasianidae	Hill Partridge	*Arborophila torqueola*
	Red Junglefowl	*Gallus gallus*
	Blood Pheasant	*Ithaginis cruentus*
	Kalij Pheasant	*Lophura leucomelanos*
	Satyr Tragopan	*Tragopan satyra*
Anatidae	Common Pochard	*Aythya ferina*
Picidae	Bay Woodpecker	*Blythipicus pyrrhotis*
	Rufous Woodpecker	*Celeus brachyurus*
	Greater Flameback	*Chrysocolaptes lucidus*
	Grey-capped Pygmy Woodpecker	*Dendrocopos canicapillus*
	Crimson-breasted Woodpecker	*Dendrocopos cathpharius*
	Darjeeling Woodpecker	*Dendrocopos darjellensis*
	Rufous-bellied Woodpecker	*Dendrocopos hyperythrus*
	Fulvous-breasted Woodpecker	*Dendrocopos macei*
	Himalayan Flameback	*Dinopium shorii*
	Pale-headed Woodpecker	*Gecinulus grantia*
	Lesser Yellownape	*Picus chlorolophus*
	Greater Yellownape	*Picus flavinucha*
Megalaimidae	Blue-throated Barbet	*Megalaima asiatica*
	Golden-throated Barbet	*Megalaima franklinii*
	Great Barbet	*Megalaima virens*
Bucerotidae	Oriental Pied Hornbill	*Anthracoceros albirostris*
Upupidae	Common Hoopoe	*Upupa epops*
Trogonidae	Red-headed Trogon	*Harpactes erythrocephalus*
Coraciidae	Dollarbird	*Eurystomus orientalis*
Halcyonidae	White-throated Kingfisher	*Halcyon smyrnensis*
Cerylidae	Crested Kingfisher	*Megaceryle lugubris*
Meropidae	Chestnut-headed Bee-eater	*Merops leschenaulti*
Cuculidae	Plaintive Cuckoo	*Cacomantis merulinus*
	Grey-bellied Cuckoo	*Cacomantis passerinus*
	Chestnut-winged Cuckoo	*Clamator coromandus*
	Pied Cuckoo	*Clamator jacobinus*
	Eurasian Cuckoo	*Cuculus canorus*

Family	Species	Scientific Name
	Indian Cuckoo	*Cuculus micropterus*
	Lesser Cuckoo	*Cuculus poliocephalus*
	Oriental Cuckoo	*Cuculus saturatus*
	Hodgson's Hawk Cuckoo	*Hierococcyx fugax*
	Large Hawk Cuckoo	*Hierococcyx sparverioides*
	Common Hawk Cuckoo	*Hierococcyx varius*
	Green-billed Malkoha	*Phaenicophaeus tristis*
Apodidae	Himalayan Swiftlet	*Collocalia brevirostris*
	White-rumped Needletail	*Zoonavena sylvatica*
Strigidae	Spot-bellied Eagle Owl	*Bubo nipalensis*
	Asian Barred Owlet	*Glaucidium cuculoides*
	Jungle Owlet	*Glaucidium radiatum*
	Tawny Fish Owl	*Ketupa flavipes*
	Brown Fish Owl	*Ketupa zeylonensis*
	Brown Wood Owl	*Strix leptogrammica*
Caprimulgidae	Grey Nightjar	*Caprimulgus indicus*
Columbidae	Emerald Dove	*Chalcophaps indica*
	Speckled Wood Pigeon	*Columba hodgsonii*
	Snow Pigeon	*Columba leuconota*
	Ashy Wood Pigeon	*Columba pulchricollis*
	Hill Pigeon	*Columba rupestris*
	Pin-tailed Green Pigeon	*Treron apicauda*
	Wedge-tailed Green Pigeon	*Treron sphenura*
	Barred Cuckoo Dove	*Macropygia unchall*
	Spotted Dove	*Streptopelia chinensis*
	Oriental Turtle Dove	*Streptopelia orientalis*
Scolopacidae	Common Sandpiper	*Actitis hypoleucos*
