AVIFAUNAL COMPOSITION AND DISTRIBUTION PATTERNS ALONG ELEVATIONAL GRADIENTS IN THE SUTLEJ AND YAMUNA RIVER BASINS OF HIMACHAL PRADESH AND UTTARAKHAND, WESTERN HIMALAYA, INDIA

Thesis submitted to the

BHARATHIAR UNIVERSITY, COIMBATORE

for the award of

DEGREE OF DOCTOR OF PHILOSOPHY

in

ZOOLOGY

by

SANTHAKUMAR. B

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Sálim Ali Centre for Ornithology and Natural History (SACON)

(*A Centre of Excellence under the Ministry of Environment, Forest and Climate Change, Govt. of India*)

Coimbatore - 641 108, India

AUGUST 2019

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CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

Understanding the spatial difference in species diversity is a key challenge in ecology (Gaston, 2000). The well-known spatial pattern is the latitudinal diversity gradient, where species richness peaks at tropics and declines towards the poles (Rosenzweig, 1992). The richness of species along the elevational gradients is just a microcosm of the global latitudinal gradient (Rahbek, 1995). Species richness along the latitudinal gradient is the most striking and perhaps best-documented pattern (Yu *et al*., 2013). The complex elevational diversity of birds has been investigated on every continent (Cavarzere & Silveira, 2012). These patterns of species distribution along elevational gradients vary across taxonomic groups. Species richness patterns along the elevational gradients generally follow three patterns; 1) the monotonic decline of species richness, 2) the hump-shaped pattern with a peak at mid-elevation and 3) increase in species richness with increasing elevation (Figure 1.1). Among these, the first two patterns are the most common ones. i.e. either decreasing richness with increasing elevation or a hump-shaped pattern, in which diversity peaks at mid-elevations (Rahbek, 1995, 2005; McCain, 2009).

Elevational gradients, though perhaps not studied as intensively as the latitudinal gradient, can provide equally striking patterns in diversity (Sanders & Rahbek, 2012). However, few studies on bird communities along the elevation gradient are continued in various parts of the globe. Various studies are available on the distribution pattern of faunal groups along elevational gradient; invertebrates (Sanders, 2002; Sanders *et al*., 2003; Levanoni *et al*., 2011; Khan *et al*., 2011; Bhardwaj *et al*., 2012; Yu *et al*., 2013; Carneiro *et al*., 2014; Acharya & Vijayan, 2015), mammals (Patterson *et al*., 1996, 1998; Brown, 2001; Md Nor, 2001; Rickart, 2001; McCain, 2004b, 2005, 2006), birds (Terborgh, 1977; Blake & Loiselle, 2000; Lee *et al*., 2004; Raman *et al*., 2005; Franco *et al*., 2007; Das, 2008; Jankowski *et al*., 2009; McCain, 2009; Acharya *et al*., 2011; Naithani & Bhatt, 2012; Wu *et al*., 2013; Joshi & Rautela, 2014; Montano-Centellas & Garitano-Zavala, 2015), herpetofauna (Hofer *et al*., 1999; Naniwadekar & Vasudevan, 2007; Chettri *et al*., 2010; Srinivas, 2011).

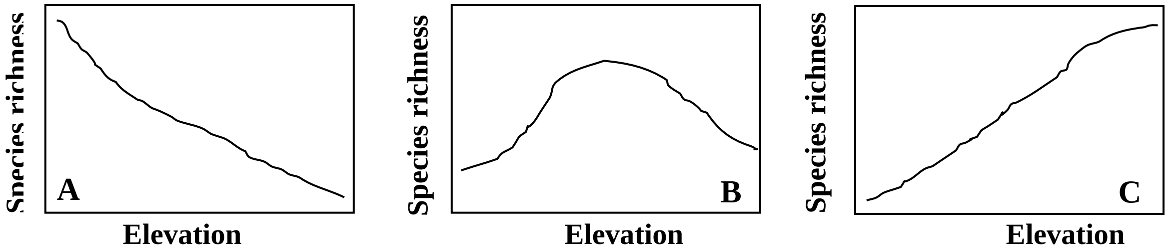


Figure 1.1 Elevational richness patterns: (A) Monotonic decline (B) Hump-shaped pattern (C) Increasing with elevation

Empirical studies have shown that bird species richness may decrease linearly with increasing elevation or may show a mid-elevation peak (McCain, 2009; Wu *et al*., 2013). The decline in species richness with increasing elevation is also widely reported as a general pattern (Stevens, 1992; Rahbek, 1995). However, Rahbek (1995) stated that this view of relationship between species richness and elevation is immature. Compositional changes in bird communities along elevations are still poorly understood (Terborgh, 1971, 1977; Blake & Loiselle, 2000; Jankowski *et al*., 2009; Acharya *et al*., 2011). Different patterns such as the monotonic decline of species richness along with the elevation (Stevens, 1992; Md. Nor *et al*., 2001; Acharya & Vijayan, 2015), Hump-shaped curve or mid-elevation peak (Rahbek, 1995, 1997; Md. Nor, 2001; Rickart, 2001; McCain, 2004; Brehm *et al*., 2007; Das, 2008; Acharya *et al*., 2011; Srinivas, 2011; Yu *et al*., 2013; Joshi & Rautela, 2014), increase in number with elevation (Sanders *et al*., 2003; Naniwadekar & Vasudevan, 2007) and 'U' shaped pattern or mid-elevation depression (Raman *et al*., 2005) in species richness have all been reported. Understanding the distribution, diversity patterns and structure of bird communities along elevational gradients are significant for planning conservation efforts in montane ecosystems (Chettri *et al*., 2001; Raman *et al*., 2005; Acharya *et al*., 2011).

In India, the unique Himalayan ecosystem is very rich in natural resources and biological wealth, mainly due to the diverse range of elevation, vegetation types, terrains and precipitation regimes. Moreover, historical influx of fauna from adjacent bio-geographical regions and subsequent speciation in relation to local environment has greatly enriched the faunal resources of the Himalayan region (Thakur & Mattu, 2011). The bird diversity of the state of Himachal Pradesh and Uttarakhand is very rich and diversified.

The mountainous state of Himachal Pradesh (30º 22' to 33º 12' N and 75º 45' to 79º 04' E) is situated in the northwest of India with a total geographical area of 55,673 km^2 (Himachal Pradesh Forest Department), encompasses 17% area of Western Himalaya. The entire region of the state is characterized by numerous mountain ranges, hills, rivers, and forests (Rahmani & Islam, 2004; Sharma & Kumar, 2012). The Sutlej river is one of the major physical features of Himachal Pradesh and flows south-westerly direction bisecting the entire state. The Sutlej river cover wide-ranging variation in elevation (498 to 6685 m), climate (tropical to temperate) and vegetation types (tropical forest to alpine meadows).

Uttarakhand (28º 44' to 31º 28' N and 77º 35' to 81º 01' E), the erstwhile Uttaranchal, is the Himalayan state in the northern part of India. The geographical area of the state is 53,483 km^2 (Rahmani & Islam, 2004), of which 93% of the area is hilly terrain. The major physical features Western and Eastern boundaries are natural with Tons and Yamuna rivers flowing southwards. The Yamuna river course encompasses wide variation in elevation (370 to 6387 m). The state has a temperate climate except in plain areas where the climate is tropical and the vegetation with high alpine areas to the sub-tropical and tropical regions. The variety of flora and fauna with high species turnover is best represented along the elevation gradient of the Sutlej and Yamuna rivers making it an excellent site for the study of distribution patterns.

Geographical variation in biological diversity is one of the most conspicuous patterns in biology (Heaney, 2001). The distribution of biota along elevation gradients varies due to diverse ecological, biological factors and historical influx (Brown, 1971; Heaney, 2001; Grytnes & McCain, 2007). Recently, the mid-domain effect has been relatively new hypothesis for explaining broad-scale patterns in species diversity. The hypothesis predicts a hump-shaped species richness pattern when species ranges are randomly distributed within a geometrically constrained domain (Colwell & Hurtt, 1994; Colwell & Lees, 2000; McCain, 2004; Colwell *et al*., 2004). The model states that geographic hard boundaries such as base and top of a mountain i.e. a species range cannot extend over the top of the mountain or below the base at sea level or the lowest regional elevation (Grytnes & McCain, 2007).

Species composition of communities between different elevation gradients possibly help to understand the elevational distribution of species and ultimately their habitat selection, and climatic condition. These differences in species composition can either be explained by similarity or dissimilarity matrices using species turnover indices (Nichols *et al*., 1998; Graham *et al*., 2005). The species turnover signifies higher replacement rate of the set of species or assemblage due to changes in habitat, climatic factors, historical perturbations, productivity and space availability (Terborgh, 1977; Rahbek, 1995).

1.2. EARLIER STUDIES

It is well known that avifauna are excellent tools for determining the environmental quality of ecosystem changes, due to their sensitivity to environmental changes (Jayson & Mathew, 2000; Aravind *et al*., 2010; Brummelhaus *et al*., 2012; Naithani & Bhatt, 2012; Akram *et al*., 2015). Bird community study is to understand the bird species composition and abundance as it provides information on the bird distribution over the landscapes (Wiens & Rotenberry, 1981; Welsh & Lougheed, 1996; Monkkonen *et al*., 1997; Sultana & Khan, 1999; Rodewald & Abrams, 2002; Laiolo, 2003; Renner *et al*., 2006; Albright *et al*., 2010; Kolecek *et al*., 2010; Sweeney *et al*., 2010; Mengesha *et al*., 2011; Brummelhaus *et al*., 2012; Kidwai *et al*., 2013; Akram *et al*., 2015; Pastur *et al*., 2015; Verma & Murmu, 2015). Montane systems are ideal to study geographic variation in the determinants of community structure (Lessard *et al*., 2011). Increasing fragmentation of natural areas and a dramatic reduction of forest cover in several parts of the world, quantifying the impact of such changes on species richness and community dynamics has been a subject of much concern (Boulinier *et al*., 2001, Mengesha *et al*., 2011, Verma & Murmu, 2015).

A number of reviews of the vast literature on ecological studies of bird species (Wiens, 1989; Tyler & Ormerod, 1993; Pramod, 1995; Iqbal *et al*., 2011) and community structure are available (Wiens & Rotenberry, 1981; Welsh & Lougheed, 1996; Monkkonen *et al*., 1997; Sultana & Khan, 1999; Rodewald & Abrams, 2002; Laiolo, 2003; Renner *et al*., 2006; Albright *et al*., 2010; Kolecek *et al*., 2010; Sweeney *et al*., 2010; Mengesha *et al*., 2011; Brummelhaus *et al*., 2012; Kidwai *et al*., 2013; Akram *et al*., 2015; Pastur *et al*., 2015; Verma & Murmu, 2015). However, the major objective of the present study is to examine distribution pattern of bird communities along an elevational gradient.

1.3. STUDIES IN INDIA

India is one of the 12 mega-biodiversity countries (McNeely, *et al*., 1990) that is well known for its wealthy flora and fauna, especially in the Himalayan States. The systematic studies on birds of Himalaya are a century old and most of these studies were concerning taxonomy, distribution and natural history (Jones, 1947a, b, 1948; Whistler, 1925, 1926a, b, c; Wynter-Blyth, 1951, 1952, 1953, Ali & Ripley, 1983). However, understanding the ecological information at community level remains incomplete (Tilak & Tyagi, 1977; Mukherjee & Chandra, 1984; Pandey, 1989; Mahabal & Sharma, 1992, 1993; Gaston *et al*., 1993; Narang & Singh, 1995; Mahabal 1996, 2000a, b, 2005; Sharma & Mahabal, 1997; Narang & Rana, 1999; Thakur *et al*., 2002, 2003, 2006, 2010a, b, 2012; Santharam, 2005; Sangha, 2005; Mattu & Thakur, 2006; Thakur, 2008; Thakur & Mattu, 2011).

The Himalayas are the foundation of many of the perennial large rivers of Asia (Xu, *et al*., 2009). This riverine habitat is an important resource base for avian communities (Trammell & Bassett, 2012). Those parts of the Himalaya, such as Himachal Pradesh and parts of Uttarakhand are located within the Western Himalaya endemic bird area (Rahmani & Islam, 2004) and a global biodiversity hotspot (Peart, 1997).

Considering the high diversity there is a lack of information on diversity patterns along the elevation gradients on birds of Himachal Pradesh and Uttarakhand. Most of the past studies were based on surveys that focused mostly on systematics and nomenclature. Himachal Pradesh is extremely important for the protection of many species of pheasants and forest birds. The total avifaunal wealth of Himachal Pradesh is 390 species includes two restricted-range species such as Cheer Pheasant *Catreus wallichii* and Western Tragopan *Tragopan melanocephalus* (Rahmani & Islam, 2004). In Uttarakhand 693 species of birds have been recorded, includes five endemic species such as Cheer Pheasant *Catreus wallichii*, Western Tragopan *Tragopan melanocephalus*, Himalayan Quail *Ophrysia superciliosa*, White-throated Tit *Aegithalos niveogularis* and Tytler's Warbler *Phylloscopus tytleri* (Mohan & Sondhi, 2015). Although species inventory and taxonomy has been dealt very well, however very little ecological information is available on community structure and diversity patterns of Avifauna in Himachal Pradesh and Uttarakhand.

Recent studies have documented the bird communities of the Himalayan region, mostly in the Kumaon region (Safiq *et al*., 1997; Sultana & Khan, 1999, 2000; Price *et al*., 2003; Sultana *et al*., 2007) and few in the eastern region (Raman *et al*., 1998; Chettri *et al*., 2001, 2005; Acharya, 2008; Acharya *et al*., 2011). Many studies on species richness pattern along the elevation gradient have been carried out in other geographical regions. Most of these studies focus on mammals, birds and invertebrates. Few studies are also reported on herpetofauna. Information on the distribution pattern of birds along elevation in India is scanty. The available information specific to elevation gradient and birds has been studied in Western Ghats (Raman *et al*., 2005, Das, 2008), Eastern Himalaya (Acharya *et al*., 2011) and Garhwal Himalaya (Joshi & Rautela, 2014).

Raman *et al*. (2005) described the pattern in birds of Kalakad-Mundanthurai Tiger Reserve (KMTR), Western Ghats and observed U-shaped pattern because of species with narrow elevational distribution. The study concluded that bird community composition was significantly correlated with elevation and tree species composition. Das (2008) studied distribution pattern of birds and their resource sharing in during breeding period in four habitats along the elevation gradient in Silent Valley National Park, Western Ghats. The species richness and abundance of bird species were higher in evergreen forest habitat and shola habitat than mid-elevation broad leaved hill forest. The distribution of birds was correlating with major vegetation structure of the elevation gradient.

Acharya *et al*. (2011) examined patterns of bird species richness and range size distribution in 22 sites along the elevation gradient in Teesta Valley, Sikkim, Eastern Himalaya. This study indicated that the species richness of birds is highest at intermediate elevation, additionally primary productivity and factors associated with the variation in bird species richness along the elevation gradient. Joshi and Rautela (2014) studied the avian diversity and community composition in seven elevation zones at Doon valley forest, Uttarakhand (Garhwal Himalaya). They reported hump-shaped distribution model of bird species richness along an elevation gradient, correlated with vegetation types.

Understanding the association between species richness and elevational gradients are essential as it provide insights into the observed patterns and processes responsible for the connection, which support in the biodiversity conservation (Stevens, 1992;

Raman *et al*., 2005; Acharya *et al*., 2011). There is no comprehensive study of birds along an elevation gradient from Sutlej and Yamuna river of Himachal Pradesh and Uttarakhand respectively. Hence, the present study fill in this lacuna in our knowledge and deals with the community structure and distribution pattern of birds along elevation gradient of Sutlej (498 – 3700 m) and Yamuna (370 – 2600 m) river of Western Himalaya.

1.4. OBJECTIVES

The purpose of this study was to examine the bird community structure and elevational distribution pattern with following specific objectives,

1. To describe the structure of bird communities in different elevation zones along select stretches of Sutlej and Yamuna river, and
2. To examine the distribution patterns in bird species richness and identify factors that governs bird species richness along the elevation gradient.
3. To study the changes in bird communities in response to hydro-electric power projects

1.5. THESIS STRUCTURE

This thesis is organized into five chapters that include the first two introductory and study area sections, followed by three main chapters which addressing the major objectives of the study and conservation importance.

The first chapter provides an overview of the research background for this study and specified the research objectives.

The second chapter describes the geographical settings of the study areas and major vegetation types found at different elevation zones.

The third chapter describes the bird community structure, in terms of species richness, diversity, relative abundance and seasonal variation in relation to elevational zones in Sutlej and Yamuna rivers.

The fourth chapter discusses the bird distribution pattern along the elevation gradient of Sutlej and Yamuna rivers and the factors governing the same.

Finally the fifth chapter discusses the effect of hydro power projects on birds of Sutlej and Yamuna rivers.

Chapter 2

CHAPTER 2

STUDY AREA

The present study was conducted along Sutlej and Yamuna river, Western Himalaya, India. The intensive study areas comprised of Sutlej and Yamuna rivers located within the states of Himachal Pradesh and Uttarakhand respectively.

2.1. INTRODUCTION

Himalayan mountain range comprises of the youngest and loftiest mountain chains in the world. It stretches over 3000 km from the Pamir in west to the Purvanchal in east exhibiting an arch shape. Himalaya covers a vast area of 7,50,000 km^2 that mainly consists of northern Pakistan, Nepal Bhutan and the northwestern and northeastern states of India (Singh *et al*., 2015). The region is characterized by a variety of climatic conditions varying from tropical to arctic (Thakur & Mattu, 2011). The ecology of the Himalaya may be traced to its enormous massiveness, great elevations of the mountain ranges and their positioning in the middle of a vast continental mass, it's origin dates backs to the Pleistocene glaciations period and continued during Post-Pleistocene era (Mani, 1974; Pandit *et al*., 2000). Depending upon the geographical position, Himalayas broadly divided into Western, Central and Eastern Himalaya. Western Himalayan region lies in Indian states of Jammu & Kashmir in the west, Himachal Pradesh in the middle and towards east of Uttarakhand. The present study focused in the Western Himalayan part of states Himachal Pradesh and Uttarakhand. In Himachal Pradesh, the study was conducted along a Sutlej river (31º 22' - 32º 10' N & 76º 75' - 78º 63' E.) and in Uttarakhand along Yamuna river (30º 41' - 31º 13' N & 77º 62' - 78º 43' E).

2.2. HIMACHAL PRADESH

The hill state of Himachal Pradesh is situated in the northwest part of India in the Himalayan range. The state shares its boundary with four Indian states namely, Jammu and Kashmir in North, Punjab in the West, Haryana in the South, Uttarakhand in the Southeast and India's international boundary with Tibet in the East. The entire region of the state is characterized by numerous mountain ranges, hills, snow-fed rivers and forests (Rahmani & Islam, 2004; Sharma & Kumar, 2012). The important rivers of the system are the Sutlej, Beas, Ravi, Chenab and Yamuna. River Sutlej is one of the most important catchment areas of Himachal Pradesh, and it is the major physical features of the state.

2.2.1. Physiography

Himachal Pradesh is entirely occupied with numerous mountains and valleys, the pristine mountainous region with natural beauty that includes gurgling streams, conifer-clad slopes and snow-covered peaks that appear to reach the skies. Variation in the mountain peaks, the physiographic of state separated into the Siwalik hills, Lesser Himalaya, Great Himalaya and Trans-Himalaya (Rodgers & Panwar, 1988; Negi, 1998). The low rolling **Siwalik hills** occur on the periphery of Himachal Pradesh and Punjab-Haryana. The highest mountains clippings in the Siwalik hills about 1000 m elevations, the major vegetation found in these regions are the scrub, sal forest, and broad-leaved forest. **Lesser Himalaya** occupies the central part of Himachal Pradesh with tallest peak at 3647 m elevation. The major region is covered with Mussoorie ridge, Shimla ridge, Pir Panjal and Dhauladhar, with vegetation including coniferous, broad-leaved forests, sub-alpine, and alpine pastures.

Great Himalayan ranges comprise snow-clad peaks with over 6000 m elevations, the well-known passes Rohtang (3915 m), Kangla (5248 m), Kunzam (4551 m), Parnag (5548 m) and Pin Parbati (4802 m). Sutlej river flows through the deep gorges across the main Himalayan range. Vegetation consist of deodar, blue pine, fir, spruce, kharsu oaks, rhododendron, sub-alpine and alpine meadows. The **Trans-Himalayan** region is situated above the main great Himalayan range with average elevation of 3000 m and highest peaks having an elevation above 6500 m. Rainfall is very low and monsoon clouds are unable to cross the range, Lahul and Spiti and Pooh of Kinnaur district lie in this zone. Ladakh is the prominent mountain range of the trans-Himalayan region of Himachal Pradesh. These regions lack forest vegetation, with occasional tuft of grass turn up the mountain slopes during the summer (Negi, 1998).