Charadriidae	Ibisbill	*Ibidorhyncha struthersii*
	River Lapwing	*Vanellus duvaucelii*
Accipitridae	Eurasian Sparrowhawk	*Accipiter nisus*
	Crested Goshawk	*Accipiter trivirgatus*
	Besra	*Accipiter virgatus*
	Steppe Eagle	*Aquila nipalensis*
	Booted Eagle	*Hieraaetus pennatus*
	Black Eagle	*Ictinaetus malayensis*
	Crested Serpent Eagle	*Spilornis cheela*
	Mountain Hawk Eagle	*Spizaetus nipalensis*
	Oriental Honey-buzzard	*Pernis ptilorhyncus*
Falconidae	Merlin	*Falco columbarius*
	Peregrine Falcon	*Falco peregrinus*
	Common Kestrel	*Falco tinnunculus*
Phalacrocoracidae	Great Cormorant	*Phalacrocorax carbo*
Ardeidae	Chinese Pond Heron	*Ardeola bacchus*

Family	Species	Scientific Name
Pittidae	Blue-naped Pitta	*Pitta nipalensis*
Eurylaimidae	Long-tailed Broadbill	*Psarisomus dalhousiae*
Irenidae	Golden-fronted Leafbird	*Chloropsis aurifrons*
	Orange-bellied Leafbird	*Chloropsis hardwickii*
Laniidae	Long-tailed Shrike	*Lanius schach*
	Grey-backed Shrike	*Lanius tephronotus*
Corvidae	Common Raven	*Corvus corax*
	Yellow-billed Chough	*Pyrrhocorax graculus*
	Red-billed Chough	*Pyrrhocorax pyrrhocorax*
	Large-billed Crow	*Corvus macrorhynchos*
	House Crow	*Corvus splendens*
	Grey Treepie	*Dendrocitta formosae*
	Eurasian Jay	*Garrulus glandarius*
	Spotted Nutcracker	*Nucifraga caryocatactes*
	Bronzed Drongo	*Dicrurus aeneus*
	Crow-billed Drongo	*Dicrurus annectans*
	Spangled Drongo	*Dicrurus hottentottus*
	Ashy Drongo	*Dicrurus leucophaeus*
	Black Drongo	*Dicrurus macrocercus*
	Greater Racket-tailed Drongo	*Dicrurus paradiseus*
	Black-naped Oriole	*Oriolus chinensis*
	Maroon Oriole	*Oriolus traillii*
	Black-winged Cuckooshrike	*Coracina melaschistos*
	Short-billed Minivet	*Pericrocotus brevirostris*
	Long-tailed Minivet	*Pericrocotus ethologus*
	Scarlet Minivet	*Pericrocotus flammeus*
	Grey-chinned Minivet	*Pericrocotus solaris*
	White-throated Fantail	*Rhipidura albicollis*
	White-browed Fantail	*Rhipidura aureola*
	Yellow-bellied Fantail	*Rhipidura hypoxantha*
	Common Green Magpie	*Cissa chinensis*
	Yellow-billed Blue Magpie	*Urocissa flavirostris*
Cinclidae	White-throated Dipper	*Cinclus cinclus*
	Brown Dipper	*Cinclus pallasii*
Muscicapidae	Oriental Magpie Robin	*Copsychus saularis*
	Golden Bush Robin	*Tarsiger chrysaeus*
	Orange-flanked Bush Robin	*Tarsiger cyanurus*
	Rufous-breasted Bush Robin	*Tarsiger hyperythrus*
	White-browed Bush Robin	*Tarsiger indicus*
	White-tailed Robin	*Myiomela leucura*
	Siberian Rubythroat	*Luscinia calliope*
	Firethroat	*Luscinia pectardens*
	Chestnut-bellied Rock Thrush	*Monticola rufiventris*

Family	Species	Scientific Name
	Blue Rock Thrush	*Monticola solitarius*
	Blue Whistling Thrush	*Myophonus caeruleus*
	White-collard Blackbird	*Turdus albocinctus*