INTENSIVE STUDY AREA- SUTLEJ

2.2.2. Sutlej River

Sutlej arises in the southern slopes of the Kailash mountain near Mansarover lake from Rakastal lake (in Tibet). It is the largest among the five rivers of Himachal Pradesh, enters at Shipkila and flows in the south-westerly direction through Kinnaur and cut across the entire state (Figure 2.1). Sutlej river is a perennial river, and it coarse in

Himachal Pradesh is 320 km. from with famous tributaries viz. the Spiti, Ropa, Taiti, Kashang, Mulgaon, Yula, Wanger, Throng, Rupi are right bank and Tirung, Gayathing, Baspa, Duling and Soldang are left bank tributaries. Sutlej total catchment area in Himachal Pradesh is 20,000 sq.km.

Sutlej river basin considered to be the most active with wide variations of natural habitats, which harbors rich regional vegetation (tropical forest to alpine meadows), varied climatic conditions (tropical to temperate) and elevational range (498 to 6685 m) at the intersection of several bio-geographical units. The above important biotic and abiotic features create the area significant for studying distribution patterns of species along environmental gradients.

2.2.3. Climate

Sutlej river basin experiences varied climatic setting due to geographical location and wide variation in elevation range from 450-6500 m. The climate varies from hot and sub-humid tropical in the southern tracts to temperate, cold alpine and glacial in the northern and eastern mountain ranges. The coldest areas are Lahaul-Spiti and Pooh, where the mean minimum temperature in winter may fall to -30ºC (Negi, 1998). The cold desert Spiti has two seasons, summer (March to September) and winter (October to February). Kinnaur region experience three seasons viz., summer, winter and rainy season. Summer lasts from mid-April to June and turn into very hot except for alpine zone. The rainy season is from July to September followed by a somewhat warm October. The winter starts from November to mid-March. Snowfall is common in alpine region (elevation above 2200 m in the High and Trans-Himalayan region).

2.2.3.1. Precipitation and Temperature

Western Himalayas is controlled by two atmospheric circulation systems viz., Western Disturbances and Mid-altitude Subtropical Westerly Jet (Dobreva *et al*., 2017). The precipitation of Sutlej river basin at higher elevation is mainly in the form of snow, while in the lower region, it is rainfall. Most of the area above 2000 m experience snowfall from November to March. Rainfall is heavy at lower elevations from June to September with a maximum in July, and the annual rainfall is 1035.1 mm. The trans-Himalayan ranges of Lahaul and Spiti, Pooh districts falls under the rain shadow area of Sutlej river basin.

Temperature varied from freezing to above normal, the minimum and maximum temperature of the river basin ranges from -3.8ºC (February) during winter and 31.9ºC (May) in summer respectively (IMD, 2012).

2.2.4. Vegetation

In India, total 45,000 species of plants are recorded; of which 3,295 species are reported in Himachal Pradesh. More than 95 of the species are endemic to Himachal Pradesh with characteristics of western Himalayan flora (Himachal Pradesh Forest Department, 2013). Champion and Seth (1968) classified the rich and diverse floristic wealth of Himachal Pradesh and categorized the vegetation into nine groups. Sutlej river basin alone supports six major forest groups viz., Sub-tropical broad-leaved hill forests, Sub-tropical pine forests, Himalayan moist and dry temperate forests, Sub-alpine forests, Moist alpine scrub forests and Dry alpine scrub forests. The following six major vegetation types are familiar along the Sutlej river basin.

Sub-tropical broad-leaved hill forests include low elevation area up to 1200 m, which consists of Khair-sissu forest (5/1S2), Dry deciduous scrub (5/DS1), Euphorbia scrub (5/DS3), Dry bamboo brakes (5/E9) and Northern dry mixed deciduous forest (5B/C2). The dominant trees are *Acacia catechu*, *Butea monosperma*, *Lannea coromandelica* and bamboo species *Dendrocalamus strictus*.

Sub-tropical pine forests extend upto elevation 1800 m, the major forest types are Lower or Siwalik Chir-pine forest (9/C1a), Upper Himalayan Chir-pine forest (9/C1b) and Himalayan sub-tropical scrub (9/DS1). The dominant species are *Pinus roxburghii*, *Carissa* sp., *Dodonaea* sp., and *Rhus parviflora*.

Himalayan moist forest falls within an elevational ranges of 1500 and 3000 m, and Dry temperate forests beyond the elevation ranges of 2000 to 3000 m, the forest vegetation represented by Oak scrub (12/C1/DS1), Himalayan temperate secondary scrub (12/C1/DS2), Moist deodar forest (12/C1c), Western mixed coniferous (12/C1d), Low-level Blue-pine forest (12/C1f), Oak scrub (12/C2/DS1), Kharsu oak forest (12/C2a), West Himalayan upper oak (12/C2b), Dry broad-leaved and coniferous forest (13(i)/C1), Dry deodar forest (13(i)/C2b), Neoza pine forest (13/C2a). The forest types support species such as *Pinus gerardiana*, *Cedrus deodara*, *Quercus* sp., *Rhododendron arboreum*, *Plectranthus rugosus*, *Pinus wallichiana* and *Abies pindrow*.

Sub-alpine forests include areas above 3600 to 4100 m elevational ranges, West Himalayan sub-alpine (14/C1b) forest type consisting of Fir (*Abies* sp.), Birch (*Betula* sp.) and *Rhododendron* sp.

Moist alpine scrub forests comprising of Birch Rhododendron scrub (15/C1) and Dwarf Rhododendron scrub (15/E1) occurring near to the snowline and major species such as *Lonicera obovata*, *Rhododendron anthopogon,* and *Sorbus foliolosa*.

Dry alpine scrub forests extend beyond Yangthang towards Spiti valley of Himachal Pradesh with an elevational range above 4100 m, covers Dry alpine scrub (16/C1) and Dwarf juniper scrub (16/E1). The coniferous vegetation turned into dwarf shrub species such as *Salix* sp., *Myricaria* sp., *Hippophae* sp. and *Juniperus* sp.

2.2.5. Wildlife

The forest area in Himachal Pradesh is 37,033 km^2 or about 66.52% of the total geographical area of the state, of which 1,896 km^2 are reserved forests and 11,387 km^2 are protected forests. Out of the total forest area 17.25% under dense forest cover, whereas area under open forest cover is 9.12% (Himachal Pradesh Forest Department, 2013). Conserve the wildlife in the state, the Government of Himachal Pradesh has declared several areas as protected area; includes 3 Conservation reserves, 26 Wildlife sanctuaries, and 5 National Parks.

Western Himalaya, which includes Himachal Pradesh is a Global Biodiversity Hotspot (Mittermeier *et al*., 2005; Chitale *et al*., 2015), Endemic Bird Area (Stattersfield *et al*., 1998) and an Important Bird Area (Rahmani & Islam, 2004). In view of the area's ecological importance, various faunal studies were conducted by several eminent researchers. The earliest paper on the avifaunal composition of Himachal Pradesh by Jones (1947 and 1948), documented 199 species from Shimla and their adjoining hills. Gaston (1993) reported 183 species from Great Himalayan National Park. Mahabal (2000) listed 61 species from Talra Wildlife Sanctuary, the birds of

Rupi Bhaba Wildlife Sanctuary by Jayapal and Ramesh (2009) reported 200 species, Thakur *et al*., (2010a, b, 2012) listed 85, 102 and 117 species from Solan and Mandi districts respectively.

The avifaunal wealth of the Kaza area of Spiti was reported to be 62 species by Thakur and Mattu (2011). Kulkarni and Goswami (2012) studied 31 species from Shimla, and Thakur (2013) listed 322 species from various parts of the State. However, the avifaunal richness of the state was cumulated by Rahmani and Islam (2004) as around 390 species. According to the Zoological Survey of India (2005), the total faunal wealth of the state include 107 mammals, 447 birds, 14 reptiles, 17 amphibians, 104 fishes and 268 butterflies.

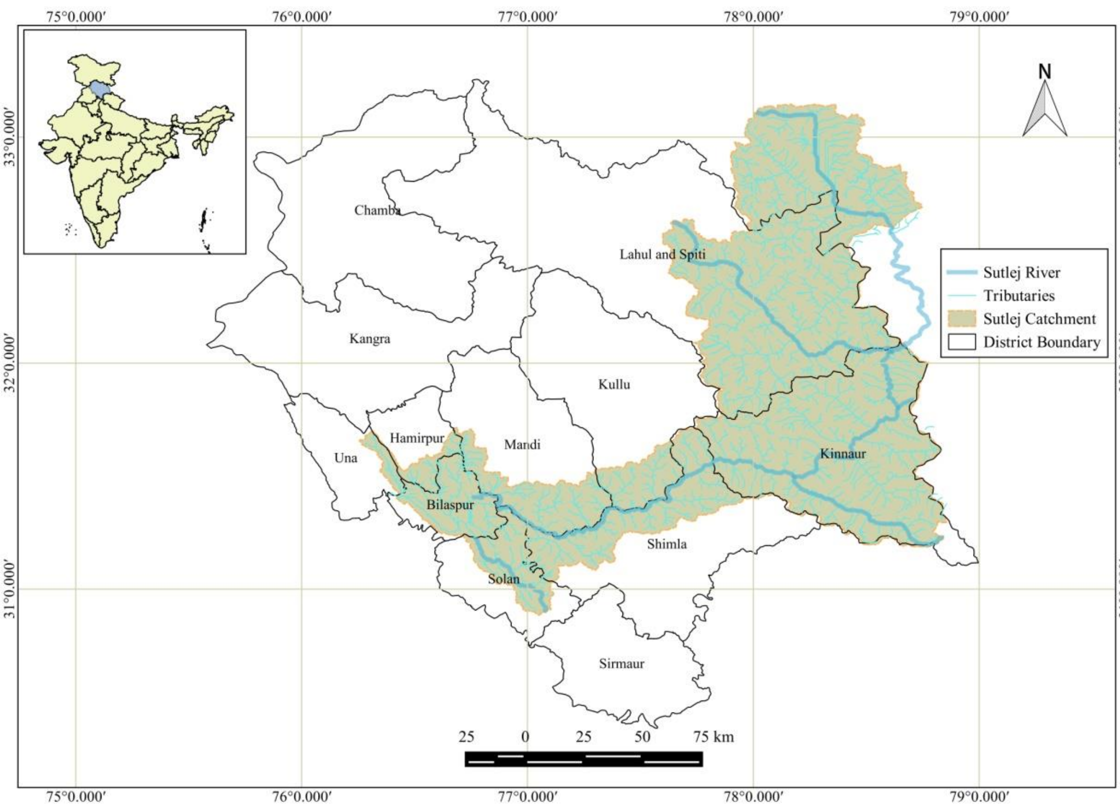


Figure 2.1. Map of Himachal Pradesh showing the Sutlej river basin

2.2.6. Sampling Locations

The sampling was carried out along the main river course of the Sutlej. For sampling purpose, a five-kilometer buffer was created in both sides of the main river and within the buffer area sampling points were placed (Figure 2.2). The points were fixed to cover all the four vegetation zones, depending upon accessibility and availability of the area. The vegetation zone broad-leaved hill forest found in low elevation areas such as Koldam, Tatapani, Bakrote, Oogli, Chaba, Sainj, Luhri, Sumej, Brondli, Nogli, Thakledge, Rampur, Arsu, Nirmand, Kotugarh and Ganvi. The sub-tropical pine forest (Rampur, Kut, Jhakri, Jlori Pass, Sorang, Bakrote, Karcham, Bhaba, and Wangtoo) and Himalayan moist forest (Sangla, Reckong Peo, Kalpa, Roogi, Spillow, Bhangi, Pooh, and Khab) found in middle valleys, and Sub-alpine forest found in high elevation areas of Sutlej river (Chitkul, Nako, Tabo, Yangthang, Spiti and Kaza).

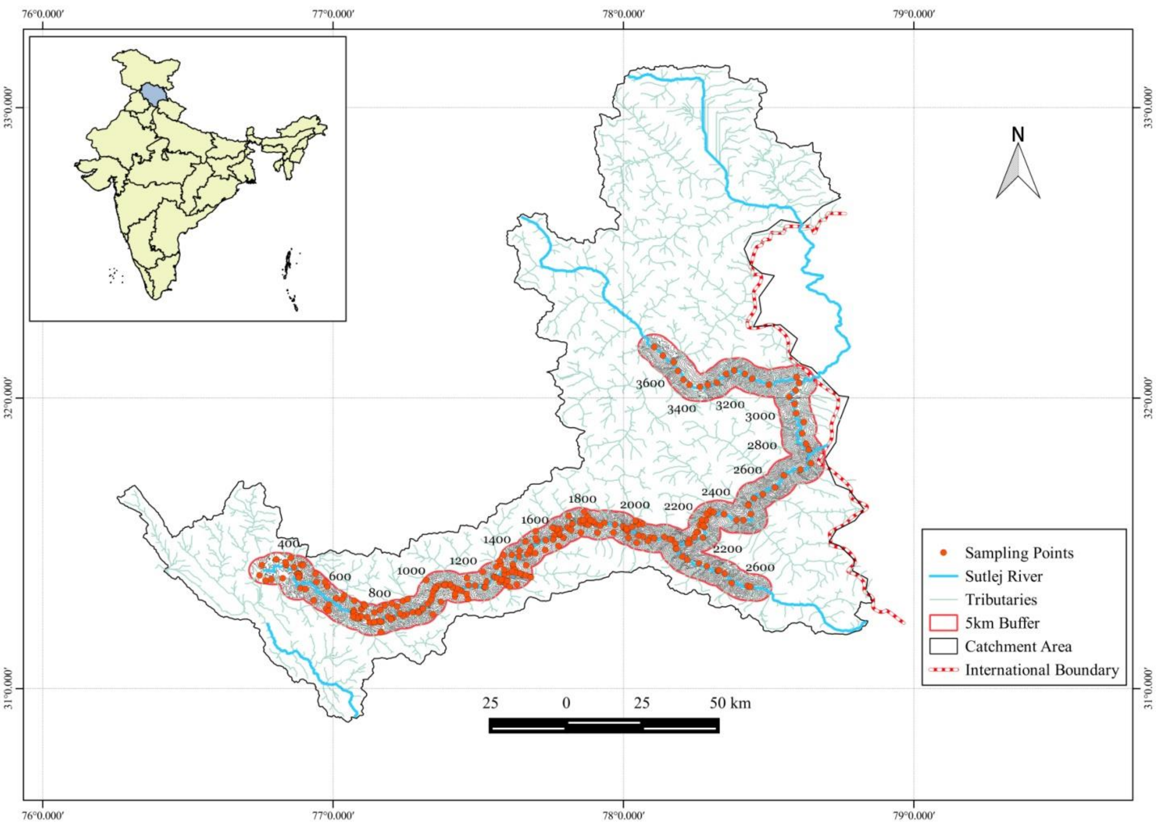


Figure 2.2. Intensive study area of Sutlej river and sampling locations in different elevation

2.3. UTTARAKHAND

Uttarakhand (previously known as Uttaranchal), is the Himalayan state in the northern part of India. It is often, referred to as the “Land of Gods” due to the existence of many Hindu temples and pilgrims (Rahmani & Islam, 2004). The state was carved out from the Uttar Pradesh by separating the hilly mountain region. Uttarakhand is surrounded by Himachal Pradesh in North-West, in North and North-East by Tibet, East by Nepal and Southern region with plains of Uttar Pradesh (Forest Government of Uttarakhand). The region falls under bio-geographic province 2B zone of the Western Himalayas (Rodgers & Panwar, 1988). The state Uttarakhand also includes six National parks, six Wildlife sanctuaries, and 14 IBA sites (Rahmani & Islam, 2004). The major physical features at Western and Eastern boundaries are Tons and Yamuna rivers. Four major rivers flowing through north India originate from the state Uttarakhand, viz., Ganga, Yamuna, Ramganga, and Sharada (Asha *et al*., 2012).

2.3.1. Physiography

Uttarakhand, a hilly state with rich green forests, perennial rivers and varied topography ranging from low lying plains to high alpine glaciers. The state have Garhwal Himalaya in west and east with Kumaon divisions. The Garhwal hills are famous for Hindu pilgrimages such as Badrinath, Kedarnath, Gangotri, and Yamunotri. There are three types of Himalayas in the Garhwal region: Siwalik Hills, the Lesser Himalayas, and the Great Himalayas (Rodgers & Panwar, 1988). Garhwal southern boundary is occupied by **Siwalik hills** with average elevation around 700 m, covered with thick Sal forests in the lower region, Chir-pine at the edge. Khair and Shisham are found along the rivers and streams. **Lesser Himalaya** is the major physical features of Garhwal, south bordered with Dun valley and north by great Himalayan ranges. This Himalayan range is connected with a number of hills, specifically Mussoorie ridge (>2000 m), Nag Tibba ridge (>2500 m), Pauri ridge (> 2000 m), Mayali ridge and Gopeshwar ridge. Vegetation consists of Chir-pine, Oaks, Deodar, Blue-pine, Fir, Spruce, Rhododendron and Sub-alpine. The northern margin of Garhwal is fenced by **Great Himalaya** ranges covered with snow-clad hills with elevation about 6500 m that expand from east to west. Several peaks are there includes Bandarpunch (6315 m), Gangotri (6614 m), Kedarnath (6940 m), Chaukhamba (7138 m), Kamet (7756 m) and significant glaciers are Yamunotri, Gangotri, Bhagirathi, Kamet, and Kathling. Forests consist of Blue-pine, Fir, Spruce, Deodar, Rhododendron, Sub-alpine and Alpine forests (Negi, 1998). Garhwal region drained by Yamuna, Bhagirathi, and Alaknanda river courses.

INTENSIVE STUDY AREA

2.3.2. Yamuna River

The Yamuna river is the largest tributary to the Ganga river, it originates from the Yamunotri glacier near Bander punch peaks in the Mussoorie range of the lower Himalayas with an elevation of about 6320 m above mean sea level in Uttarkashi district of Uttarakhand (Figure 2.3). In upper reaches Rishi Ganga at right bank and Unta and Hanuman Ganga at left bank join the Yamuna river. The lower Himalaya receives water from Kamal, Tons, Giri and Bata on its right bank and left bank receives through Aglar and Asan river tributaries. Among all these tributaries Tons is the most important tributary. Having a diverse range of elevation (370 to 6387 m), climate (Temperate to Tropical), and vegetation (high alpine areas to sub-tropical and tropical regions) makes the Yamuna river an ideal place to study bird distribution patterns across a gradient of elevation.

2.3.3. Climate

Climatic features in Yamuna river basin vary widely due to geographical location and elevation, lower region prevailing with tropical and the temperate at higher elevations, while arctic and sub-arctic conditions experienced in areas near snowline. The Southwest monsoon normally sets around late June and withdraws by the end of September. The river Tons climate is typical Himalayan, with medium rainfall during monsoon at lower elevations and extreme cold and snow at upper reaches during winter months. At higher elevations, snow is the most common form of precipitation, with a permanent snowline at elevations over 5000 meters.

2.3.3.1. Precipitation and Temperature

The precipitation on Yamuna river basin at higher elevation is mostly in the form of snow and most of the alpine region remains under snow throughout the year, while lower region receives rainfall. The Yamuna river basin receives maximum snowfall from the month of January and February (Panwar & Singh, 2014). Rainfall is heavy from June to September, and the annual rainfall is 1735.4 mm (IMD, 2013), about 85% of the annual rainfall is received during the monsoon period (Ranade *et al*., 2007). Temperature varied from freezing to above normal, the minimum temperature 2.6ºC and maximum 43.1ºC during winter and summer respectively (IMD, 2012).

2.3.4. Vegetation

Uttarakhand harbours a wide variety of flora. Floristically the state falls under the west Himalayan biogeography zone with an estimated 4000 species of flowering plants and more than 225 species of Orchids (Uttarakhand Forest Department, 2017). The natural vegetation of the state broadly classified in to four major zones such as, Tropical and sub-tropical forest (below 1800 m elevation), Temperate forest (1500 - 3300 m), Sub-alpine (2500 - 3500 m) and Alpine pasture and scrub (above 3500 m) (Champion & Seth, 1968; Raza, 2006).

Sub-tropical forest

The well-mixed forests, dominated with tree species including *Toona ciliate*, *Mallotus philippensis*, *Pinus roxburgii*, *Quercus leucotricophora*, *Rhododendron arboreum*, *Prunus cerasoides*, *Aesculus indica*, and shrubby habitat by *Colebrookia oppositifolia*, *Pyracantha crenulata*, and *Zizyphus mauritiana*.

Temperate forest

The major trees are *Quercus leucotrichophora*, *Q. semicarpifolia*, *Q. dilatata*, *Cadres deodar*, *Juglans regia*, *Abides windrow*, *Corylus jacquemontii*, *Acer caesium*, *Meliosma dilleniaefolia*, *Taxus baccata*, *Thamnocalamus spathiflora*, and *Rhododendron arboreum*. The main shrub species are *Viburnum continifolium*, *Berberis* sp., and *Hippophae rhamnoides*.

Subalpine forest

The important tree species include *Pinus wallichiana*, *Abies pindrow*, *Prunus cornuta*, *Aber caesium*, *Taxus wallichiana*, *Quercus semecarpifolia*, *Rhododendron campanulatum*, and *Betula utilis*. The common shrubs are *Cotoneaster* sp., *Berberis* sp., and *Rosa webbiana*. Herbaceous species include *Delphinium* sp., *Swertia* sp., and *Pedicularis* sp.

Alpine pasture and scrub

This habitat is observed above the treeline, alpine comprise of *Rhododendron campanulatum* and herbaceous species such as *Cyanthus* sp., *Rannunculus* sp., *Gentiana* sp., *Danthonia* sp., *Potentilla* sp., *Geranium* sp., *Rhododendron barbatum*. The dwarf shrubs are *Eurotia* sp., *Juniperus* sp., *Lonicera* sp., and the medicinal plants such as *Picrorhiza* sp., *Nardostachys grandiflora* are commonly seen.

2.3.5. Wildlife

Owing to the rich biodiversity of the state, 12% of the geographical area has been declared as a protected area network (7,765.49 km^2). In addition, the state is also ecologically important because of multiple reasons. The state has areas falling under biographic zone 2B Western Himalaya, 7B Shiwaliks, Global Biodiversity Hotspot (Mittermeier *et al*., 2005; Chitale *et al*., 2015), Endemic Bird Area (Stattersfield *et al*., 1998), Important Bird and Biodiversity Area (Rahmani & Islam, 2004) and UNESCO world heritage site. For conserving the biodiversity, the state forest department has established National Parks, Wildlife Sanctuaries and Conservation Reserves (Uttarakhand Forest Department, 2017).

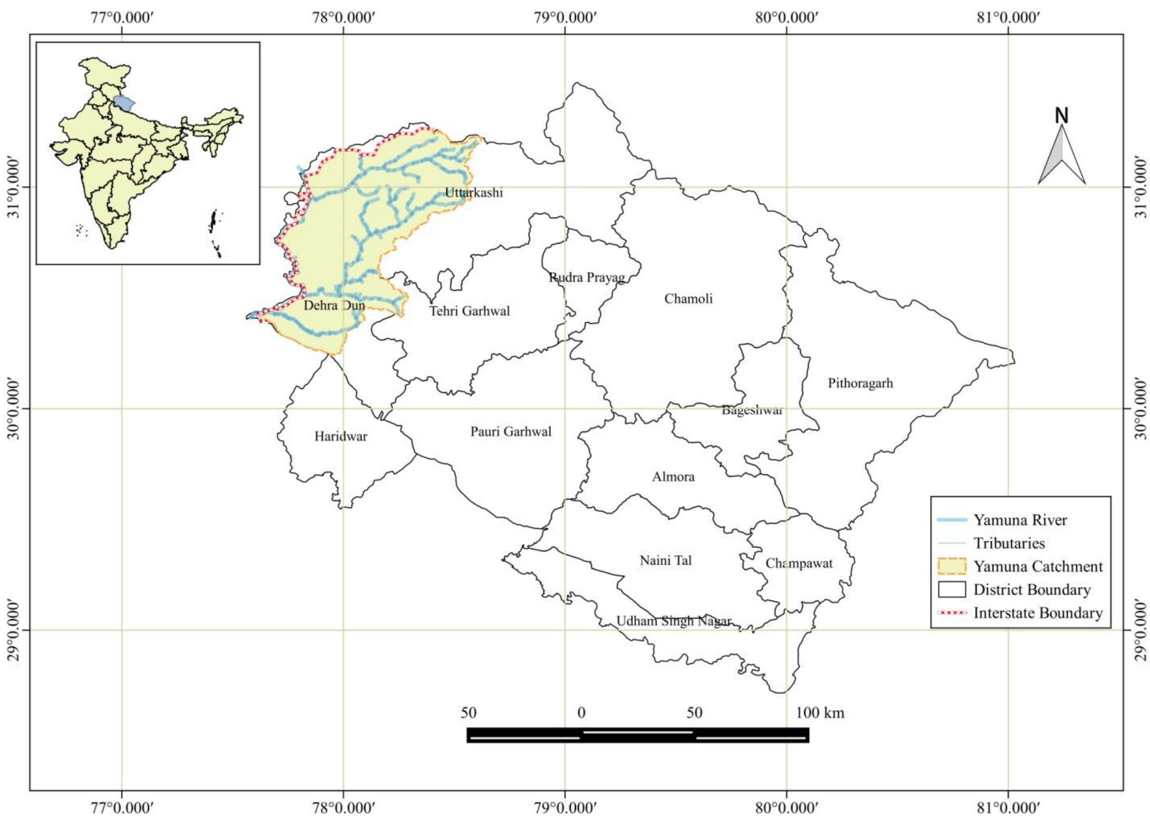


Figure 2.3. Map of Uttarakhand showing the Yamuna river basin

Many scientific studies have been conducted in various parts of the state. It is estimated that there are around 5,096 species of Angiosperms and Gymnosperms, 3382 invertebrates excluding 567 lepidopteron species (ENVIS, 2013) and vertebrates including 124 fishes, 19 amphibians, 70 reptiles, 600 birds and 102 mammals (Uttarakhand Forest Department, 2017). Apart from the above list, specific faunal studies by several authors (Osmaston, 1935; Rattray, 1987; Waltner, 1991; Mohan, 1992, Singh, 2000; Rahmani & Islam, 2004; Gupta, 2004; Kumar *et al*., 2004; Vasudevan & Sondhi, 2010; Bhardwaj *et al*., 2012; Joshi & Rautela, 2014) and floral studies were performed (Marten, 1909; Nayar, 1964; Kala, 2007; Jalal & Rawat, 2009; Bartwal *et al*., 2011; Tiwari *et al*., 2012; Alam, 2013; and Rawat, 2014) along the Yamuna river basin, Uttarakhand.

2.3.6. Sampling Locations

The sampling was carried out along the main river course of the Yamuna. Both sides of the Yamuna river five-kilometer buffer fixed and within those sampling points were established (Figure 2.4). The sampling points established based on characteristics of vegetation type and elevation, into three zones, depending upon accessibility and availability of the area. The vegetation zone Tropical deciduous forest found in low elevation areas such as Kulhal, Dhalipur, Dhakrani, Khodri, Chibro, Amlawa, Kishau, Vyasi, Lakhwar, Galogi, Purkul, Ringali, Bhadri Gad, Barnigad and Naingaon. Sub-tropical pine forest found in middle elevation (Langrasu, Sauli Barnigad, Riknal Gad, Garsad Gad, Ringali, Rayat, Tiuni, Hanol, Arakot, Mori Hanol, Naitwar Mori, Koti, Rupin, Kuthnaur, Syanachatti and Ranachatti), and Himalayan temperate forest found in high elevation areas (Jakhol, Sankri, Taluka, Hanuman Ganga, Janki Chatti and Yamunotri).

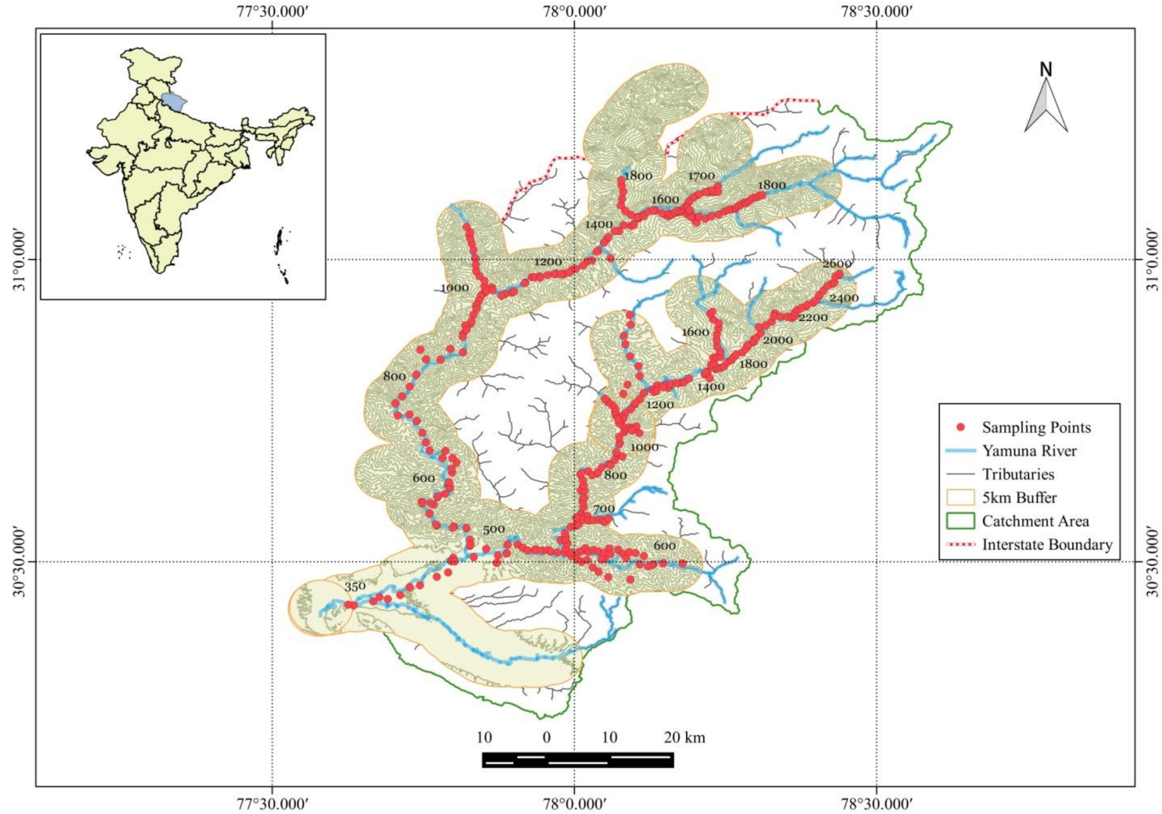


Figure 2.4. Intensive study area of Yamuna river and sampling locations in different elevation

Chapter 3

CHAPTER 3

PATTERNS OF BIRD SPECIES DIVERSITY IN SUTLEJ AND YAMUNA RIVER BASINS

3.1. INTRODUCTION

Avian community assessment has become a powerful monitoring tool in biodiversity conservation (Jayson & Mathew, 2000; Chettri *et al*., 2001). The term community refers to the group of organisms occurring together in a given area and interacting with each other (Odum, 1996; Begon *et al*., 2006). Historically, an obvious way to describe community compositions has been the diversity in terms of the species number and abundance (Pavoine & Bonsall, 2011). Several biotic and abiotic factors have been known to influence the abundance and distribution pattern of species varying at different temporal and spatial scales (Tokeshi, 1999).

Many studies have been conducted on the associations of the community structure of birds in different parts of the world (Wiens & Rotenberry, 1981; Welsh and Lougheed, 1996; Monkkonen *et al*., 1997; Renner *et al*., 2006; Albright *et al*., 2010; Kolecek *et al*., 2010; Sweeney *et al*., 2010; Brummelhaus *et al*., 2012; Kidwai *et al*., 2013; Pastur *et al*., 2015). The majority of studies have been conducted in temperate regions, and little quantitative information is available on bird community structure in tropical areas (Terborgh *et al*., 1990; Petit & Petit, 2003; Blake, 2007; Jankowski *et al*., 2012).

The species richness, diversity and composition of bird communities vary from region to region (Pearson, 1975; Karr, 1976), as well as from habitat to habitat within the same region (Blake & Loiselle, 2000; Blake, 2007; Das, 2008; Naithani & Bhatt, 2012). Several studies have identified the factors responsible for variations in bird distribution patterns and species diversity across regions and habitats (Orians & Wittenberger, 1991; Rahbek, 1997; Colwell & Lees, 2000; Lee *et al*., 2004; Hawkins *et al*., 2007; Rowe, 2009; Sanders & Rahbek, 2012; Graham *et al*., 2014; Dixit *et al*., 2016).

Measuring species richness is an essential objective for ecologists and conservation biologists. The number of species in a local assemblage is an instinctive and natural index of community structure, and patterns of species richness have been measured at both small and large spatial scales (Blake & Loiselle, 2000). This biotic community differs in species richness and their abundance forming definite pattern across habitats or elevation zones (Wiens, 1989). In ecology and conservation biology the number of species that remain in a community represents the ultimate scorecard in the fight to preserve and restore disturbed communities (Gotelli & Colwell, 2011).

The seasonal changes are an additional prominent characteristic of mountain ecosystems that can influence the temporal and spatial variations of bird species richness and composition (Stevens, 1992; Blake & Loiselle, 2000). The bird communities in mountain environments are sensitive to the seasonal variation in climate, resource bottlenecks for available food and water resources, productivity and habitat quality (Blake, 1984; Loiselle & Blake, 1991; Shoo, 2005; Renner *et al*., 2012; Girma *et al*., 2017). The species diversity and abundance reaches peaks when food resources such as insect, fruit and nectar become abundant (Levey, 1988; Loiselle & Blake, 1991; Blake & Loiselle, 2000; Renner *et al*., 2012). The extent of seasonal fluctuations of birds among different habitats is caused by movements of birds within and between habitats due to seasonal variations in biological and environmental factors (Poulin *et al*., 1993; Acharya, 2008).

A 'guild' is defined as a group of species that exploit the same class of environmental resources in a similar way (Simberloff & Dayan, 1991). Food is a potential source for seasonal fluctuations in activity patterns and elevational movements of bird species (Loiselle & Blake, 1991). Feeding habits reflect the importance of various food resources within a community and variation in trophic structure may reflect variation in the availability of food resources among bird communities (Blake, 1984). Productivity influences the abundance of food for bird populations and as such has an influence on the seasonality of various important life-history traits such as breeding and migration (Girma *et al*., 2017). The fluctuations in resource abundance are therefore likely to have a strong impact on bird populations (Blake, 1984).

Due to the threat of extinction hanging over a significant portion of the earth's biota (Wijesinghe & Brooke, 2004), endemics with small geographical ranges and threatened species with low populations face a greater risk (Stattersfield *et al*., 1998; Lei *et al*., 2003). Hence these species draw considerable attention from the ecologists and conservationists compared to the common widespread species. The endemic and threatened species are more sensitive to disturbance and invite immediate conservation concern (Brooks *et al*., 1997; Lei *et al*., 2003; Pandit *et al*., 2007). Information on status and distribution of endemic and threatened species consequently helps in the prediction of disturbance level and implementation of conservation effort at all potential sites of their occurrence (Stattersfield *et al*., 1998; Robin & Sukumar, 2002).

The Western Himalaya, which includes Himachal Pradesh and Uttarakhand, is one among globally recognized endemic bird areas and is global biodiversity hotspot (Peart, 1997; Rahmani & Islam, 2004). The systematic studies on birds of Western Himalaya started during 19th century (Shah *et al*., 2016) and most of the studies covered taxonomy, distribution and natural history (Whistler, 1925; Jones, 1947; Wynter-Blyth, 1951; Ali and Ripley, 1983). However, understanding of the ecological information at the community level was largely ignored and has gained considerable attention during recent years. Among the available literature, most of the studies are focused on documentation of bird communities in particular sites of Himalaya (Safiq *et al*., 1997; Sultana and Khan, 1999, 2000; Price *et al*., 2003; Sultana *et al*., 2007). However, information on bird community structure such as the species richness, diversity and the composition within the elevation gradient of Sutlej and Yamuna river basins are incomplete. The primary reason for bird community study is to understand the bird species richness, diversity and composition, as it provides baseline information as to how bird species are distributed over the landscape.

The purpose of this chapter is to provide an overview of how bird communities are composed, including species richness, diversity, evenness, family composition and relative abundance in four vegetation zones located at different elevations along the Sutlej river basin in Himachal Pradesh and three vegetation zones located along the Yamuna river basin in Uttarakhand. In addition, seasonal variation, trophic diversity and IUCN status of the bird species in the study area have been explored.

3.2. METHODS

Data Collection

Similar methods were followed for data collection and analysis for both Sutlej and Yamuna river basins.

For sampling purposes, study areas were divided into four zones in Sutlej river basin according to elevation and vegetation type: zone I (Sub-tropical broad-leaved hill forest, 400-1200 m), zone II (Sub-tropical pine forest, 1200-1800 m), zone III (Himalayan moist forest, 1800-3000 m), and zone IV (Sub-alpine vegetation, 3000-3600 m), and three zones in Yamuna river basin, zone I (Tropical deciduous forest, 300-1200 m), zone II (Sub-tropical pine forest, 1200-1800 m) and zone III (Himalayan temperate forest, 1800-2600 m). The zone-wise details of Sutlej and Yamuna rivers, such as major vegetation, area availability and number of sampling points are given in the table 3.

Table 3 Zone-wise major vegetation, area availability and number of sampling points in Sutlej and Yamuna River

Zones	Major Vegetation	Area Availability (sq.km)	Number of Sampling Points
Sutlej I	*Acacia catechu, Butea monosperma, Lannea coromandelica*	783	133
II	*Pinus roxburghii, Carissa sp., Dodonaea sp.,*	534	85
III	*Pinus gerardiana, Cedrus deodara, Quercus sp., Rhododendron arboreum, Plectranthus rugosus, Pinus wallichiana*	687	77
IV	*Lonicera obovata, Rhododendron anthopogon, Sorbus foliolosa, Myricaria sp., Hippophae sp.,*	467	23
Yamuna I	*Toona ciliate, Mallotus philippensis, Prunus cerasoides, Aesculus indica*	1153	216
II	*Pinus roxburgii, Quercus leucotricophora, Rhododendron arboreum*	1094	144
III	*Quercus leucotrichophora, Q. semicarpifolia, Q. dilatata, Cadres deodar, Juglans regia, Abides windrow, Corylus jacquemontii, Acer caesium, Meliosma dilleniaefolia, Taxus baccata, Thamnocalamus spathiflora*	814	69

3.2.1. Bird Surveys

The study was conducted in the Sutlej river basin in Himachal Pradesh between June 2012 and April 2013, and Yamuna river basin in Uttarakhand between September 2013 and June 2014. The field surveys were conducted between 498 to 3,700 m asl in Sutlej and 378 m to 2,600 m asl in Yamuna river basin.

Three hundred and eighteen (318) and four hundred and twenty-nine (429) permanent sampling points were laid in the Sutlej and Yamuna river basins, respectively. The points were sampled four times a year, in the summer, monsoon, post monsoon and in the winter. The study area was sampled throughout all the seasons, but heavy snowfall prevented Sutlej zone IV and Yamuna zone III from being sampled during winter. There were 1,239 data points collected in the Sutlej river basin and 1,578 data points in the Yamuna river basin during the study period.

An analysis of the bird abundance and richness along elevational gradients was conducted in both Sutlej and Yamuna river basins using point count methods (Gaston, 1975; Bibby *et al*., 2000). The point count method has been widely used for the study of bird communities, particularly useful when surveying very large areas (Sorace *et al*., 2000; Robinson *et al*., 2000; Raman *et al*., 2005). The minimum distance between consecutive points was maintained at 1 km. All birds observed within the fixed radial distance of 50 m were recorded during 10 minute (Ralph *et al*., 1993; Raman, 2003) intervals. The number of individuals and species were recorded based on both direct observations as well as indirect observations. The sampling was avoided in inaccessible areas and at point count stations with evidence of human settlement. The surveys were carried out 30 minutes after dawn and 30 minutes before sunset on days with suitable weather conditions for bird activity. Generally the point counts were conducted from 0600 to 1100 hours in the morning and from 1500 to 1800 hours in the evening. The average species richness of sampling replications has been used for analyses. The migratory status and taxonomic system of birds used in this study followed Grimmett, *et al*. (2011).

3.2.2. Data Analysis

Analyses were done using statistical software packages namely SPSS version 17.0, PAST version 2.17, EstimateS version 9.1.0 and Microsoft Excel for windows.

(1) Bird species richness was measured as the cumulative number of species.

(2) Abundance was estimated as the number of individual birds per point.

(3) Species richness was estimated using non-parametric statistical software EstimateS version 9.1.0 (Colwell, 2016). The sample order was randomized 100 times without replacement. Randomizations of sample order were done to eliminate the arbitrariness in species accumulation that occurs due to sampling error or real heterogeneity (Colwell & Coddington, 1994).

i. Rarefaction richness, standardizing for sampling effort using Coleman rarefaction curves (Colwell, 2016). Rarefaction estimation assumes that all individuals in the community are randomly distributed among samples and is used to sample a large community (Krebs, 1989).

ii. Non-parametric estimators of EstimateS is based on the mark-recapture model provide robust estimates (Colwell & Coddington, 1994). The Chao 1, Chao 2 and Jackknife 1 are non-parametric estimators, wherein the Chao 1 estimator calculates the true number of species in an assemblage based on the number of rare species in the sample. The estimator based on the distribution of individuals among species with singletons (species with only one individual) or doubletons (species with only two individuals). The Chao 2 estimator is based on the distribution of species among samples and requires only presence-absence data (Colwell & Coddington, 1994).

iii. The Jackknife 1 estimator is based on the number of unique detections (i.e. the number of species detected in one sample) in the samples and extrapolates without bias (Colwell & Coddington, 1994).