	Grey-winged Blackbird	*Turdus boulboul*
	Tickell's Thrush	*Turdus unicolor*
	Scaly Thrush	*Zoothera dauma*
	Dark-sided Thrush	*Zoothera marginata*
	Plain-backed Thrush	*Zoothera mollissima*
	Long-billed Thrush	*Zoothera monticola*
	Grandala	*Grandala coelicolor*
	Large Niltava	*Niltava grandis*
	Small Niltava	*Niltava macgrigoriae*
	Rufous-bellied Niltava	*Niltava sundara*
	White-capped Water Redstart	*Chaimarrornis leucocephalus*
	White-winged Redstart	*Phoenicurus erythrogaster*
	Blue-fronted Redstart	*Phoenicurus frontalis*
	Black Redstart	*Phoenicurus ochruros*
	White-throated Redstart	*Phoenicurus schisticeps*
	Plumbeous Water Redstart	*Rhyacornis fuliginosus*
	Black-backed Forktail	*Enicurus immaculatus*
	Spotted Forktail	*Enicurus maculatus*
	Slaty-backed Forktail	*Enicurus schistaceus*
	Little Forktail	*Enicurus scouleri*
	Rusty-bellied Shortwing	*Brachypteryx hyperythra*
	White-browed Shortwing	*Brachypteryx montana*
	Gould's Shortwing	*Brachypteryx stellata*
	Purple Cochoa	*Cochoa purpurea*
	Grey-headed Canary Flycatcher	*Culicicapa ceylonensis*
	Hill Blue Flycatcher	*Cyornis banyumas*
	Tickell's Blue Flycatcher	*Cyornis tickelliae*
	Pale Blue Flycatcher	*Cyornis unicolor*
	Verditer Flycatcher	*Eumyias thalassina*
	Snowy-browed Flycatcher	*Ficedula hyperythra*
	White-gorgeted Flycatcher	*Ficedula monileger*
	Sapphire Flycatcher	*Ficedula sapphira*
	Rufous-gorgeted Flycatcher	*Ficedula strophiata*
	Slaty-blue Flycatcher	*Ficedula tricolor*
	Ferruginous Flycatcher	*Muscicapa ferruginea*
	Brown-breasted Flycatcher	*Muscicapa muttui*
	Rusty-tailed Flycatcher	*Muscicapa ruficauda*
	Dark-sided Flycatcher	*Muscicapa sibirica*
	Grey Bushchat	*Saxicola ferrea*
	Common Stonechat	*Saxicola torquata*

Family	Species	Scientific Name
Sturnidae	Common Myna	*Acridotheres tristis*
	Hill Myna	*Gracula religiosa*
	Chestnut-tailed Starling	*Sturnus malabaricus*
Sittidae	Kashmir Nuthatch	*Sitta cashmirensis*
	Chestnut-bellied Nuthatch	*Sitta castanea*
	Velvet-fronted Nuthatch	*Sitta frontalis*
	White-tailed Nuthatch	*Sitta himalayensis*
	Wallcreeper	*Tichodroma muraria*
Certhiidae	Eurasian Treecreeper	*Certhia familiaris*
	Rusty-flanked Treecreeper	*Certhia nipalensis*
	Winter Wren	*Troglodytes troglodytes*
Paridae	Fire-capped Tit	*Cephalopyrus flammiceps*
	Sultan Tit	*Melanochlora sultanea*
	Coal Tit	*Parus ater*
	Grey-crested Tit	*Parus dichrous*
	Green-backed Tit	*Parus monticolus*
	Rufous-vented Tit	*Parus rubidiventris*
	Rufous-naped Tit	*Parus rufonuchalis*
	Yellow-cheeked Tit	*Parus spilonotus*
	Yellow-browed Tit	*Sylviparus modestus*
Aegithalidae	Black-throated Tit	*Aegithalos concinnus*
	Rufous-fronted-Tit	*Aegithalos iouschistos*
Hirundinidae	Nepal House Martin	*Delichon nipalensis*
	Northern House Martin	*Delichon urbica*
Regulidae	Goldcrest	*Regulus regulus*
Pycnonotidae	Ashy Bulbul	*Hemixos flavala*
	Black Bulbul	*Hypsipetes leucocephalus*
	Red-vented Bulbul	*Pycnonotus cafer*
	Himalayan Bulbul	*Pycnonotus leucogenys*
	White-eared Bulbul	*Pycnonotus leucotis*
	Black-crested Bulbul	*Pycnonotus melanicterus*
	Striated Bulbul	*Pycnonotus striatus*
Cisticolidae	Hill Prinia	*Prinia atrogularis*
	Grey-crowned Prinia	*Prinia cinereocapilla*
	Striated Prinia	*Prinia criniger*
	Yellow-bellied Prinia	*Prinia flaviventris*
	Plain Prinia	*Prinia inornata*
	Rufescent Prinia	*Prinia rufescens*
Zosteropidae	Oriental White-eye	*Zosterops palpebrosus*
Sylviidae	Rusty-fronted Barwing	*Actinodura egertoni*
	Hoary-throated Barwing	*Actinodura nipalensis*
	Rufous-winged Fulvetta	*Alcippe castaneceps*
	Golden-breasted Fulvetta	*Alcippe chrysotis*

Family	**Species**	**Scientific Name**
	Rusty-capped Fulvetta	*Alcippe dubia*
	Brown-throated Fulvetta	*Alcippe ludlowi*
	Nepal Fulvetta	*Alcippe nipalensis*
	Rufous-throated Fulvetta	*Alcippe rufogularis*
	White-browed Fulvetta	*Alcippe vinipectus*
	Cutia	*Cutia nipalensis*
	Black-faced Laughingthrush	*Garrulax affinis*
	White-throated Laughingthrush	*Garrulax albogularis*
	Chestnut-crowned Laughingthrush	*Garrulax erythrocephalus*
	White-crested Laughingthrush	*Garrulax leucolophus*
	Spotted Laughingthrush	*Garrulax ocellatus*
	Greater Necklaced Laughingthrush	*Garrulax pectoralis*
	Rufous-chinned Laughingthrush	*Garrulax rufogularis*
	Blue-winged Laughingthrush	*Garrulax squamatus*
	Striated Laughingthrush	*Garrulax striatus*
	Puff-throated Babbler	*Pellorneum ruficeps*
	Golden Babbler	*Stachyris chrysaea*
	Grey-throated Babbler	*Stachyris nigriceps*
	Rufous-fronted Babbler	*Stachyris rufifrons*
	Jungle Babbler	*Turdoides striatus*
	Slender-billed Scimitar Babbler	*Xiphirhynchus superciliaris*
	Coral-billed Scimitar Babbler	*Pomatorhinus ferruginosus*
	Streak-breasted Scimitar Babbler	*Pomatorhinus ruficollis*
	White-browed Scimitar Babbler	*Pomatorhinus schisticeps*
	White-browed Shrike Babbler	*Pteruthius flaviscapis*
	Black-eared Shrike Babbler	*Pteruthius melanotis*
	Green Shrike Babbler	*Pteruthius xanthochlorus*
	Long-billed Wren Babbler	*Rimator malacoptilus*
	Scaly-breasted Wren Babbler	*Pnoepyga albiventer*
	Rufous Sibia	*Heterophasia capistrata*
	Silver-eared Mesia	*Leiothrix argentauris*
	Red-billed Leiothrix	*Leiothrix lutea*
	Blue-winged Minla	*Minla cyanouroptera*
	Red-tailed Minla	*Minla ignotincta*
	Chestnut-tailed Minla	*Minla strigula*
	Fire-tailed Myzornis	*Myzornis pyrrhoura*
	Mountain Tailorbird	*Orthotomus cuculatus*
	Common Tailorbird	*Orthotomus sutorius*