A complete inventory of species richness at a given place for a specific community is often hard to get (Krebs, 1989; Hortal *et al*., 2006). Estimators are needed to provide a clear picture of species richness patterns. The estimators Chao 1, Chao 2 and Jackknife 1 were preferred because these estimators are less sensitive to the patchiness of species distribution, variability in the probability of finding species (Hortal *et al*., 2006).

Since the estimators have their own bias and precision, among the non-parametric estimators Chao and Jackknife estimators perform better than other estimators (Walther & Moore, 2005).

(4) Shannon diversity, calculated as $-\sum(pi \ln pi)$, where *pi* is the proportion of the i^{th} species. **ln** is the natural logarithm and summation is across all species in the pooled samples.

(5) Evenness, calculated as (E) = H'/ln *S*, where H' is the Shannon Index and *S* is the number of species observed.

(6) Relative abundance, calculated as (%) = $(n_i /N)\times100$, where n_i is the number of individuals of i^{th} species and N is the total number of individuals of all species.

The species richness, abundance, diversity, and evenness of birds were calculated for the entire study area along all the elevation zones and seasons. The estimation of species using non-parametric estimators and species accumulation curve was obtained for all the elevation zones of Sutlej and Yamuna river basin. The species richness, diversity, relative abundance and seasonal variation of bird species thus obtained were compared among zones. In addition to that, the data were also analyzed for the composition of the families. Statistical significance of species richness between elevation zones during different seasons was assessed using repeated measure ANOVA.

As per Ali and Ripley (1983), bird species could be divided into eight trophically distinct groups based on their major diets, which are insectivores, carnivores, omnivores, granivores, frugivores, scavengers, piscivores, and nectarivores. Instead of looking at the broad pattern, it was thought to be interesting to examine its dietary component to see whether they all respond similarly to the gradient (Terborgh, 1977).

The occurrence of threatened species obtained was compared among elevation zones, to find out the threatened species distribution.

3.3. RESULTS

3.3.1. Species Richness

Altogether 241 species of birds belonging to 59 families were recorded during the present study from both Sutlej and Yamuna river basins. A total of 203 species have been recorded from the Sutlej river basin belonging to 57 families and 135 genera (Appendix I), while 179 species have been recorded from the Yamuna river basin belonging to 51 families and 119 genera (Appendix II). Sixty-two and 38 species are unique to the Sutlej and Yamuna river basins, respectively. Remaining 141 species out of the total 241 species were found common to both the basin areas. A total of 37,926 individual birds from Sutlej and 32,586 individual birds from the Yamuna river basin were recorded during the study. Of all the birds recorded, 147 bird species were residents and 56 were non-residents in Sutlej, likewise in Yamuna 126 were residents and 53 were non-residents.

The bird species richness in different vegetation zones of Sutlej and Yamuna river basin varied from 39 to 168 (Table 3.1a) and 72 to 162 (Table 3.1b) respectively. The highest numbers of species were observed in the lower elevation (zone I) in both Sutlej and Yamuna river basins, and the lowest number in highest elevation (zone IV in Sutlej and zone III in the Yamuna). The estimation of species accumulation curve (sample-based rarefaction curve) showed a plateau for all the elevation zones in both Sutlej and Yamuna river basin (Figure 3.1a). The rarefaction curves are used to compare the species richness of the different vegetation zones with continuous sampling effort at each location (Colwell *et al*., 2004). The rarefaction curves of birds in all the zones of Sutlej and Yamuna river basin showed that higher number of species was observed in the zone I than other zones (Figure 3.1a&b).

The non-parametric species richness estimators (Chao1, Chao2, and Jackknife1) also showed the highest value in the zone I compared to other higher zones (i.e. zones II, III and IV of Sutlej (Table 3.1a), and zones II and III of Yamuna river basin (Table 3.1b)). Among the three estimators, Jackknife1 estimated the maximum number of species in zones I and III of Sutlej, and II and III of Yamuna river basin. Whereas, Chao2 estimated the higher number of species in zones II and IV of Sutlej, but in the Yamuna river basin, both Chao2 and Jackknife1 contributed the same value in the zone I (Table 3.1b). However, the standard deviation of Jackknife1 was lower than Chao2 in all the elevational zones. The estimator Chao1 showed comparatively less number of species in all the zones of Sutlej and Yamuna river basin (Table 3.1a & b).

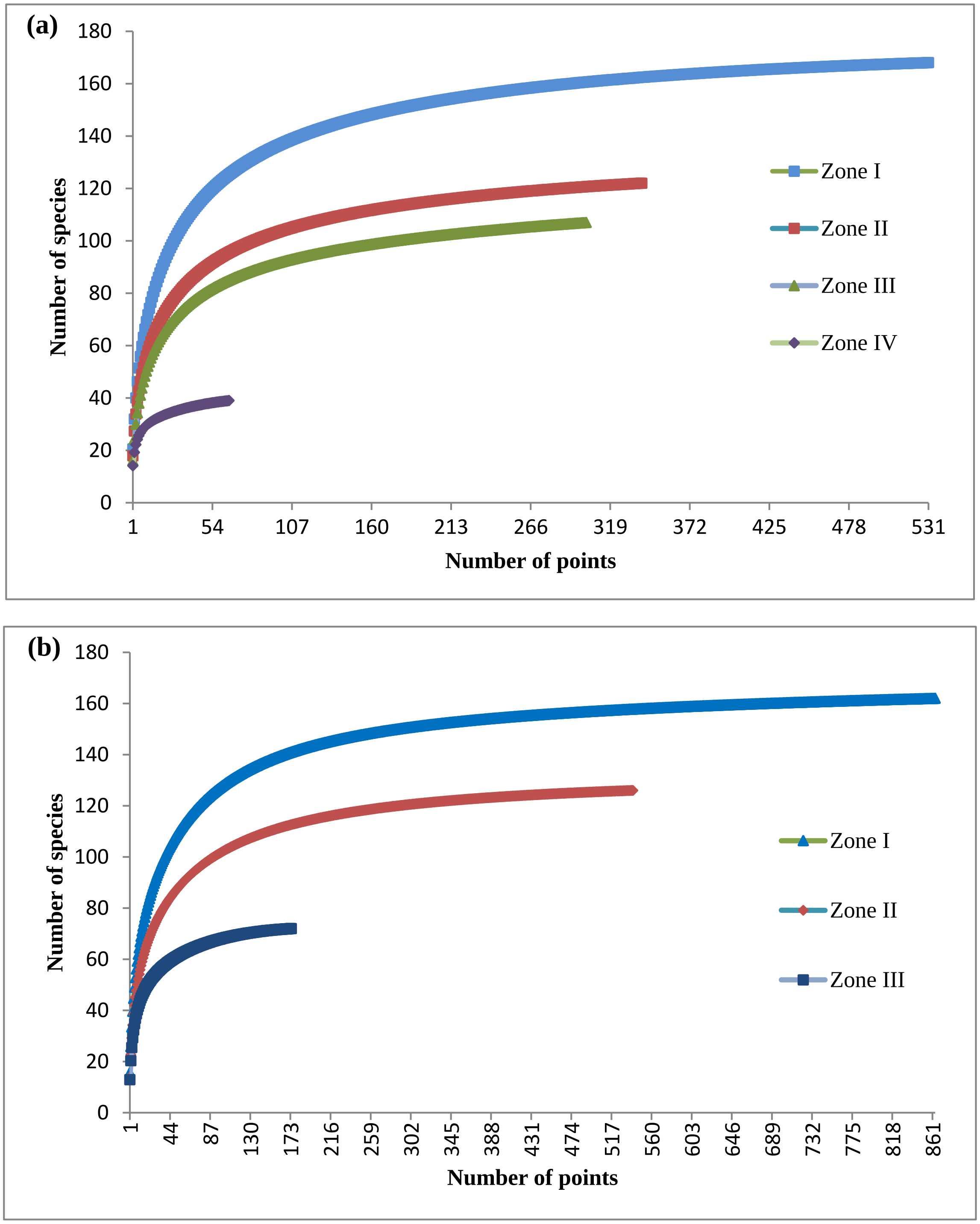


Figure 3.1 Species rarefaction curves of birds, based on the number of point counts estimated from four elevational zones in the Sutlej (a) and three elevation zones in the Yamuna (b) river basin.

Table 3.1a Observed and estimated (Chao1, Chao2, and Jackknife1) bird species richness in four elevational zones of the Sutlej river basin, Himachal Pradesh

Zones	Observed species	Chao 1±SD	Chao 2± SD	Jackknife 1± SD
I	168	172.55±3.83	193.94±12.92	195.79±7.98
II	122	127.5±4.39	159.06±18.29	151.65±6.84
III	107	115±6.04	132.79±12.85	134.64±6.42
IV	39	40.6±2.16	48.68±8.65	47.61±3.59

Table 3.1b Observed and estimated (Chao1, Chao2, and Jackknife1) species richness in three elevational zones of the Yamuna river basin, Uttarakhand

Zones	Observed species	Chao 1±SD	Chao 2± SD	Jackknife 1± SD
I	162	167.33±4.93	185.89±12.91	185.89±8.19
II	126	129.06±3.1	135.78±6.41	141.89±4.48
III	72	73±1.46	86.51±8.97	89.74±5.55

3.3.2. Species Diversity and Evenness

The Species diversity and evenness estimates for the birds of Sutlej and Yamuna river basin are given in Table 3.2a&b. The Shannon diversity and evenness of birds for pooled samples from all the elevation zones of Sutlej was 3.85 and 0.23, and that of Yamuna was 3.90 and 0.28. The diversity values ranged between 3.73 for zone I and 2.89 for zone IV in Sutlej, and 3.85 for zone I and 3.41 for zone III in Yamuna river basins. The evenness was higher in zone IV (0.46) and low in the zone I (0.25) of Sutlej, and in the Yamuna, it was high in zone III (0.42) and low in the zone I (0.29). The results indicated that species diversity considerably less in high elevations namely, zone IV of Sutlej and zone III of Yamuna, but evenness showed a comparatively higher value in these zones.

Table 3.2a Results of Shannon diversity (H') and Evenness (E) of birds from different elevational zones, Sutlej river basin.

Zones	No. of points sampled	Shannon Diversity (H')	Evenness (E)
I	531	3.73	0.25
II	340	3.58	0.29
III	303	3.41	0.28
IV	65	2.89	0.46
Total	1239	3.85	0.23

Table 3.2b Results of Shannon diversity (H') and Evenness (E) of birds from different elevational zones, Yamuna river basin.

Zones	No. of points sampled	Shannon Diversity (H')	Evenness (E)
I	864	3.85	0.29
II	540	3.67	0.31
III	174	3.41	0.42
Total	1578	3.90	0.28

3.3.3. Family Composition

A total of 59 bird families were recorded among all the elevational zones of both Sutlej and Yamuna river basin. Fifty-seven families solely represented the Sutlej river basin, and 51 families in Yamuna river basin. Muscicapidae (23 species) topped the list of the most diverse families in the Sutlej river basin, followed by Accipitridae (13 species), Corvidae and Timaliidae (10 species each), while 19 families had only one species, and 11 families had two species (Figure 3.2a). A similar pattern was observed in the Yamuna basin with Muscicapidae dominating (18 species), followed by Accipitridae, Anatidae, and Timaliidae (each nine species). In addition, 14 families were represented by one species each and 11 families had two species each (Figure 3.2b).

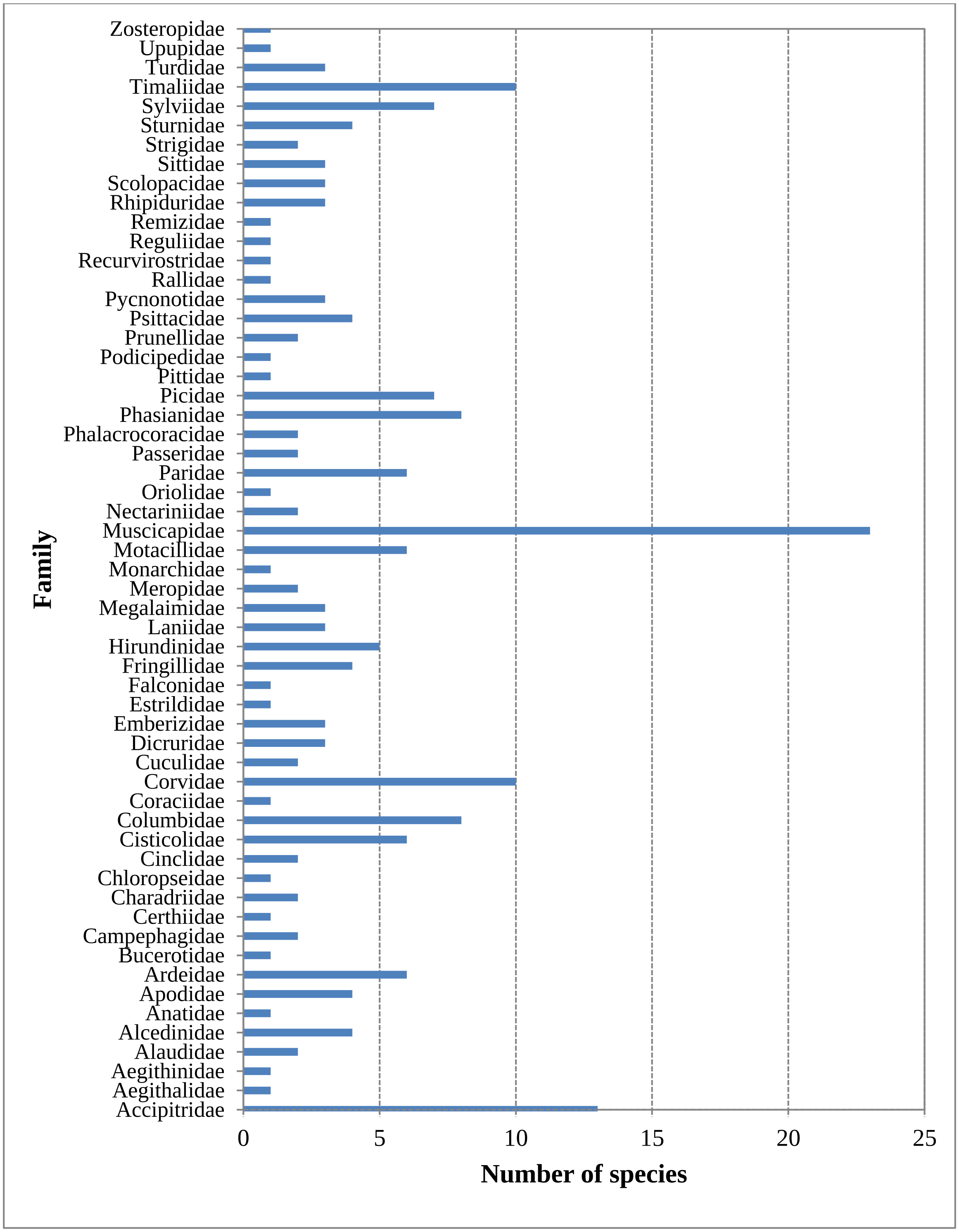


Figure 3.2a Family wise species representations of birds in Sutlej river basin, Himachal Pradesh

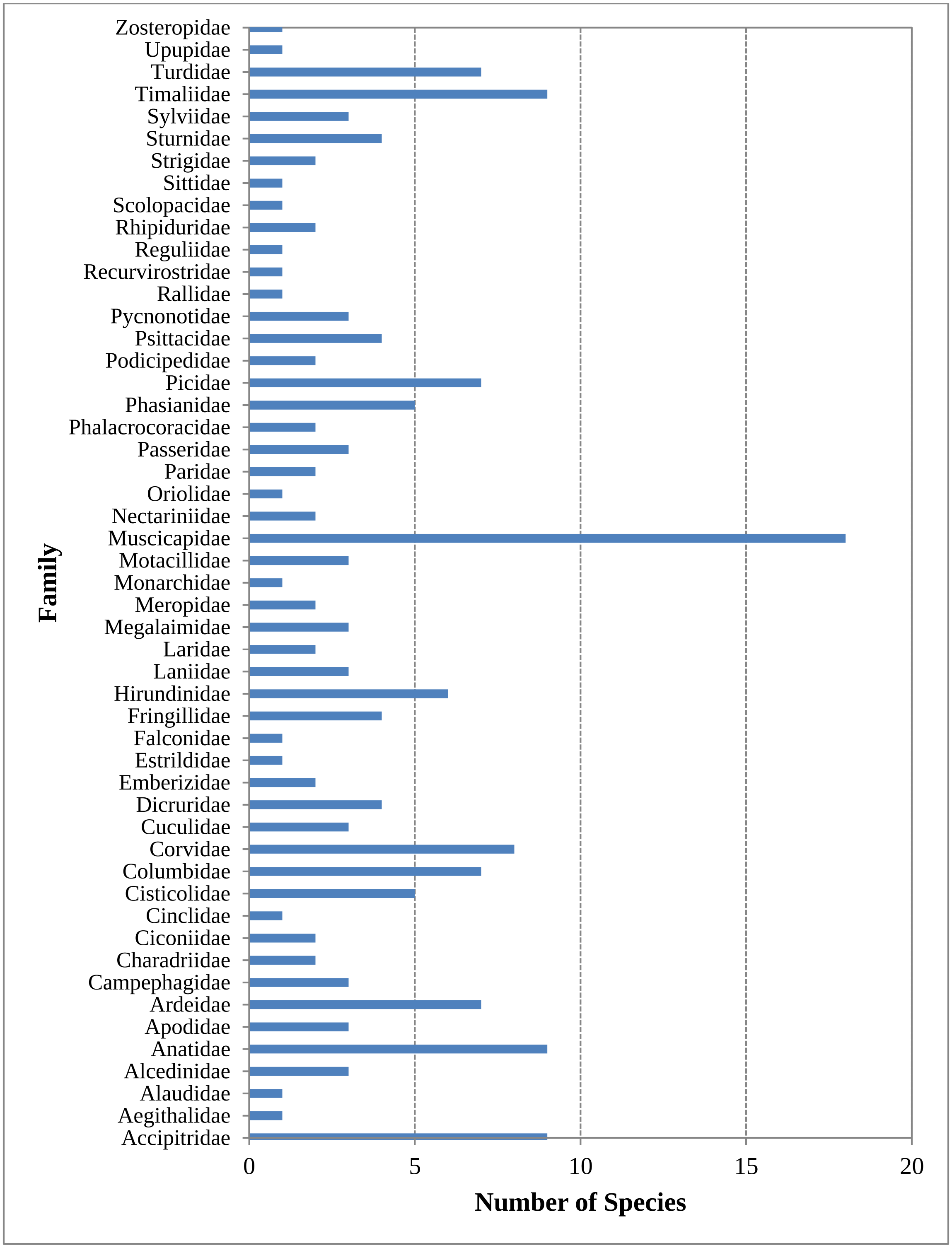


Figure 3.2b Family wise species representations of birds in Yamuna river basin, Uttarakhand

3.3.4. Relative Abundance

There are 13 (representing 58% of total records) species of birds from Sutlej river basin and 15 (56% of total records) species of birds from Yamuna river basin that are relatively abundant (Table 3.3a&b). Most of the species observed during sampling showed very low relative abundance (< 1%). Among the species records, around 32% (65 species) of Sutlej and 24% (43 species) of Yamuna river basin had less than 10 individuals recorded. This included 13 singletons (species having only one individual sighting) and 15 doubletons (species having two individuals) for Sutlej and five species each of singletons and doubletons for Yamuna river basin. The three most abundant species recorded from the study area (Sutlej and Yamuna river basins combined) were Himalayan Bulbul (12.68% and 15.45% respectively for Sutlej and Yamuna), Large-billed Crow (10.48% and 7.44%) and House Sparrow (5.81% and 5.37%) respectively (Table 3.3a&b).