	Great Parrotbill	*Conostoma oemodium*
	Grey-headed Parrotbill	*Paradoxornis gularis*
	Black-throated Parrotbill	*Paradoxornis nipalensis*
	Brown Parrotbill	*Paradoxornis unicolor*
	Yellow-vented Warbler	*Phylloscopus cantator*

Family	Species	Scientific Name
	Lemon-rumped Warbler	*Phylloscopus chloronotus*
	Eastern Crowned Warbler	*Phylloscopus coronatus*
	Smoky Warbler	*Phylloscopus fuligiventer*
	Dusky Warbler	*Phylloscopus fuscatus*
	Hume's Warbler	*Phylloscopus humei*
	Yellow-browed Warbler	*Phylloscopus inornatus*
	Ashy-throated Warbler	*Phylloscopus maculipennis*
	Western Crowned Warbler	*Phylloscopus occipitalis*
	Buff-barred Warbler	*Phylloscopus pulcher*
	Greenish Warbler	*Phylloscopus trochiloides*
	Black-faced Warbler	*Abroscopus schisticeps*
	Blyth's Leaf Warbler	*Phylloscopus reguloides*
	Tickell's Leaf Warbler	*Phylloscopus affinis*
	Large-billed Leaf Warbler	*Phylloscopus magnirostris*
	Spotted Bush Warbler	*Bradypterus thoracicus*
	Yellowish-bellied Bush Warbler	*Cettia acanthizoides*
	Grey-sided Bush Warbler	*Cettia brunnifrons*
	Aberrant Bush Warbler	*Cettia flavolivacea*
	Brownish-flanked Bush Warbler	*Cettia fortipes*
	Chestnut-crowned Bush Warbler	*Cettia major*
	White-spectacled Warbler	*Seicercus affinis*
	Golden-spectacled Warbler	*Seicercus burkii*
	Chestnut-crowned Warbler	*Seicercus castaniceps*
	Grey-cheeked Warbler	*Seicercus poliogenys*
	Grey-hooded Warbler	*Seicercus xanthoschistos*
	Broad-billed Warbler	*Tickellia hodgsoni*
	Chestnut-headed Tesia	*Tesia castaneocoronata*
	Grey-bellied Tesia	*Tesia cyaniventer*
	Slaty-bellied Tesia	*Tesia olivea*
	White-naped Yuhina	*Yuhina bakeri*
	Striated Yuhina	*Yuhina castaniceps*
	Whiskered Yuhina	*Yuhina flavicollis*
	Stripe-throated Yuhina	*Yuhina gularis*
	Black-chinned Yuhina	*Yuhina nigrimenta*
	Rufous-vented Yuhina	*Yuhina occipitalis*
Alaudidae	Hume's Short-toed Lark	*Calandrella acutirostris*
	Greater Short-toed Lark	*Calandrella brachydactyla*
	Horned lark	*Eremophila alpestris*
Nectariniidae	Mrs Gould's Sunbird	*Aethopyga gouldiae*
	Fire-tailed Sunbird	*Aethopyga ignicauda*
	Green-tailed Sunbird	*Aethopyga nipalensis*
	Black-throated Sunbird	*Aethopyga saturata*
	Crimson Sunbird	*Aethopyga siparaja*

Family	Species	Scientific Name
	Fire-breasted Flowerpecker	*Dicaeum ignipectus*
	Thick-billed Flowerpecker	*Dicaeum agile*
	Streaked Spiderhunter	*Arachnothera magna*
Passeridae	House Sparrow	*Passer domesticus*
	Black-headed Munia	*Lonchura malacca*
	White-rumped Munia	*Lonchura striata*
	Tibetan Snowfinch	*Montifringilla adamsi*
	Blyth's Pipit	*Anthus godlewskii*
	Olive-backed Pipit	*Anthus hodgsoni*
	Rosy Pipit	*Anthus roseatus*
	Long-billed Pipit	*Anthus similis*
	White Wagtail	*Motacilla alba*
	Grey Wagtail	*Motacilla cinerea*
	Yellow Wagtail	*Motacilla flava*
	Alpine Accentor	*Prunella collaris*
	Brown Accentor	*Prunella fulvescens*
	Maroon-backed Accentor	*Prunella immaculata*
	Robin Accentor	*Prunella rubeculoides*
	Rufous-breasted Accentor	*Prunella strophiata*
Fringillidae	Collared Grosbeak	*Mycerobas affinis*
	White-winged Grosbeak	*Mycerobas carnipes*
	Spot-winged Grosbeak	*Mycerobas melanozanthos*
	Tibetan Siskin	*Carduelis thibetana*
	Dark-rumped Rosefinch	*Carpodacus edwardsii*
	Common Rosefinch	*Carpodacus erythrinus*
	Dark-breasted Rosefinch	*Carpodacus nipalensis*
	Beautiful Rosefinch	*Carpodacus pulcherrimus*
	Red-fronted Rosefinch	*Carpodacus puniceus*
	Pink-browed Rosefinch	*Carpodacus rodochrous*
	Blanford's Rosefinch	*Carpodacus rubescens*
	Streaked Rosefinch	*Carpodacus rubicilloides*
	White-browed Rosefinch	*Carpodacus thura*
	Scarlet Finch	*Haematospiza sipahi*
	Brandt's Mountain Finch	*Leucosticte brandti*
	Plain Mountain Finch	*Leucosticte nemoricola*
	Gold-naped Finch	*Pyrrhoplectes epauletta*
	Red-headed Bullfinch	*Pyrrhula erythrocephala*
	Little Bunting	*Emberiza pusilla*

Appendix II. List of woody plants recorded during the study period (2003-2006) from the Teesta valley, Sikkim. The classification follows Polunin and Stainton (1990), Rai and Rai (1994), and Hajra and Verma (1996).

Family	**Species**	**Local name**
Acanthaceae	*Adhatoda vasica*	*Basak*
	Strobilanthes sp.	*Kibu*
Aceraceae	*Acer campbellii*	*Kapasey*
	Acer laevigatum	*Pootli*
Alangiaceae	*Alangium begoniaefolium*	*Akhaney*
Anacardiaceae	*Mangifera* sp.	*Jangli Aap*
	Rhus insignis	*Bhalayo*
	Rhus semialata	*Bhakimilo*
	Spondias axillaris	*Lapsi*
Apocynaceae	*Alstonia scholaris*	*Chhatiwan*
Aquifoliaceae	*Ilex sikkimensis*	*Lise*
Araliaceae	*Brassiopsis mitis*	*Chuletro*
	Gamblea ciliate	*Kurshinglo*
	Macropanax oreophilum	*Chindey*
	Pentapanax leschenaultii	*Chindey*
	Trevesia palmate	*Dhabrey*
Asteraceae	*Artemisia vulgaris*	*Titepati*
	Vernonia sp.	*Nandhikay*
Berberidaceae	*Berberis concinna*	*Kadey rukh*
	Berberis edgeworthiana	*Muslendey*
	Mahonia sikkimensis	*Lise*
Betulaceae	*Alnus nepalensis*	*Uttis*
	Betula alnoides	*Saur*
	Betula cylindrostachys	*Saur*
	Betula utilis	*Saur*
Bignoniaceae	*Oroxylum indicum*	*Totola*
	Stereospermum tetragonium	*Parari*
Bombacaceae	*Bombax ceiba*	*Simal*
Burseraceae	*Garuga pinnata*	*Dabdabey*
Caesalpiniaceae	*Acacia lenticularis*	*Khakar*
	Bauhinia purpurea	*Tanki*
	Bauhinia variegata	*Koiralo*
	Bauhinia wallichi	
Combretaceae	*Terminalia chebula*	*Harra*
	Terminalia myriocarpa	*Pani saj*
Cornaceae	*Aucuba himalaica*	*Kalikath*
	Nyssa javanica	*Lekh chilaune*
	Swida sp.	