Table 3.3a Relative abundance of thirteen most abundant bird species in different elevation zones of Sutlej river basin, Himachal Pradesh

S. No.	Species	Zone I (%)	Zone II (%)	Zone III (%)	Zone IV (%)	Overall (%)
1	Himalayan Bulbul	17.06	13.66	5.05	-	12.68
2	Large-billed Crow	8.07	10.35	16.66	7.05	10.48
3	House Sparrow	3.80	7.35	6.67	12.74	5.81
4	Rock Dove	2.78	4.09	6.64	4.43	4.05
5	Common Myna	5.27	3.26	1.09	-	3.56
6	Fire-fronted Serin	0.35	2.72	9.81	6.29	3.33
7	Streaked Laughingthrush	1.95	4.19	4.74	2.57	3.17
8	Red-vented Bulbul	5.03	2.38	0.43	-	3.08
9	Blue Whistling-thrush	2.46	4.09	3.25	0.40	2.95
10	Plumbeous Water-redstart	2.77	3.28	2.38	-	2.68
11	Slaty-headed Parakeet	2.71	2.85	0.61	-	2.15
12	Oriental White-eye	2.80	2.33	0.47	-	2.03
13	Himalayan Griffon	0.70	3.51	3.35	0.91	2.02

The relative abundance of bird species varied among elevational zones. In both Sutlej and Yamuna river basin, Himalayan Bulbul (Zone I, 17.06% and 17.04%; Zone II, 13.66% and 15.44% Sutlej and Yamuna respectively) were found as the most abundant species in zone I and II respectively and followed by Large-billed Crow (Zone I, 8.07% and 5.35%; Zone II, 10.35% and 8.46% Table 3.3a&b). Similarly, Large-billed Crow (16.66%) and Fire-fronted Serin (9.81%) were most abundant in zone III of Sutlej, and Large-billed Crow (16.12%) and House Sparrow (8.26%) of Yamuna river basin. Species such as Yellow-billed Chough (14.35%), House Sparrow (12.74%), Hill Pigeon (11.83%), Snow Pigeon (8.91%), Large-billed Crow (7.05%) and Fire-fronted Serin (6.29%) were most abundant species in zone IV of Sutlej (species such as Yellow-billed Chough, Hill Pigeon, and Snow Pigeon are not shown in table due to their low relative abundance in zone I, II and III). In addition out of 13 abundant species of Sutlej, seven abundant species recorded from each of the four zones separately as well as combined for all zones (Table 3.3a); whereas in the Yamuna, all 15 abundant species were recorded from all the zones (Table 3.3b). Interestingly one species, the Himalayan Griffon, globally near-threatened species was relatively the most abundant species in both Sutlej (2.02%) and Yamuna (1.60%) river basin (Table 3.3a&b).

Table 3.3b Relative abundance of fifteen most abundant bird species in different elevation zones of Yamuna river basin, Uttarakhand

S. No	Species	Zone I (%)	Zone II (%)	Zone III (%)	Overall (%)
1	Himalayan Bulbul	17.04	15.44	6.36	15.45
2	Large-billed Crow	5.35	8.46	16.12	7.44
3	House Sparrow	3.40	7.97	8.26	5.37
4	Red-vented Bulbul	4.37	2.44	0.28	3.33
5	Oriental White-eye	2.94	3.40	2.97	3.09
6	Plumbeous Water-redstart	2.61	3.32	4.56	3.04
7	Blue Whistling-thrush	2.34	3.38	5.57	3.00
8	Pied Bushchat	3.05	2.34	1.83	2.69
9	Great Tit	1.96	2.72	1.35	2.15

S. No	Species	Zone I (%)	Zone II (%)	Zone III (%)	Overall (%)
10	Common Myna	1.73	2.67	1.16	1.98
11	Streaked Laughingthrush	1.06	2.35	4.46	1.82
12	Rock Dove	1.77	1.29	3.36	1.77
13	Little Swift	1.99	1.18	2.17	1.75
14	Russet Sparrow	1.52	1.88	2.54	1.74
15	Himalayan Griffon	1.00	2.26	2.87	1.60

3.3.5. Seasonal Variation of Bird Community

The species richness and diversity of the birds varied significantly between seasons (winter, summer, monsoon and post-monsoon), and across different elevation zones of Sutlej and Yamuna river basin (Table 3.4a&b). The overall bird species richness was high during summer with 144 and 138 species recorded from Sutlej and Yamuna river basins respectively. Richness was low during monsoon observed 109 and 84 species respectively in Sutlej and Yamuna. The results of repeated measure ANOVA revealed a significant difference in species richness between seasons (Sutlej, df = 3, $F = 69.67$, $P < 0.000$; Yamuna, df = 3, $F = 23.36$, $P < 0.000$).

Seasonally the bird species richness among elevational zones of Sutlej river basin was maximum during summer and minimum during monsoon in zones I, II, and III. Whereas, in zone IV, maximum species richness was during monsoon and minimum in winter (Table 3.4a). Likewise, in the Yamuna river basin, the bird species richness for zones, I and II were high during summer and low during monsoon and post-monsoon in the zone I and zone II respectively (Table 3.4b). In zone III, the species richness was high during monsoon and low during winter. In addition, both Sutlej and Yamuna river basins, showed maximum species richness in winter at low elevation (zone I) and minimum at high elevations (zone IV and III). Also, the bird species richness was found high at lower (zone I) elevation in both Sutlej and Yamuna river basin (Table 3.4a&b).

Sutlej river basin had highest species diversity in summer (H' = 3.81) and least diversity in monsoon (H' = 3.58) (Table 3.5a), and Yamuna river basin had highest diversity in winter (H' = 3.86) and lowest diversity in monsoon (H' = 3.35) (Table 3.5b).

All four zones of Sutlej observed maximum diversity during summer (Zone I, II, III, and IV). In Yamuna, diversity was maximum during winter in zones I and II, and during monsoon in zone III. The species diversity was lowest in zone IV and III in all the seasons in Sutlej and Yamuna river basin respectively. The Shannon diversity also showed seasonal variation among zones (Table 3.5a&b). The diversity was the highest in zone I during winter (H' = 3.56 and H' = 3.71 in Sutlej and Yamuna respectively), followed by summer (H' = 3.59 and H' = 3.64), monsoon (H' = 3.59 and H' = 3.29) and post-monsoon (H' = 3.47 and H' = 3.37). The Evenness was high during monsoon (0.42) in the zone I, during winter in zones II (0.43) and III (0.44), and during summer (0.62) in zone IV of Sutlej river basin (Table 3.5a). Whereas in the Yamuna river basin, the Evenness was high during monsoon in zones I (0.36) and III (0.55) followed by post-monsoon (0.46) in zone II (Table 3.5b). Among the zones, Evenness was maximum in zones IV and III during all the seasons in Sutlej and Yamuna river basins respectively (Table 3.5a&b).

Table 3.4a Seasonal variation in bird species richness in four elevation zones of Sutlej river basin, Himachal Pradesh

Zones/Seasons	Winter	Summer	Monsoon	Post monsoon	Total
I	106	121	86	89	402
II	75	91	59	62	287
III	61	81	53	59	254
IV	22	23	30	23	98
Overall	123	144	109	111	487

Table 3.4b Seasonal variation in bird species richness in three elevation zones of Yamuna river basin, Uttarakhand

Zones/Seasons	Winter	Summer	Monsoon	Post monsoon	Total
I	119	122	74	80	395
II	79	100	65	61	305
III	30	41	44	39	154
Overall	129	138	84	86	437

Table 3.5a Seasonal variation of Shannon diversity (H') and Evenness (E) of birds in four elevation zones of Sutlej river basin, Himachal Pradesh

Zones/Seasons	Winter		Summer		Monsoon		Post monsoon	
	H'	**E**	**H'**	**E**	**H'**	**E**	**H'**	**E**
I	3.56	0.33	3.59	0.30	3.59	0.42	3.47	0.36
II	3.49	0.43	3.58	0.39	3.12	0.38	3.17	0.38
III	3.29	0.44	3.48	0.40	3.05	0.40	2.94	0.32
IV	2.41	0.51	2.65	0.62	2.59	0.44	2.54	0.55
Overall	3.70	0.33	3.81	0.31	3.58	0.33	3.59	0.33

Table 3.5b Seasonal variation of Shannon diversity (H') and Evenness (E) of birds in three elevation zones of Yamuna river basin, Uttarakhand

Zones/Seasons	Winter		Summer		Monsoon		Post monsoon	
	H'	**E**	**H'**	**E**	**H'**	**E**	**H'**	**E**
I	3.71	0.34	3.64	0.31	3.29	0.36	3.37	0.36
II	3.56	0.44	3.54	0.34	3.20	0.38	3.33	0.46
III	2.64	0.46	3.07	0.52	3.18	0.55	2.91	0.47
Overall	3.86	0.37	3.79	0.32	3.35	0.34	3.46	0.37

3.3.6. Trophic Diversity

The bird species of Sutlej and Yamuna river basin were classified into eight different guilds based on their general diet preferences. In Sutlej river basin, insectivores had the highest species richness, accounting for 54% (110 species) of the community followed by granivores (13%) and carnivores (13%) (Figure 3.3a). The omnivores, frugivores, scavengers, piscivores, and nectarivores comprised 17, 12, 4, 4, and 2 species respectively. Similarly, 38% of individual birds accounted for insectivores followed by granivores (21%) and frugivores (19%) (Figure 3.3b). In Yamuna river basin, 48% (86) of species were insectivores, 15% (27) were carnivores, 13% (24) were omnivores and 12% (21) were granivores. Frugivores, scavengers, piscivores, and nectarivores comprised 13, 4, 2, and 2 species respectively. Among other guilds, the insectivore guilds showed the highest species richness in the river basin (Figure 3.4a). Similarly, 34% of birds recorded during the sampling were insectivores followed by frugivores (21%), omnivores (21%) and granivores (18%). Other guilds comprised less than 4% of the total individuals (Figure 3.4b).

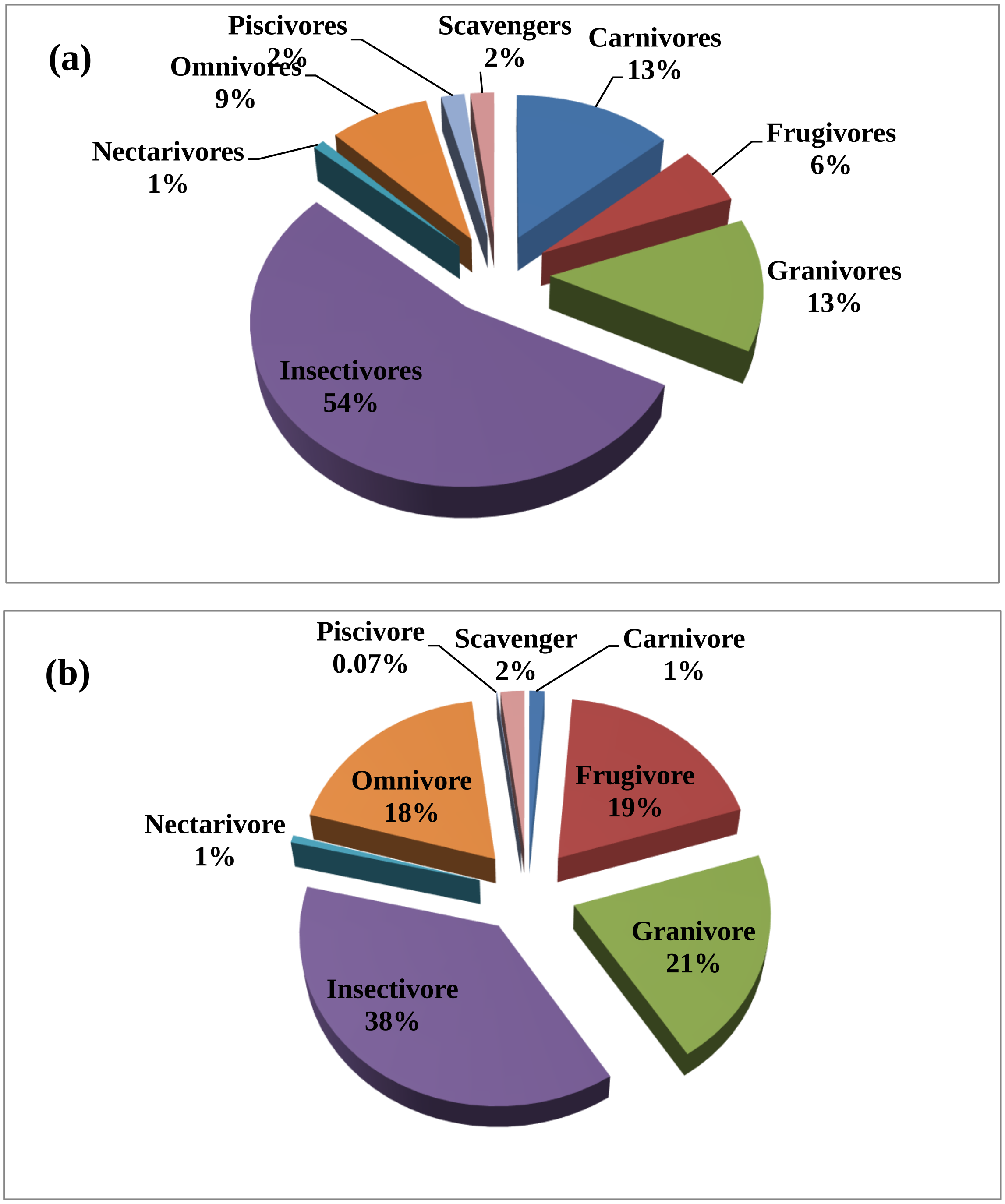


Figure 3.3 Relative percentages of species richness (a) and abundance (b) of birds in different trophic groups in the Sutlej river basin, Himachal Pradesh.

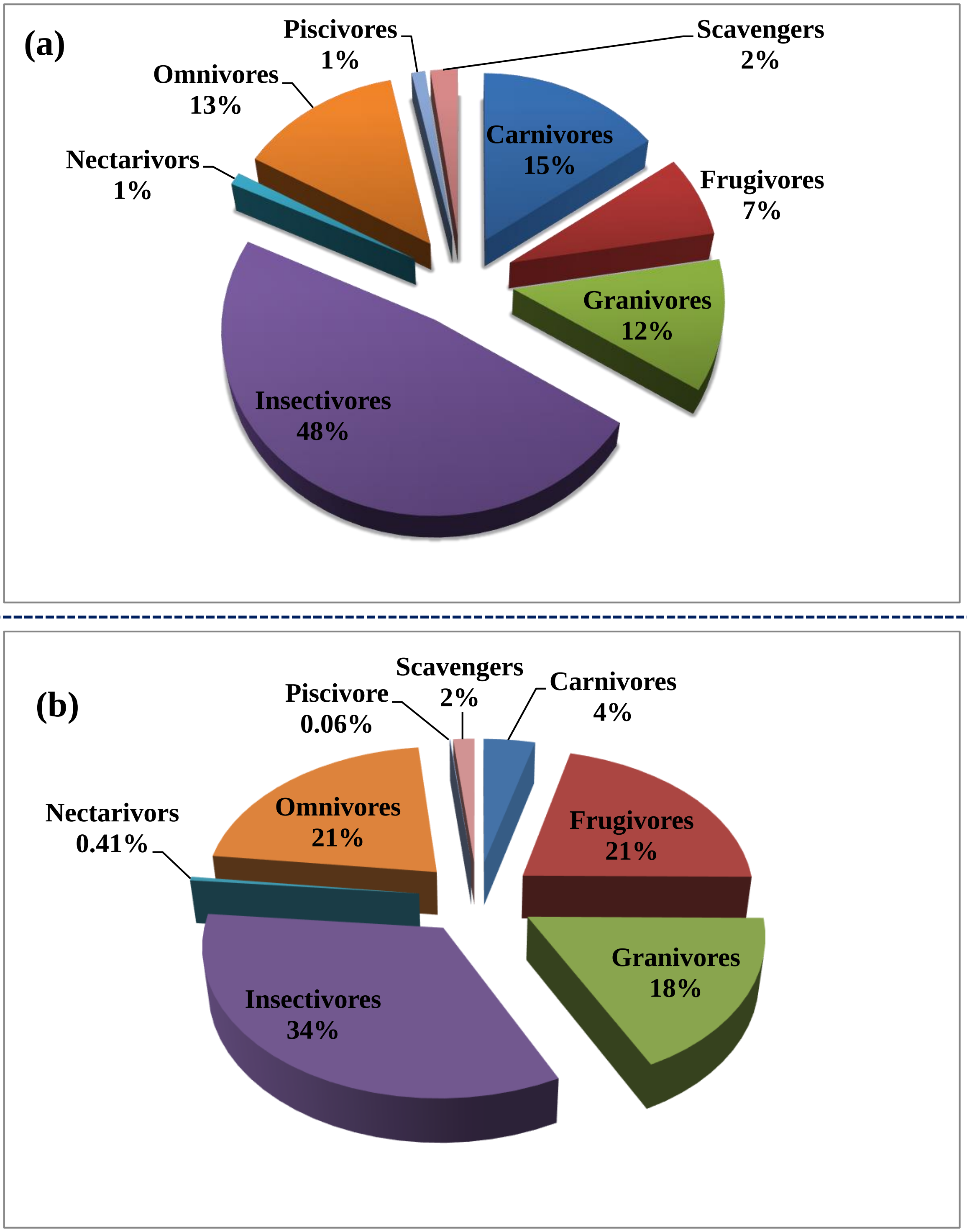


Figure 3.4 Relative percentages of species richness (a) and abundance (b) of birds in different trophic groups in the Yamuna river basin, Uttarakhand.

3.3.7. IUCN Status of Birds

Threatened Birds

The region of Himachal Pradesh is known to host ten restricted-range bird species (Rahmani & Islam, 2004), and one of them, the *Catreus wallichii*, was observed during the present study (Table 3.6a). Out of 241 bird species recorded during this study from the Sutlej and Yamuna river basins, seven species comprising 388 individuals are under various threat categories (IUCN), including one Critically Endangered, two Endangered and four Vulnerable species. In overall, 24 individuals belonging to six species of threatened birds recorded from Sutlej and, 364 individuals belonging to four species from Yamuna river basins. The zone-wise contribution of threatened species richness and abundance in Sutlej and Yamuna river basins was found more from zone I, followed by zone II. There were no threatened species record from zone III and IV of Sutlej and III of Yamuna river basin (Table 3.6a&b).

Table 3.6a List of Threatened, Near-threatened and endemic bird species recorded in the four elevation zones of Sutlej river basin (VU-Vulnerable, EN-Endangered and CR-Critically Endangered; IUCN, 2019) (E-Endemic; Rahmani & Islam, 2004).

Threatened Species	**I**	**II**	**III**	**IV**	**Total**
Red-headed Vulture *Sarcogyps calvus* [CR]	-	1	-	-	1
Egyptian Vulture *Neophron percnopterus* [EN]	5	-	-	-	5
Pallas's Fish-eagle *Haliaeetus leucoryphus* [EN]	6	4	-	-	10
Cheer Pheasant *Catreus wallichii* [E, VU]	1	-	-	-	1
Common Pochard *Aythya ferina* [VU]	6	-	-	-	6
Great Slaty Woodpecker *Mulleripicus pulverulentus* [VU]	-	1	-	-	1
Overall	18	6			24
Near-Threatened Species					
Bearded Vulture *Gypaetus barbatus*	1	5	-	-	6
Himalayan Griffon *Gyps himalayensis*	125	346	276	18	765
Pallid Harrier *Circus macrourus*	3	-	2	-	5
Alexandrine Parakeet *Psittacula eupatria*	332	37	11	-	380
Overall	461	388	289	18	1156

Near-threatened Birds

Overall, seven near-threatened species recorded from Sutlej and Yamuna river basins. Of these, four species (1,156 individuals) recorded from Sutlej river basin and six species (694 individuals) from Yamuna river basin (Table 3.6a&b). In both the river basins, zone-wise species richness and abundance was found more from zone I (Sutlej: 4 species, 461 individuals; Yamuna: 5 species, 343 individuals), followed by zone II and III. But in zone IV of Sutlej, only one species (Himalayan Griffon) were recorded. Among the near-threatened birds, Bearded Vulture and Himalayan Griffon was recorded in all the elevation zones of Sutlej and Yamuna river basins, while other species were recorded either one or two zones, except for Alexandrine Parakeet (recorded in three zones of Sutlej) (Table 3.6a&b). Himalayan Griffon was the most common threatened species in all the elevation zones and its abundance was accounting for 66% in Sutlej and 75% in Yamuna river basin.

Table 3.6b List of Threatened and Near-threatened bird species recorded in the three elevation zones of Yamuna river basin

Threatened Species	**I**	**II**	**III**	**Total**
Egyptian Vulture *Neophron percnopterus* EN	4	2	-	6
Pallas's Fish-eagle *Haliaeetus leucoryphus* EN	-	1	-	1
Common Pochard *Aythya ferina* VU	355	-	-	355
Asian Woollyneck *Ciconia episcopus* VU	2	-	-	2
Overall	361	3		364
Near-Threatened Species				
Painted Stork *Mycteria leucocephala*	33	-	-	33
River Lapwing *Vanellus duvaucelii*	85	-	-	85
Bearded Vulture *Gypaetus barbatus*	6	2	3	11
Himalayan Griffon *Gyps himalayensis*	187	239	94	520
Cinereous Vulture *Aegypius monachus*	-	2	-	2
Alexandrine Parakeet *Psittacula eupatria*	32	11	-	43
Overall	343	254	97	694

3.4. DISCUSSION

The hill state of Himachal Pradesh and Uttarakhand has great avifaunal diversity (Mohan & Sondhi, 2015), with 390 species of birds reported from Himachal Pradesh (Islam& Rahmani, 2004). This present study documented 203 species, which constituted 52% of those reported in Himachal Pradesh as occurring in the Sutlej. Mohan and Sondhi (2015) have reported 693 bird species from the Uttarakhand of which the present study area of Yamuna river basin recorded 30% (179) of the species. The result indicates that Sutlej and Yamuna river basin is very rich in avifauna, and also bird abundance data suggest that habitats along the river basins of Sutlej and Yamuna support a large number of birds.

The diversity of vegetation along the river basins, with wide variation in elevation, climate and soil types supports diverse habitats allowing many species of birds to co-exist. In Sutlej river basin, vegetation changes from sub-tropical broad-leaved hill forest in the zone I to sub-tropical pine forest and Himalayan moist forest in zones II and III, and zone IV merging with Tibetan plateau as typical cold desert alpine meadows. Similarly in Yamuna river basin, vegetation changes from the tropical deciduous forest in the zone I to the sub-tropical pine forest and Himalayan temperate forest in zones II and III. The climatic conditions and other environmental factors also change in a similar manner (Xu *et al*., 2009). A number of tributaries flowing through the Sutlej and Yamuna river basin (Figure 2.1 & 2.3) keep the riverine forests moist and productive all round the year (Buckton & Ormerod, 2008). In addition, the forest in Himachal Pradesh and Uttarakhand, especially the lower valleys, are a part of the continuous larger tract of sub-tropical broad-leaved hill forest and tropical deciduous forest of Western Himalaya that enrich the avifauna of these regions. Bulbuls, laughingthrushes, doves, bushchats, drongos, magpies and warblers are some of the species with high diversity in the study area. Besides these species, the temperate forest and alpine meadows at the higher elevation of both river basins support the fauna of temperate and Palaearctic dominance (Thakur & Mattu, 2011). However, the above mentioned factors contribute to the avifauna wide increase and diversification of these regions.

The shape of species accumulation curves in all the elevation zones of both river basins reached an asymptote, suggesting the completeness of the sampling (Colwell & Coddington, 1994; Mao *et al*., 2005). However, in Sutlej the higher elevation zone IV, species accumulation curve plateaued early indicating a close estimation of species richness with less sampling effort. However, there could have been chances of encountering more species with increased sampling effort. The efforts were limited due to heavy snow fall during winter in the upper zone especially in Kinnaur, Lahaul and Spiti districts, thereby restricted the accessibility. The species accumulation curve for both river basins showed that most of the species were detected during early sampling and only few rare species were added later with additional sampling.

Detecting all the species in a natural community is usually not possible (Walther & Moore, 2005) and hence, the estimated richness using estimators served as a useful tool for assessing the biodiversity of the area (Thompson *et al*., 2003). Due to incompatibility in the accuracy of the predictions of species richness estimators, selection of more than one estimator is preferred (Hortal, 2006). Chao 1, Chao 2 and Jackknife 1 were selected to estimate the species richness in each elevation zones of Sutlej and Yamuna river basin. These estimators showed relatively less standard deviation compared to other estimators, and less variance is considered as effective estimators (Walther & Moore, 2005). However, the two estimators Chao and Jackknife perform better and their performance varies with sample size (Walther & Martin, 2001; Walther & Moore, 2005; Hortal *et al*., 2006). The non-parametric species estimator (Chao 1) values were very close to the actual number of species observed in both river basins. This result indicates that most of the species are detected during sampling in all the zones and only very few species might be added with additional sampling. Whereas, estimators Chao 2 and Jackknife 1 showed slightly higher than the observed richness in all the zones of Sutlej and Yamuna river basin, shows that enhanced sampling effort may add new unrecovered species.

The species diversity measured in numerous ways decreased with increasing elevation, and most of this decrease can be accounted for by the decrease in species richness (Able & Noon, 1976). Zone I showed higher species diversity in comparison with any other zones of Sutlej (zones II, III and IV) and Yamuna river basin (zones II and

III). The higher diversity at a lower elevation is the most general trend observed across many taxa and regions (Terborgh, 1971; Terborgh & Weske, 1975; Rahbek, 1997; Hawkins, 1999; Mallet-Rodrigues *et al*., 2010). The extension of species ranges from upper and middle zones contributes to the higher avian diversity at lower elevations. Further, the factors such as habitat complexity, climate, plant species richness, diversity and environmental factors (Terborgh, 1975; Weir, 2006; McCain, 2009; Yu *et al*., 2013) individually or in combination with each other, might be responsible for high species diversity at lower elevation. The evenness was found maximum in the higher zone of Sutlej and Yamuna showed that the species were distributed more evenly in the higher elevation zones.

Muscicapidae was the most contributing family with 23 and 18 species of birds from Sutlej and Yamuna river basin respectively. This finding with a significant number of bird species in a family is consistent with other studies elsewhere in western Himalayan part of India (Joshi & Bhatt, 2011; Naithani & Bhatt, 2012; Joshi *et al*., 2012; Joshi & Bhatt, 2013). The higher number of species under this family could be due to their adaptability to use a wide range of habitats. In addition, the bird families Accipitridae, Anatidae, Corvidae, Timaliidae from Sutlej and Yamuna river basin were also abundant, similarly attributed to resource abundance and availability (Ramesh *et al*., 2012). However, most of the families had a smaller proportion of bird species, in accordance with the theory, that in a community it is expected that a few species would be common, whereas most species would be rare (Magurran, 1988).

The most relatively abundant species from Sutlej and Yamuna were considered for analyses. The results indicate that the relative abundance of species was different among elevational zones. Out of the 13 most abundant species from Sutlej, only seven species occurred in all the elevation zones. However, in the Yamuna river basin, all 15 species occurred throughout the elevation zones with varying abundances. The differences in patterns of relative abundance among assemblages suggest that different factors or mechanisms are concerned in shaping the abundances of species in these assemblages (Tokeshi, 1999).

Interestingly one near-threatened species Himalayan Griffon *Gyps himalayensis* and least concern species House Sparrow *Passer domesticus* were relatively abundant in the entire study area indicating the steady population of these species. This result lends support to the earlier studies from Himachal Pradesh by Thakur (2014), who reported the population status of the *Gyps himalayensis* with breeding records. The other noticeable species *Passer domesticus*, has been reported to be on decline from parts of India and other countries (Summers-Smith, 2003; Everaert & Bauwens, 2007; Dandapat *et al*., 2010; Murgui & Macias, 2010). Moreover, the present sighting of *Passer domesticus* as an abundant species in the study concurred with the similar study reported from Garhwal Himalaya (Naithani & Bhatt, 2012). It could be argued that the availability of food and nesting sites is accountable for the high abundance of *Passer domesticus* in the study area, while food and nest site limitation has been suggested as being responsible for the decrease in their population for many areas (Dandapat *et al*., 2010).

However, the both river basins, Himalayan Bulbul *Pycnonotus leucogenys* was found most abundant followed by Large-billed Crow *Corvus macrorhynchos* and House Sparrow *Passer domesticus*. The assemblage is shaped by various factors such as climate, habitat complexity, food, breeding habitat and competition among co-existing species. In addition, the type of resources and their abundance with its uniform distribution are the major factors that determine the community structure of any particular region (Wiens, 1989).

The bird species richness and diversity of the study areas showed marked seasonal variation along elevational zones. Maximum richness and diversity was observed at low elevation (zone I, in Sutlej and Yamuna). Overall, bird species richness was high during summer in both river basins, whereas diversity was observed maximum during summer in Sutlej and winter in Yamuna. The seasonal changes in richness and diversity of birds are caused by weather condition or fluctuations in resource availability (Loiselle & Blake, 1991; Shiu, & Lee, 2003; Norris & Marra, 2007; Pastur *et al*., 2015). Rainfall and humidity are found to be closely associated with food abundance (Mallet-Rodrigues *et al*., 2015). The first shower during summer causes the appearance of young leaves facilitating an increase in the abundance of invertebrates (Kai & Corlett, 2002). Hence, increases in food abundance during summer, especially insects, ultimately increase the diversity and population of birds (Terborgh, 1977; Wiens, 1989; Naithani & Bhatt, 2012; Joshi & Bhatt, 2015).

The local bird migrations along the river basins cause the seasonal fluctuations among zones, which are reported previously in other parts of the Himalaya (Sultana *et al*., 2007; Naithani & Bhatt, 2012). At the beginning of cold weather from October to February, the birds start migrating from a higher elevation to lower. This trend was more prominently observed in Yamuna river basin which showed maximum diversity during winter at lower elevations. After winters, they again start migrating from the lower elevations to higher. Apart from the weather, the seasonal changes in species diversity and richness could also be caused by fluctuations in resource availability (Loiselle & Blake, 1991; Kai & Corlett, 2002; Norris & Marra, 2007). In addition the variation in temperature and intensity of rain (Terborgh, 1977) might also cause the seasonal movements of birds along the elevation zones (Loiselle & Blake, 1991; Norris & Marra, 2007).

Insectivorous birds were found to be the most dominant trophic group in Sutlej and Yamuna river basin. The maximum number of species and abundance were recorded among this group, indicating the abundance and easy availability of insects in the river basins. Several studies have shown that insectivore feeding groups are the major feeding groups in a bird community (Terborgh, 1977; Herzog *et al*., 2003; Sultana *et al*., 2007; Bonilla *et al*., 2012; Singh *et al*., 2014; Bhandari & Bisht, 2015; Katuwal, 2016). However, in the present study nectarivores were found to be the least represented trophic-group in the river basins. Generally in most parts of the country nectarivores exhibit less representation in a bird community (Wiens, 1989). The trophic structure of a community in a particular habitat is decided by the availability of food resources, vegetation structure, suitable microhabitats and foraging habitats (Karr, 1976; Terborgh, 1977; Karr *et al*., 1990; Lefebvre & Poulin, 1997).

Sutlej basin of Himachal Pradesh lies in the Western Himalaya Endemic Bird Area (EBA) (Rahmani & Islam, 2004). Eleven species are confined to this EBA (Stattersfield *et al*., 1998), of these ten species are known to occur in this state with confirmed records. Out of the ten endemics, the present study recorded only one species (Cheer Pheasant *Catreus wallichii*). The remaining nine endemic species were not observed during the course of this study. These restricted range species are confined to the elevation between 1,500 to 3,600 m in the temperate coniferous or broadleaf forest, sub-alpine forest and montane grassland (Stattersfield *et al*., 1998) which are similar to zones II, III and IV of Sutlej river basin.

Yamuna basin of Uttarakhand state falls in the Western Himalaya Endemic Bird Area (Rahmani & Islam, 2004). Five species recorded in the state, are endemic to the Western Himalaya (Mohan & Sondhi, 2015), namely Western Tragopan *Tragopan melanocephalus*, Cheer Pheasant *Catreus wallichii*, Himalayan Quail *Ophrysia superciliosa*, White-throated Tit *Aegithalos niveogularis* and Tytler’s Warbler *Phylloscopus tytleri*. During this present study none of them were sighted and the species reported to occur in habitats such as temperate forest, montane grassland and sub-alpine forest (Stattersfield *et al*., 1998) were similar to zones II and III of Yamuna river basin.

Of the 203 bird species recorded from Sutlej, there were six threatened and four near-threatened bird species (IUCN, 2019) (Table 3.6a). Species such as Cheer Pheasant *Catreus wallichii*, Common Pochard *Aythya ferina*, Egyptian Vulture *Neophron percnopterus*, Red-headed Vulture *Sarcogyps calvus* and Great Slaty Woodpecker *Mulleripicus pulverulentus* were recorded from either zone I or zone II, exhibiting narrow distribution range compared to other species such as Bearded Vulture *Gypaetus barbatus*, Pallid Harrier *Circus macrourus* and Pallas's Fish-eagle *Haliaeetus leucoryphus* recorded in two zones either from zones I and II or I and III. Only one near-threatened species i.e. the Himalayan Griffon *Gyps himalayensis* was recorded in all the four zones of the study area indicating its wider distribution range. Likewise, another near-threatened species, Alexandrine Parakeet *Psittacula eupatria* was also recorded in all the three zones of the study area except in the highest elevation, zone IV.

Similarly, out of 179 species of Yamuna river basin, four species falls under threatened category and six species were near-threatened (IUCN, 2019) (Table 3.6b). The endangered species, the Egyptian Vulture *Neophron percnopterus* and near-threatened Alexandrine Parakeet *Psittacula eupatria* recorded in zones I and II exhibited wider habitat utilization. However, other endangered species Pallas's Fish-eagle *Haliaeetus leucoryphus* from zone II, vulnerable species such as Common Pochard *Aythya ferina*, Asian Woollyneck *Ciconia episcopus* from zone I, and near-threatened species such as Painted Stork *Mycteria leucocephala*, River Lapwing *Vanellus duvaucelii* from zone I and Cinereous Vulture *Aegypius monachus* from zone II were indicative of having a narrow distribution range in this study area. Only two near-threatened species in this study area showed larger distribution range, namely Bearded Vulture *Gypaetus barbatus* and Himalayan Griffon *Gyps himalayensis*.

Result shows that the number of threatened and near-threatened bird species is very low in Himachal Pradesh and Uttarakhand. In the Himalaya region, habitat loss and fragmentation are considered as the leading causes for declines in threatened and endemic bird populations (Rahmani & Islam, 2004; Pandit *et al*., 2007; Xu *et al*., 2009; Pandit & Grumbine, 2012; Grumbine & Pandit, 2013; Joshi & Rautela, 2014). The present study found that the decline in the proportion of threatened birds along the elevational zones reveals the conservation status of montane forests is of less concern (associated with forest loss and fragmentation) (Pandit & Grumbine, 2012; Mallet-Rodrigues *et al*., 2015). The endemic birds are vulnerable to extinction when their local habitat is deforested or altered (Lei *et al*., 2003). Pandit *et al*., (2007) reported that a quarter of the endemic species from Indian Himalaya will be extinct due to habitat loss by the end of this 21st century. According to Pan *et al*., (2016) extinction rate will be higher for species with smaller ranges. The result of the present study where most of the threatened birds were found to be having smaller elevational ranges, highlight the conservation importance of such priority species. The available information in the literature and the present study on the current status of these birds suggests large-scale conservation efforts including habitat protection and restoration, are urgently needed to prevent deforestation leading to threatened and endemic species losses in this Himalayan river basins.

3.5. SUMMARY

The study was conducted along the two major river basins viz., Sutlej and Yamuna, western Himalaya. Species richness, diversity and composition of birds were studied in four different elevation zones of Sutlej from June 2012 to April 2013, and three zones of Yamuna from September 2013 to June 2014, using point count sampling method. Altogether 241 species of birds (203 species from Sutlej and 179 from Yamuna) belonging to 59 families were recorded from the river basins. The results showed that the river basins shelter high diversity and abundance of birds.

The lower zone (I) was the most diverse and rich avifaunal zone of Sutlej (occupied with broad-leaved hill forest) and Yamuna river basin (deciduous forest). The bird data showed that the river basins contain exclusive (restricted to one elevation zone) and generalists (present in more than two zones) species. Out of the total number of bird species recorded from Sutlej, 37% were exclusive to a specific elevation zone, likewise in Yamuna were 34% of species were exclusive to particular zone. The entire elevation zones were utilized by 22 species from Sutlej and 62 from Yamuna river basin.

Muscicapidae was the most diverse family from these river basins, with 23 species represented from Sutlej and 18 from Yamuna. Among all the families of Sutlej, 19 families showed single species each, likewise in Yamuna 14 families showed single species each. Out of 13 most relative abundant species from the Sutlej, only seven species occurred in all the elevation zones, but in Yamuna 15 species considered as the most abundant and all were found in all the elevation zones. Most of the species from Sutlej and Yamuna showed < 1% of relative abundance, includes 13 singletons from Sutlej and 5 from Yamuna. Over all from Sutlej and Yamuna river basin, the top most three species noticed as most abundant, namely Himalayan bulbul, Large-billed crow and House sparrow. Snow Pigeons were relatively most abundant and restricted species from higher elevation zone IV of Sutlej. Interestingly one near-threatened species Himalayan griffon was found relatively most abundant and occurred in all the elevation zones of both river basins.

Seasonal variation in bird species richness and diversity was observed in different elevation zones of both river basins. Richness and diversity was observed high at low elevation zone I in Sutlej and Yamuna river basins. Overall, species richness was high during summer in both river basins, whereas diversity was observed maximum during summer in Sutlej and winter in Yamuna. Insectivores dominated the bird community in the river basins comprising 54% species from Sutlej 48% from Yamuna respectively. Nectarivore trophic group constituted lowest species and abundance in the river basins.

Out of 203 species recorded from Sutlej, 1,180 individuals belonging to 10 species confirmed to various threat categories, including one endemic species (*Catreus wallichii*).

Similarly, in Yamuna a total of 179 species, 1,058 individuals belonging to 10 species falls under different threat categories. Number of threatened species (six from Sutlej and, four from Yamuna) and their abundance (18 and 361 of Sutlej and Yamuna respectively) was highest in zone I of both river basins. Among the red listed species recorded from Sutlej and Yamuna, only one near-threatened species *Gyps himalayensis*, abundance was found more from both river basins. Out of the ten western Himalayan endemic species, only one species was recorded from the Sutlej, and none of them were sighted in Yamuna. A complete ecological study of threatened and endemic species is needed for planning conservation action in these montane river basins.

Overall, 1,239 point count data points were covered for sampling birds in Sutlej, and 1,578 points from Yamuna river basin during the study period. A total of 203 species (37,926 individuals) from Sutlej representing 57 families and, 179 species (32,586 individuals) from the Yamuna representing 51 families were recorded from these river basins. Zone I was the most diverse and rich avifaunal zone of Sutlej and Yamuna river basins occupied with broad-leaved hill forest and deciduous forest respectively. Species accumulation curves reached an asymptote in all the elevation zones of both river basins. Species richness (observed and estimate) and diversity were highest in the zone I and lowest in zone IV of Sutlej and highest and lowest in zones I and III of Yamuna river basin. Evenness was comparatively higher in zone IV and lower in the zone I of Sutlej and in the Yamuna higher in zone III and lower in zone I. Seventy-five species from Sutlej and 60 species from the Yamuna found exclusively in one specific elevation zone, whereas entire elevation zones were utilized by 22 species from Sutlej and 62 from the Yamuna. Muscicapidae was the most diverse family with the representation of 23 species from Sutlej and 18 species from the Yamuna. Nineteen families from Sutlej and 14 families from the Yamuna recorded were single species each. Himalayan Bulbul was the most relative abundant bird species in the study areas. Thirteen dominant species from Sutlej and 15 species from the Yamuna comprised around 58% and 56% of birds respectively. Interestingly one near-threatened species Himalayan Griffon was found relatively most abundant and occurred in all the elevation zones of both river basins.

Overall, species richness was high during summer and low during winter in both river basins, whereas diversity was the highest during summer and lowest during monsoon in Sutlej and in Yamuna highest during winter and lowest during monsoon. Noticeable seasonal variation in bird species richness, diversity and evenness were observed within and between elevation zones of both river basins. Among the eight trophic groups of birds, insectivores group was the most and dominant trophic groups represented 54% species from Sutlej and 48% from the Yamuna. Nectarivores group constituted the lowest species and abundance in the river basins. Out of the 10 restricted-range species from Himachal Pradesh only one species (*Catreus wallichii*) were recorded from Sutlej, but in Yamuna five endemic species are reported, none of them were sighted during this study. Out of the total number of species from Sutlej, 10 species recorded were red listed categories which included six threatened and four near-threatened species, similarly in Yamuna, 10 species were red listed categories included four threatened and six near-threatened species. The result of these studies indicated the rich variety and abundance of the avian species in the Sutlej and Yamuna river basin. The presence of threatened and endemic species in the study areas designates the importance of this area and suggests a study in detail on the ecology of globally threatened species is needed for specific conservation action plans.

Chapter 4

CHAPTER 4

DISTRIBUTION PATTERN OF BIRDS ALONG THE ELEVATIONAL GRADIENTS IN SUTLEJ AND YAMUNA RIVER BASINS

4.1. INTRODUCTION

The study of biodiversity's global distribution is one of the most important objectives for ecology and biogeography (Gaston, 2000). The variation of species richness pattern along environmental gradients and the possible mechanisms underlying that variation is the basic questions in ecology (Rosenzweig, 1995; Lomolino, 2001). Of these patterns, latitudinal gradients in species richness have received more scientific attention than elevational gradients (Rosenzweig, 1992; McCain, 2004). The species richness along the elevational gradients is a mirror of latitudinal gradients (Rahbek, 1995). Elevational gradients, though perhaps not studied as intensively as the latitudinal gradient, provide equally striking patterns in diversity (Sanders & Rahbek, 2012). Elevational gradients distributed across the globe are an effective test system for understanding biodiversity (Grytnes & McCain, 2007; McCain, 2009; Dixit *et al*., 2016). The mountain ecosystems are hot spots of biological diversity, and study of species distributions along an elevational gradient is essential to understanding the principles of community organization while conserving the species of the region (Lomolino, 2001; Raman *et al*., 2005)

Rahbek (1995) reported that species richness follows one of three basic patterns along elevation gradients; (i) monotonic decline (species richness decreases with increasing elevation), (ii) hump-shaped pattern with a peak at mid-elevation (mid-domain) and (iii) species richness increase with an increasing elevation. Among these, commonly observed patterns are monotonic declines in species richness with increasing elevation and a hump-shaped pattern with richness peak at intermediate elevations (Rahbek 1995; Grytnes & McCain, 2007). The decline in species richness with increasing elevation is widely accepted as a general pattern (Rahbek, 1995).