Cupressaceae	*Juniperus recurva*	
Dipterocarpaceae	*Shorea robusta*	*Sakhuwa*
Elaeagnaceae	*Hippophae* sp.	*Amilo*
Elaeocarpaceae	*Echinocarpus dasycarpus*	*Gobrey*
	Elaeocarpus lancaeofolius	*Bhadrasey*
	Elaeocarpus sikkimensis	*Bhadrasey*
Ericaceae	*Andromeda elliptica*	*Angeri*
	Andromeda sp.	*Angeri*

Family	Species	Local name
	Lyonia sp.	*Cutmiro like*
	Rhododendron arboreum	*Lali gurans*
	Rhododendron barbatum	
	Rhododendron campanulatum	
	Rhododendron cinnabarium	
	Rhododendron decipens	
	Rhododendron falconeri	
	Rhododendron fuelgen	*Chimal*
	Rhododendron grande	
	Rhododendron hodgsonii	*Kuringlo*
	Rhododendron lanatum	
	Rhododendron nivale	
	Rhododendron setosum	
	Rhododendron sp.	
	Rhododendron sp.	
	Rhododendron sp.	
	Rhododendron thomsonii	
	Rhododendron sp.	
Euphorbiaceae	*Aporosa dioica*	*Barkunley*
	Bischofia javanica	*Kainjal*
	Emblica officinalis	*Amala*
	Glochidion acuminatum	*Lathikath*
	Macaranga denticulata	*Ghampey malato*
	Macaranga indica	*Jauley malato*
	Macaranga peltata	*Malata*
	Mallotus philippinensis	*Sindurey*
	Ostodes paniculatus	*Bepari*
	Sapium baccatum	*Aakha tarwa*
Fagaceae	*Castanopsis hystrix*	*Katus*
	Castanopsis tribuloides	*Katus*
	Quercus lamellosa	*Bajranth*
	Quercus lineate	*Phalant*
	Quercus pachyphylla	*Bantey*
	Quercus semicarpefolia	*Bajranth*
	Quercus spicata	*Arkhaulow*
	Castanopsis sp.	*Katus*
Flacourtiaceae	*Gynocardia odorata*	*Gantey*
Hamamelidaceae	*Symingtonia populnea*	*Pipli*
Juglandaceae	*Engelhardtia* sp.	*Auley mauwa*
	Engelhardtia spicata	*Mauwa*
	Juglans regia	*Okhar*
Lamiaceae	*Leucosceptrum canum*	*Ghurpis*
Lauraceae	*Beilschemiedia sikkimensis*	*Tarsing*
	Cinnamomum cecidodaphne	*Sinkauli*
	Cinnamomum impressinervium	*Sissi*
	Litsaea citrate	*Siltumur*
	Litsaea elongata	*Pahaley*
	Litsaea polyantha	*Kutmero*
	Machilus edulis	*Phunsey*
	Machilus indica	*Kaulo*

Family	**Species**	**Local name**
	Machilus odoratissima	*Ghiu kaulo*
	Machilus sp	*Kaulo*
	Machilus sp.	*Bhaisey kaulo*
	Machilus sp.	
	Machilus villosa	*Jhakri kaulo*
	Phoebe lanceolata	*Jhakri kath*
Lythraceae	*Woodfordia fruticosa*	*Dhangero*
Magnoliaceae	*Magnolia indica*	*Chanp*
	Magnolia liliflora	*Chanp*
	Taluma hodgsoni	
Melastomataceae	*Melastoma* sp.	*Sano chulesi*
	Osbeckia nepalensis	*Sano chulesey*
	Oxyspora paniculata	*Chulesey*
Meliaceae	*Amoora rohituka*	*Lasuney*
	Amoora sp.	
	Amoora wallichi	*Lalli*
	Aphanamixis polystachya	
	Cedrela toona	*Tuni*
	Chikrassia tabularis	*Chekrasey*
	Heynea trijuga	*Aakha tarwa*
	Walsura tubulata	*Phalamey*
Mimosaceae	*Albizzia lebbeck*	*Siris*
	Albizzia marginata	*Kalo siris*
	Albizzia procera	*Seto siris*
Moraceae	*Artocarpus heterophylus*	*Rukh kathar*
	Ficus clavata	*Lutey khanium*
	Ficus cunia	*Khasrey khanium*
	Ficus hirta	*Khasrey*
	Ficus hispida	*Kalo khasrey*
	Ficus nemoralis	*Dudhilo*
	Ficus roxburghii	*Nebhara*
	Morus indica	*Kimbu*
Moringaceae	*Moringa oleifera*	*Sajana*
Myrsinaceae	*Maesa chisia*	*Bilaune*
	Maesa rugosa	*Bhogatey*
Myrtaceae	*Eucalyptus* sp	*Tarpin*
	Jambosa formosa	*Awley ambakey*
	Jambosa kurzii	*Ambakey*
	Syzgium cumini	*Jamuna*
Oleaceae	*Fraxinus paxiana*	*Lankuri*
Pandanaceae	*Pandanus furcatus*	*Tarika*
Papilionaceae	*Erythrina arborescens*	*Roringe*
	Erythrina stricta	*Phaledo*
Pinaceae	*Abies webbiana*	*Gobrey salla*
	Larix griffithii	*Barge salla*
Poaceae	*Bambusa lulda*	*Bans*
	Thysanolaena maxima	*Amliso*
	Arundinaria hookeriana	*Pareng*
Proteaceae	*Helicia* sp.	*Bandre*
Rhamnaceae	*Berchemia floribunda*	*Bangi*

Family	**Species**	**Local name**
Rosaceae	*Prinsepia utilis*	
	Prunus cerasoides	*Painyoo*
	Prunus nepaulensis	*Arupatey*
	Prunus rufa	*Lekh payun*
	Rubus ellipticus	*Aiselu*
	Rubus niveus	*Aiselu*
	Sorbus sp.	
	Cotoneaster sp.	
Rubiaceae	*Mussaenda truetleri*	*Dhobi*
	Pavetta indica	*Kainyo*
Rutaceae	*Evodia fraxinifolia*	*Khanakpa*
Sabiaceae	*Meliosma wallichii*	*Lekh Dabdabey*
Salicaceae	*Salix sikkimensis*	
Santalaceae	*Pyrularia edulis*	*Amphi*
Sapindaceae	*Sapindus detergens*	*Ritha*
Scrophulariaceae	*Weightia gigantea*	*Bahuney kath*
Simaroubaceae	*Ailanthus grandis*	*Gokul*
Solanaceae	*Datura stramonium*	*Dhokrey phool*
	Solanum sp.	
Sonneratiaceae	*Duabanga sonneratioides*	*Lampatey*
Staphyleaceae	*Turpinia nepalensis*	*Thali*
Sterculiaceae	*Pterospermum acerifolium*	*Hattipaile*
Symplocaceae	*Symplocos glomerata*	*Kharane*
	Symplocos ramisissima	*Kholme*
	Symplocos theifolia	*Kharane*
Taxodiaceae	*Cryptomeria japonica*	*Dhuppi*
Theaceae	*Eurya acuminata*	*Jhingni*
	Eurya symplocina	*Jhingni*
	Schima wallichi	*Awley chilauney*
Thymeliaceae	*Daphne cannabina*	*Kagatay*
	Edgeworthia gardeneri	*Aargeli*
Ulmaceae	*Celtis tetrandra*	*Khari*
	Trema politoria	*Kuhel*
Urticaceae	*Debregeasia velutina*	*Tusarey*
	Pouzolzia sp.	*Chipley*
Verbenaceae	*Calicarpa arborea*	*Guenylo*
	Clerodendron sp.	
	Gmelina arborea	*Khamari*
	Lantana camera	
	Premna bengalensis	*Gineri*
	Viburnum cordifolium	*Asarey*
	Viburnum mullah	*Ghora khari*
	Viburnum nervosum	*Asarey*