Geographic patterns of species richness are influenced by multiple factors that are often interacting with each other (Orians & Wittenberger, 1991; Colwell & Lees, 2000; Lee *et al*., 2004). Temperature, moisture, and oxygen partial pressure vary between low valleys and mountain summits. These changes favor some species, allowing them to increase in number or to inhabit at specific elevations, but disfavor others, causing them to decrease or sometimes inducing their extinction. This turnover in species and habitats results in mountains having higher diversity than other habitats of equivalent area (Brown *et al*., 2001; Graham *et al*., 2014; Dixit *et al*., 2016).

The patterns of elevational species richness can be explained by a number of hypotheses; productivity, environment, species-area interactions and the resource diversity hypothesis (Rahbek, 1995, 2005; Sanders & Rahbek, 2012). There are various underlying causes ranging from biological factors such as productivity, habitat complexity, habitat diversity, interspecific competition (Rosenzweig, 1995; Lomolino, 2001; Rowe, 2009), climatic conditions including temperature and precipitation (Hawkins *et al*., 2003; Brown *et al*., 2004), spatial factors including geometric constraints and area (Rahbek, 1997; Lomolino, 2001), evolutionary and historical process such as isolation, speciation and endemism (Lomolino, 2001; Hawkins *et al*., 2007; Machac *et al*., 2011). Among these studies, most of them concluded that rather than a single factor, several factors were involved in shaping species richness at different elevations (Rahbek, 1997).

Species richness in a species assemblage is a significant measure of biodiversity at the habitat level (Colwell & Coddington, 1994; Mao *et al*., 2005). To examine the completeness of the sampling in a survey, it is necessary to estimate species richness by sampling the target species assemblage. The species accumulation curve is one among several non-parametric methods for estimating species richness, in which the function of sampling effort is described as a graph of the expected number of observed species (Colwell *et al*., 2004; Mao *et al*., 2005). Since the magnitude of different estimators might vary with respect to the observed species, it will be useful to compare more than one estimator (Southwood & Henderson, 2000).

Elevational distribution of species is determined by various factors, most importantly by species richness of an area (Rahbek, 1997; Sanders, 2002). The influence of the area on the richness pattern has rarely been studied. Schoener (1976) reported that large areas often support more species than the smaller areas. However, few studies have reported on the relationship among area, elevation and species richness (Rahbek, 1995, 1997; Sanders, 2002; McCain, 2009).

Food resources are also known to determine bird species richness pattern along an elevational gradient (Terborgh, 1977; McCain, 2009; Joshi & Rautela, 2014). The dietary components such as insect abundance, fruit and nectar production, and abundance of small vertebrates are to be low in cold temperature regions (Loiselle & Blake, 1991; Navas, 2002). This might influence the distribution pattern of species richness along the elevational gradients.

The turnover of species occurs when species composition changes from one place to another (Whittaker, 1960). The high turnover rate of species richness resulted in mountains having higher diversity than other habitats of equivalent area (Graham *et al*., 2014). The high turnover of species along the elevational gradient is due to fluctuations in a range of factors such as temperature, rainfall, humidity, vegetation, productivity and availability of area (Terborgh, 1977; Rahbek, 1997; Raman *et al*., 2005; Graham *et al*., 2005; McCain, 2007). For conservation prioritization, it is important to understand the spatial turnover pattern of species richness in montane regions (Dixit *et al*., 2016).

Range size distribution pattern of birds varies along the elevation gradients. The Rapoport's rule, attempt to explain latitudinal diversity gradients *i.e.* species geographic range size increase with latitude (Stevens, 1989). Stevens (1992) extended the latitudinal Rapoport's rule to elevational gradients as well, suggesting that high elevation species which have broader climatic tolerance and hence larger range sizes, whereas low elevation species which have smaller elevational range sizes in response to their climatic tolerance. This might help to predict the species with survival risk.

The world enclosed with boundaries imposes geometric constraints on the distribution of species ranges. Geometric constraints or mid-domain effect (MDE) is considered as one of the suitable null models to explain the distribution of species along an elevation gradient (Colwell & Lees, 2000; Jetz & Rahbek, 2001). The definition of MDE is the increase in overlap of species ranges towards the center of a shared geographic domain due to geometric constraints (such as oceans and mountaintops) in relation to the distribution of species range sizes and midpoints (Colwell & Lees, 2000; McCain, 2004; Colwell *et al*., 2004). The MDE null model predicted richness can be compared with empirical richness if there is a deviation of empirical pattern, there is a need to look into some other factors besides spatial constraints (McCain, 2004). MDE makes no contribution to the richness pattern; on the other hand, the MDE hypothesis makes additional powerful predictions about species richness pattern (Romdal *et al*., 2005; Currie & Kerr, 2008). Although the MDE model has been a controversial and debatable topic with several objections raised (Jetz & Rahbek, 2001; Zapata *et al*., 2003, 2005; Colwell *et al*., 2004; Hawkins *et al*., 2005; Currie & Kerr, 2008). However, it is still being considered as one of the possible mechanisms which help to interpret the richness pattern along with some other factors (Romdal *et al*., 2005).

There are several studies at the global level on bird species distribution pattern along elevation gradients. Most of the studies on birds supported monotonic decline in species richness with elevation (Able & Noon, 1976; Terborgh, 1977; McCain, 2009; Montano-Centellas & Garitano-Zavala, 2015) and few recent studies followed mid-elevation species richness peak (Rahbek, 1997; Kattan & Franco, 2004; Lee *et al*., 2004). In India, elevational studies on birds were scanty on this aspect, particularly studies from the Eastern Himalayas (Acharya *et al*., 2011) and Western Himalayas (Joshi *et al*., 2012; Joshi & Rautela, 2014; Joshi & Bhatt, 2015) confirmed mid-elevation peak or hump-shaped patterns. A study from the Western Ghats observed 'U' shaped pattern or mid-elevation depression in species richness with elevation (Raman *et al*., 2005). The fluctuation in species richness pattern with elevation was associated with the availability of food resources, microhabitat, physiological requirements or other climatic variations (McCain, 2009; Joshi & Rautela, 2014).

The Indian Himalayas is well recognized for its biodiversity and ecological values (Bhattacharya & Sathyakumar, 2007). The western part of Himalaya is an important area of regional endemism and is a priority region for conservation (Rahmani & Islam, 2004). The main objective of this study is to compare the patterns in the elevational distribution of bird species of two major river basins (Sutlej and Yamuna) of western Himalaya. In view of the above, this chapter intends to document, describe and explain the elevational distribution pattern of bird species richness along an elevational gradient of the Sutlej river basin, Himachal Pradesh and Yamuna river basin, Uttarakhand, Western Himalaya.

4.2. METHODS

Data collection and data analysis for both Sutlej and Yamuna river basin were approached in a similar manner.

4.2.1. Bird Surveys

Field surveys were carried out in Sutlej and Yamuna river basin along topographically distinct elevation gradients. The river basins were sampled for birds considering representation of various aspects, such as vegetation types, human interference, availability, and accessibility of suitable plots into consideration. To determine the sampling intensity, the availability of river basins was stratified at 200 m elevation intervals (*i.e*. the proportion of sampling depends on the area availability). By following this procedure, bias sampling at a particular elevation would be minimized. Birds were sampled for both river basin using the point count method (Gaston, 1975). The elevational gradient of the Sutlej river basin was sampled between 498 m and 3700 m above sea level (a.s.l.) using 16 elevational bands with 200 m intervals (Table 4.1a). A similar sampling protocol was followed in the Yamuna river basin, where 11 elevation bands were sampled between 378 m and 2600 m (Table 4.1b). The distance between two consecutive points within elevational bands was kept at a minimum of 1 km. To enhance the probability of detecting elusive or rare species, point counts varied between one to four replications in each season (summer, winter and rainy season).

Digital Elevation Model (DEM) data at 90-m resolution was downloaded from the Shuttle Radar Topography Mission (SRTM) (http://srtm.csi.cgiar.org/SELECTION/ inputCoord.asp) using the software 'Global Mapper trial version 10' to extract the extent of area available at each 200m elevational band in the study area.

Mid-Domain Effect

A Monte Carlo simulation programme (Mid-Domain Null programme) was used to test the effect of geographical boundaries on species distribution (McCain, 2004). The Mid-Domain Null models were generated by using software Visual Basic (McCain, 2004).

4.2.1.1. Environmental Factors

Mean Annual Temperature and Mean Annual Precipitation

In this study, annual temperature and precipitation data were obtained from the WorldClim database (http://www.worldclim.org), which contains a fine-scale climatic dataset covering the entire globe, based on climatic records from several meteorological stations. Database corresponding to 19 bioclimatic variables including information on elevation, mean annual temperature and mean annual precipitation was extracted. The database presents climatic data from 1950-2000 (50 Years) at a spatial resolution of one kilometer (Hijmans *et al*., 2005). To acquire the values of temperature and precipitation in each 200 m band by averaging all grid cells within the band based on the elevational value of each grid cell.

Productivity

Normalized Difference Vegetation Index (NDVI) data were downloaded using Landsat 7 at 32-day intervals from Google Earth Engine (https://earthengine.google.com/datasets/). The NDVI data were obtained for Sutlej and Yamuna river basin, for the years 2012 to 2013 and 2013 to 2014 respectively. Data from the NDVI have a spatial resolution of about 30-meter.

4.2.2. Data Analysis

4.2.2.1. Species Richness, Abundance, and Diversity

An analysis of species richness, abundance and diversity was carried out for all elevational bands. To detect all species in natural communities over limited time and space (Colwell & Coddington, 1994; Chao *et al*., 2005) non-parametric estimators (Chao1 and Chao2) to were used to calculate the estimated species richness using the statistical program Estimates 9.1 (Colwell & Coddington, 1994; Colwell, 2016; http://viceroy.eeb.uconn.edu/estimates). A precise estimate of observed species richness and estimated species richness for a sampling interval was assumed if the species accumulation curve approached a plateau (Chao *et al*., 2005). Regression (Sokal & Rohlf, 1995) analysis was performed to examine the relationship between observed and the estimated species richness. Analyses were carried out to evaluate whether species diversity was sampled adequately for the elevational gradient.

Differences in species richness and abundance of birds were measured using One-way **ANOVA** along the elevation gradient and between/within different trophic groups. In order to investigate the relationship between observed species richness, diversity and estimated species richness against elevation gradients, a **Regression** analysis was conducted. **Correlation** analyses were performed to examine the relationship between species richness of each trophic group against the elevational gradient, in addition, the correlation between observed species richness and abundance, and estimated species richness were calculated.

Regression and correlation analysis were performed in statistics software package SPSS 17.0 (Chicago, IL, USA), ANOVA was performed in PAST version 2.17 (Hammer *et al*., 2001; http://folk.uio.no/ohammer/past/) and Microsoft Excel for Windows.

4.2.2.2. Spatial Factor (Area)

In order to observe the relationship between area and elevation, the availability of area was calculated at each elevational band. The extracted DEM data (GeoTiff) file was analyzed using the Global Mapper and then estimated surface areas were plotted along the ascending elevational gradients with 200 m intervals. Pearson correlation was performed to find out the association of proportion of area with sampling points and species richness.

4.2.2.3. Species Turnover

The replacement of species from one region to another is known as species turnover (Blake & Loiselle, 2000). Using Sorenson's similarity index (Rahbek, 1997), the turnover or dissimilarity of species richness between consecutive elevational bands was examined. The turnover between adjacent elevation categories was calculated as (1-*X*), where *X* is Sorenson's similarity index (Wolda, 1981). Pearson correlation was used to test the significant trends in turnover along elevation gradient.

4.2.2.4. Range Size

Elevation range size of each species was calculated as the difference between the lowest and highest elevation at which the species was recorded. From the highest and lowest elevational occurrences of a species it was assumed that the species is present in all the intermediate elevations (Patterson *et al.*, 1998; McCain, 2004). An analysis of Pearson correlation was performed to determine if the size of the range was correlated with the lower and upper limits of each species.

4.2.2.5. Mid-Domain Null Model

This Monte Carlo program simulates species richness curves based on empirical range sizes or range midpoints within a bounded domain (McCain, 2004). It is based on analytical–stochastic models (Colwell & Hurtt, 1994). The species range sizes are randomly shuffled within a bounded geographical domain resulting peak species richness at intermediate elevation (Colwell & Lees, 2000). To test the geometric constraints in relation to the distribution of species richness, 95% prediction curves were raised based on 50,000 simulations without replacement using empirical range sizes (with 200 m elevational increases). Regression analysis was performed between empirical species richness and the predicted number of species to examine the fit of the null model (McCain, 2005). Significant deviations from the null model predictions indicated the influences of other potential factors.

4.2.2.6. Explanatory Factors

Simple linear regression analysis was performed to explore the effect of each explanatory variable, which could support the bird species richness along an elevation gradient. The explanatory variables such as mean annual temperature, mean annual precipitation, area, NDVI (used for Sutlej - February, March, April, July, October and November; and Yamuna - February, March, May, June, September, October and December) and MDE predicted richness were regressed with estimated species richness (Chao1). Among the environmental and habitat variables, highly correlated variables were selected for stepwise multiple regression analysis to identify the best explanatory variables predicting the species richness patterns along an elevation gradient. In the set of variables, estimated species richness was treated as dependent variable and others were independent variables. In each successive step, the model with significant results was dropped and tried with another variable to find the next significant one.

4.3. RESULTS

Species Richness Estimates

The species accumulation curves across all the elevational bands almost reached an asymptote, except the elevational band 900 m, 2300 m, 2500 m and 3700 m (Figure 4.2a). Few additional species were being detected in some of the elevational bands and estimators Chao1 and Chao2 were used to estimate the species number. The number of species estimated (Chao1) at all the elevation bands was very close to the actual number of species observed (Table 4.1a). The correlation of the observed species richness against the estimated species richness (Chao1, $r = 0.99$, $p < 0.000$) indicated that the sampling was adequate to accurately characterize the species richness pattern along the elevation gradient. Linear regression model was used between elevation and the estimated species richness Chao1 ($r^2 = 0.85$; $p < 0.000$) and Chao2 ($r^2 = 0.87$; $p < 0.000$) to establish the relationship (Table 4.1a). The curve was the best fit with estimated richness and showed a decreasing trend with increasing elevation (Figure 4.1a).

Similarly, species accumulation curves in the Yamuna also reached an asymptote, except at a few elevational bands (Figure 4.2b). Only some additional species were being detected, and the numbers of species estimated (Chao1) was very close to the observed species richness (Table 4.1b). Pearson correlation between observed species richness and estimated richness (Chao1, $r = 0.99$, $p < 0.000$) indicated that the sampling was enough to predict the richness patterns along the elevation gradient. The quadratic function of estimated species richness Chao1 ($r^2 = 0.84$; $p < 0.001$) and Chao2 ($r^2 = 0.77$; $p < 0.003$) peaked at 1400 m elevation with decreasing trend (Figure 4.1b).

4.3.1. Species Richness of Elevational Bands

The number of observed bird species recorded in each elevational band varied from lowest 20 and highest 140 species and, estimated species richness (Chao1) varied from lowest 21 and highest 155 species from Sutlej river basin (Table 4.1a). In Yamuna, observed species richness ranged from lowest 18 and highest 115 species, and estimated richness lowest 18 and highest 119 species (Table 4.1b). The bird species richness showed a decreasing trend with increasing elevation (Figure 4.1a) in Sutlej, wherein it was highest at approximately 700 m elevation and lowest at 2700 m. The observed species richness significantly differed across elevational bands (one-way ANOVA; $F_{15, 302} = 12.97$, $p < 0.000$). The linear model regression between elevational band and the observed species richness showed a significant relationship ($r^2 = 0.87$; $p < 0.000$; Table 4.1a). The model showed a decreasing trend with elevation.

A similar pattern was observed in the Yamuna and showed bird species richness declining with increasing elevation, although the maximum number of species was recorded at the middle elevational band (around 1400 m). The highest number of bird species was observed in the elevational band between 600 and 1400 m (Figure 4.1b). The observed species richness significantly differed across elevational bands (one-way ANOVA; $F_{10, 418} = 19.37$, $p < 0.000$). The quadratic model regression between the elevational band and the observed species richness showed a significant relationship ($r^2 = 0.84$; $p < 0.001$; Table 4.1b) with a peak around 1400 m elevation (Figure 4.1b).

4.3.2. Species Diversity and Abundance

The number of individual birds observed from each elevational band of Sutlej river basin ranged from 308 to 7,465 and the number of individuals per point ranged from 13 to 161 birds. Birds records from Yamuna river basin along the elevational bands ranged from 260 to 5,979 and the number of individuals per point ranged from 6 to 469 birds.

The bird species abundance significantly differed across elevational bands in Sutlej river basin (one-way ANOVA; $F_{15, 302} = 2.71$, $p < 0.001$). Abundance peaked at the lower elevational band at 700 m and also at 3500 m elevation (Table 4.1a). Bird species richness and abundance were significantly correlated with each other (Pearson correlation; $r = 0.62$; $p < 0.000$). In the Yamuna river basin there was a significant variation between the bird species abundance and the elevational bands (one-way ANOVA; $F_{10, 418} = 5.71$, $p < 0.000$). The bird abundance peaked at the lower elevational band around 600 m elevation (Table 4.1b). The correlation of the bird species richness against the abundance showed a significant correlation ($r = 0.14$; $p < 0.003$).

The Shannon diversity also followed the decreasing trend with increasing elevation in the Sutlej river basin (Figure 4.1a). Linear relationship between diversity and elevation was significant (Regression; $r^2 = 0.73$; $p < 0.000$). The maximum diversity was found at 700 m elevation and minimum at a high elevation of 2700 m (Table 4.1a).

The diversity declined in the high elevational bands compared to the low elevational bands. The Shannon's diversity index for Yamuna river basin showed species diversity peaked at the middle elevation around 1400 m (Figure 4.1b). The diversity was considerably higher at middle elevation (1400 m) and lower at the highest elevation 2600 m (Table 4.1b). The linear regression of the diversity and elevation were significantly correlated with each other and showed quadratic relationship ($r^2 = 0.83$; $p < 0.001$).

Table 4.1a Sutlej: Summary of observed and estimated species richness (Chao1 and Chao2), abundance and Shannon diversity index value (H') with elevational bands; below table regression values are given, all values are significant at $p < 0.001$, except abundance value.

Elevation (m)	Observed species	Abundance	Shannon (H')	Chao1	Chao2
700	140	39.71	3.73	144.71	158.80
900	129	30.74	3.57	154.50	151.84
1100	86	29.44	3.38	87.50	127.79
1300	101	28.63	3.48	105.12	131.83
1500	81	26.95	3.39	87.60	114.93
1700	95	31.10	3.54	97.80	108.22
1900	90	26.65	3.47	94.50	133.50
2100	71	27.59	3.23	76.14	95.69
2300	54	21.73	3.26	63.32	68.94
2500	49	20.93	3.03	59.49	72.21
2700	20	28.67	2.28	21.00	22.29
2900	36	26.85	2.78	37.20	49.48
3100	39	31.90	2.84	39.86	51.61
3300	28	25.33	2.70	28.75	31.31
3500	27	36.09	2.68	27.00	27.16
3700	30	30.33	2.80	34.98	47.49
	0.87	**0.03**	**0.74**	**0.85**	**0.87**

Table 4.1b Yamuna: Summary of observed and estimated species richness, abundance and Shannon diversity index value with elevational bands; below table regression values are given, all values are significant at $p < 0.003$, except abundance value.

Elevation (m)	Observed species	Abundance	Shannon (H')	Chao1	Chao2
600	108	50	3.51	114.11	128.83
800	70	16	3.27	72.54	84.86
1000	114	16	3.38	115.56	133.84
1200	109	18	3.50	112.11	123.01
1400	115	21	3.61	118.88	126.46
1600	93	18	3.53	99	106.06
1800	75	19	3.49	79	97.8
2000	63	18	3.46	65.62	80.09
2200	44	18	3.17	44.37	53.55
2400	41	21	3.02	43.99	77.67
2600	18	24	2.27	18.33	27.55
	0.84	**0.48**	**0.83**	**0.84**	**0.77**

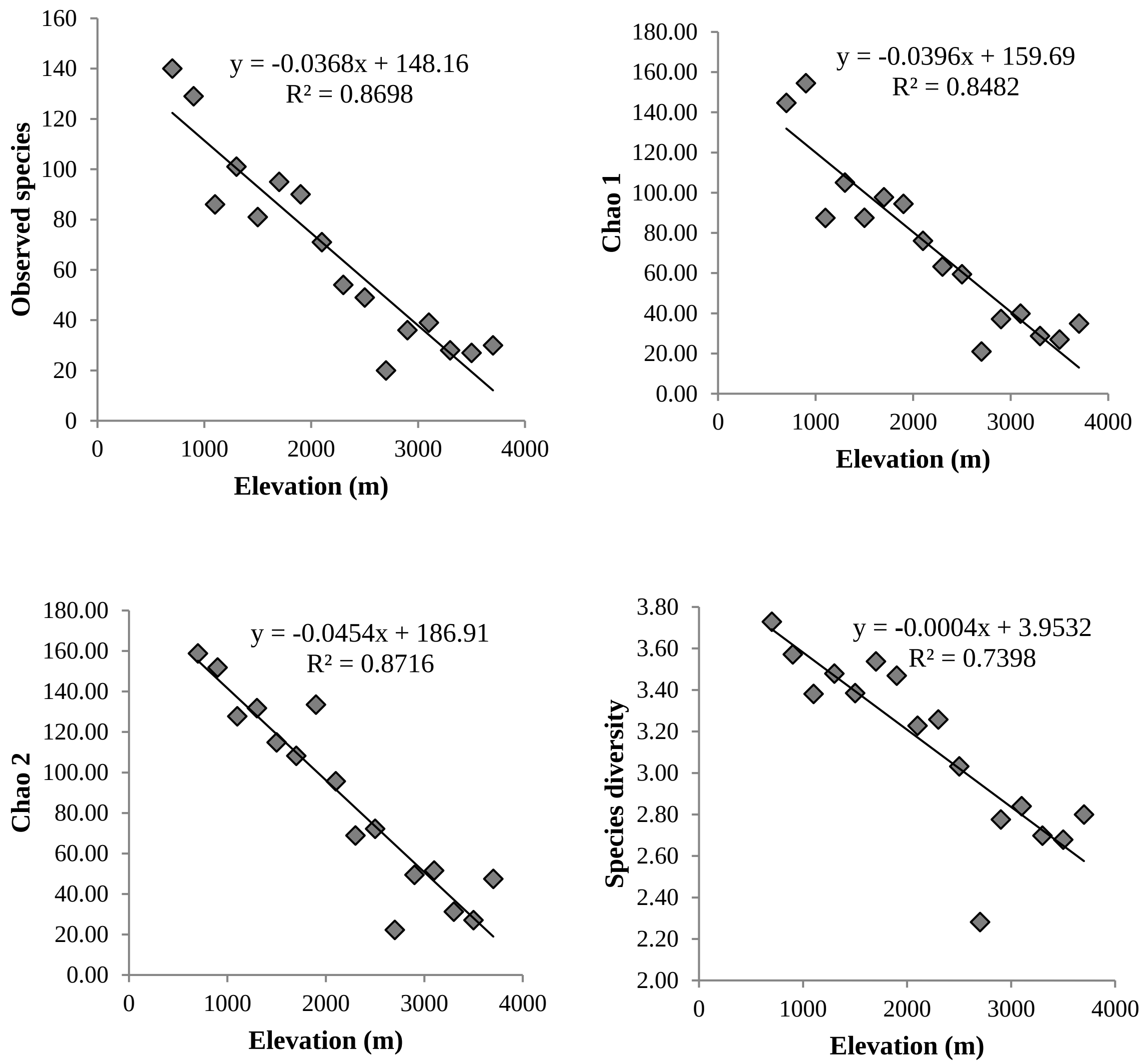


Figure 4.1a. Scatter plot showing elevational band wise bird species richness (Observed, Chao1, Chao2), and Shannon diversity index across the Sutlej river basin.

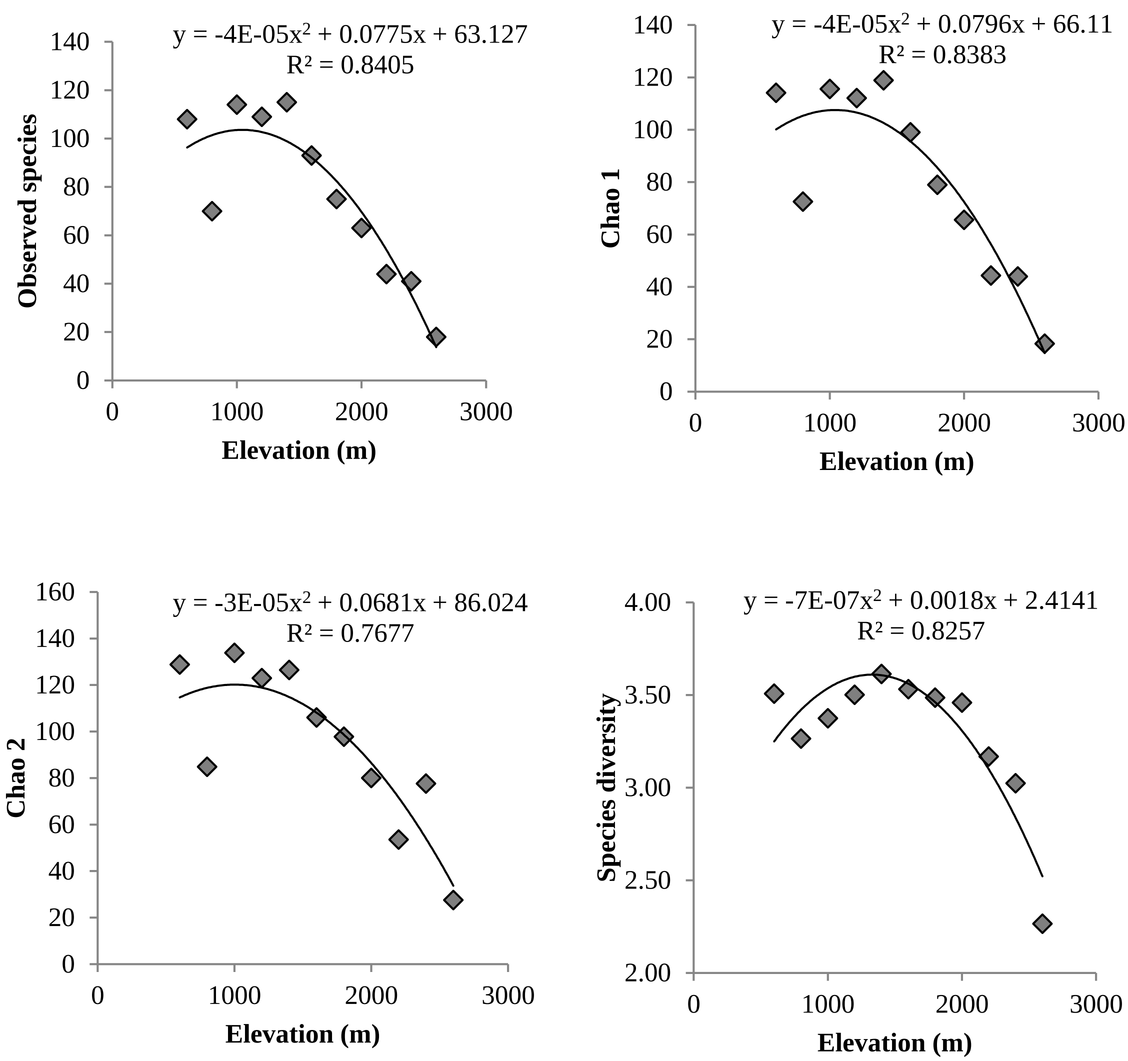
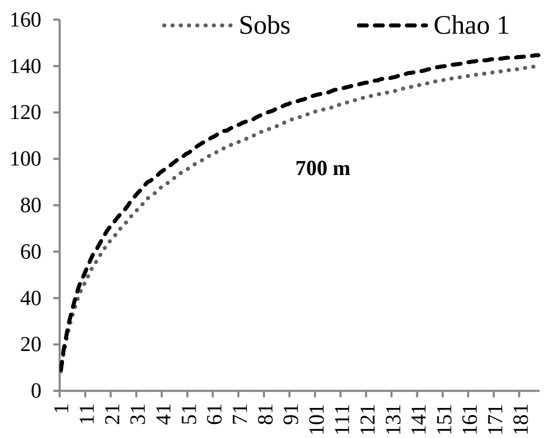
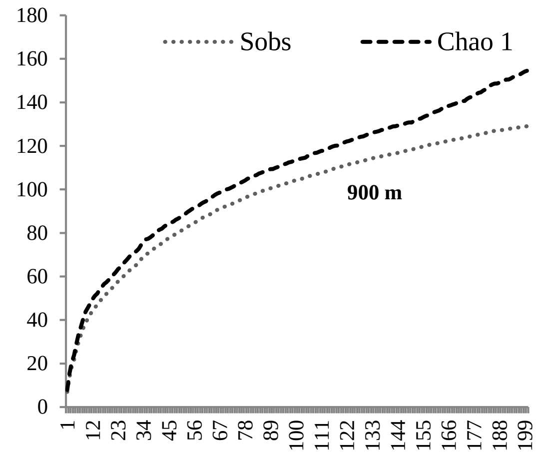
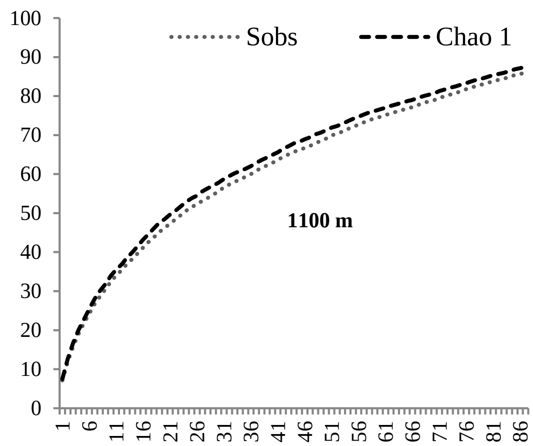
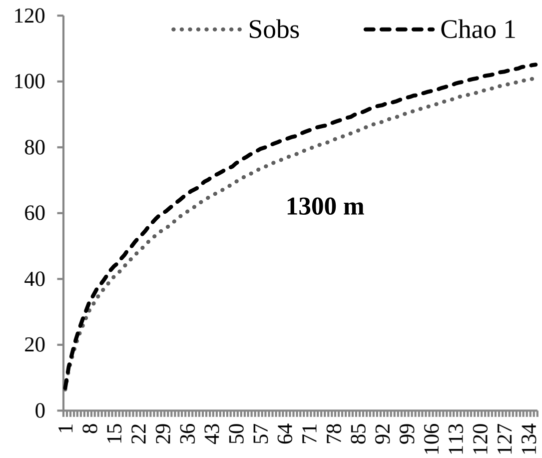


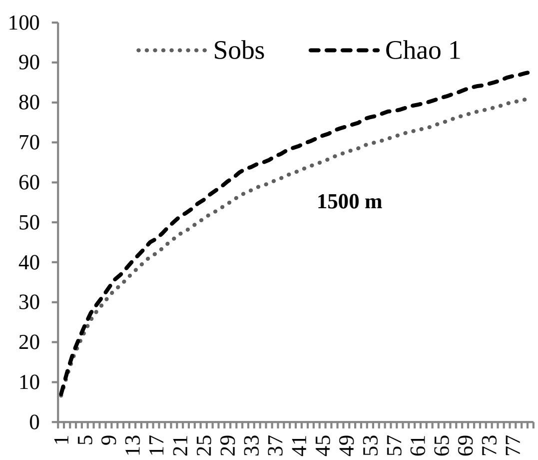
Figure 4.1b. Scatter plot showing elevational band wise bird species richness (Observed, Chao1, Chao2), and Shannon diversity index across the Yamuna river basin.

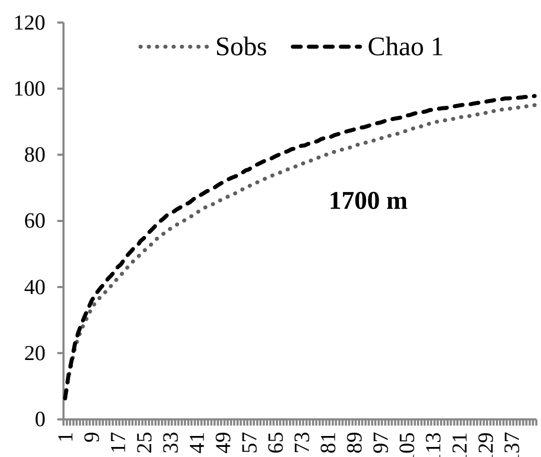

Sobs
Chao 1
700 m
0 20 40 60 80 100 120 140 160
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181

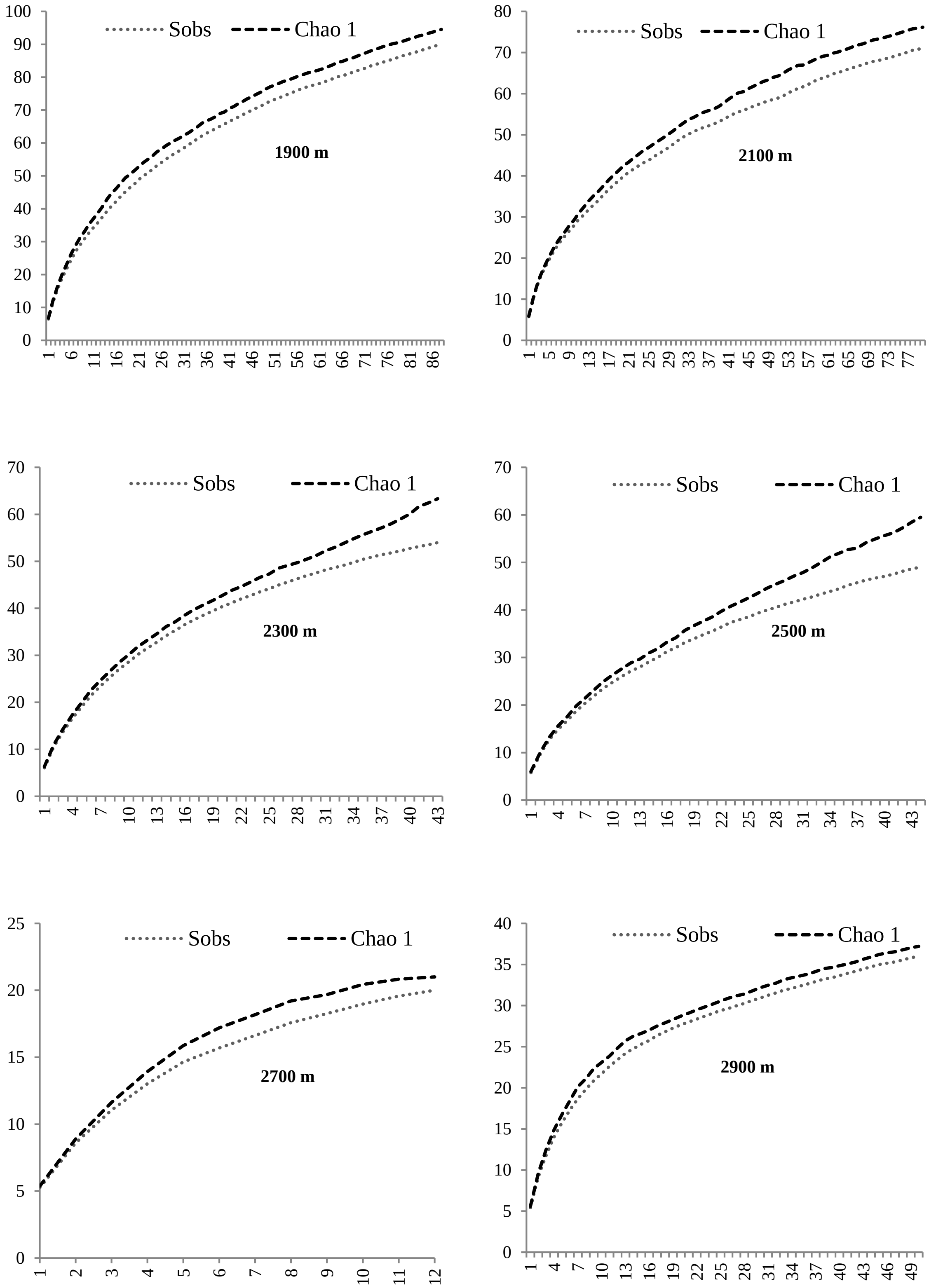

Sobs
Chao 1
900 m
0 20 40 60 80 100 120 140 160 180
1 12 23 34 45 56 67 78 89 100 111 122 133 144 155 166 177 188 199


Sobs
Chao 1
1100 m
0 10 20 30 40 50 60 70 80 90 100
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86


Sobs
Chao 1
1300 m
0 20 40 60 80 100 120
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134


Sobs
Chao 1
1500 m
0 10 20 30 40 50 60 70 80 90 100
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77


Sobs
Chao 1
1700 m
0 20 40 60 80 100 120
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137


Sobs
Chao 1
1900 m
2100 m
2300 m
2500 m
2700 m
2900 m
0 10 20 30 40 50 60 70 80 90 100
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86
0 10 20 30 40 50 60 70 80
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77
0 10 20 30 40 50 60 70
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43
0 10 20 30 40 50 60 70
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43
0 5 10 15 20 25
1 2 3 4 5 6 7 8 9 10 11 12
0 5 10 15 20 25 30 35 40
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49

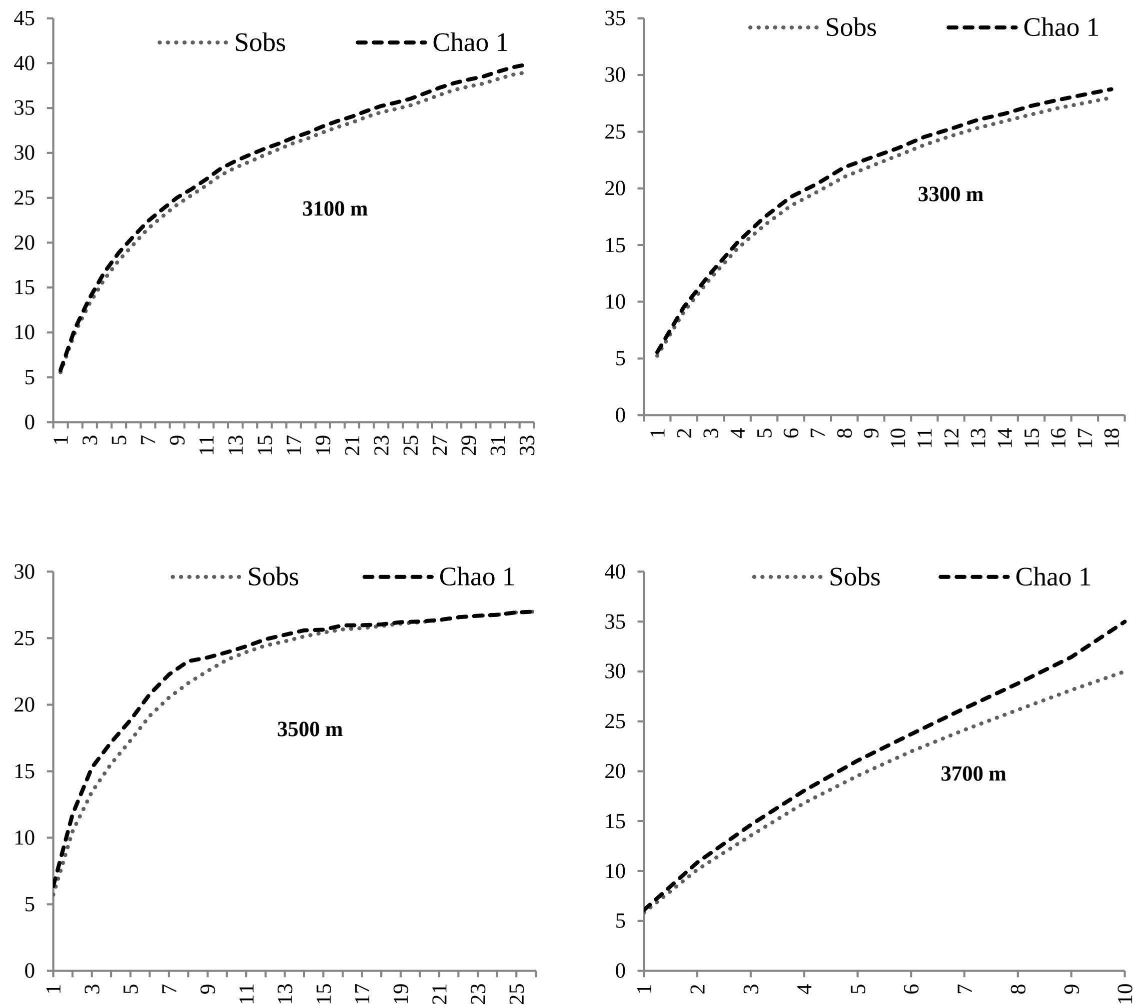
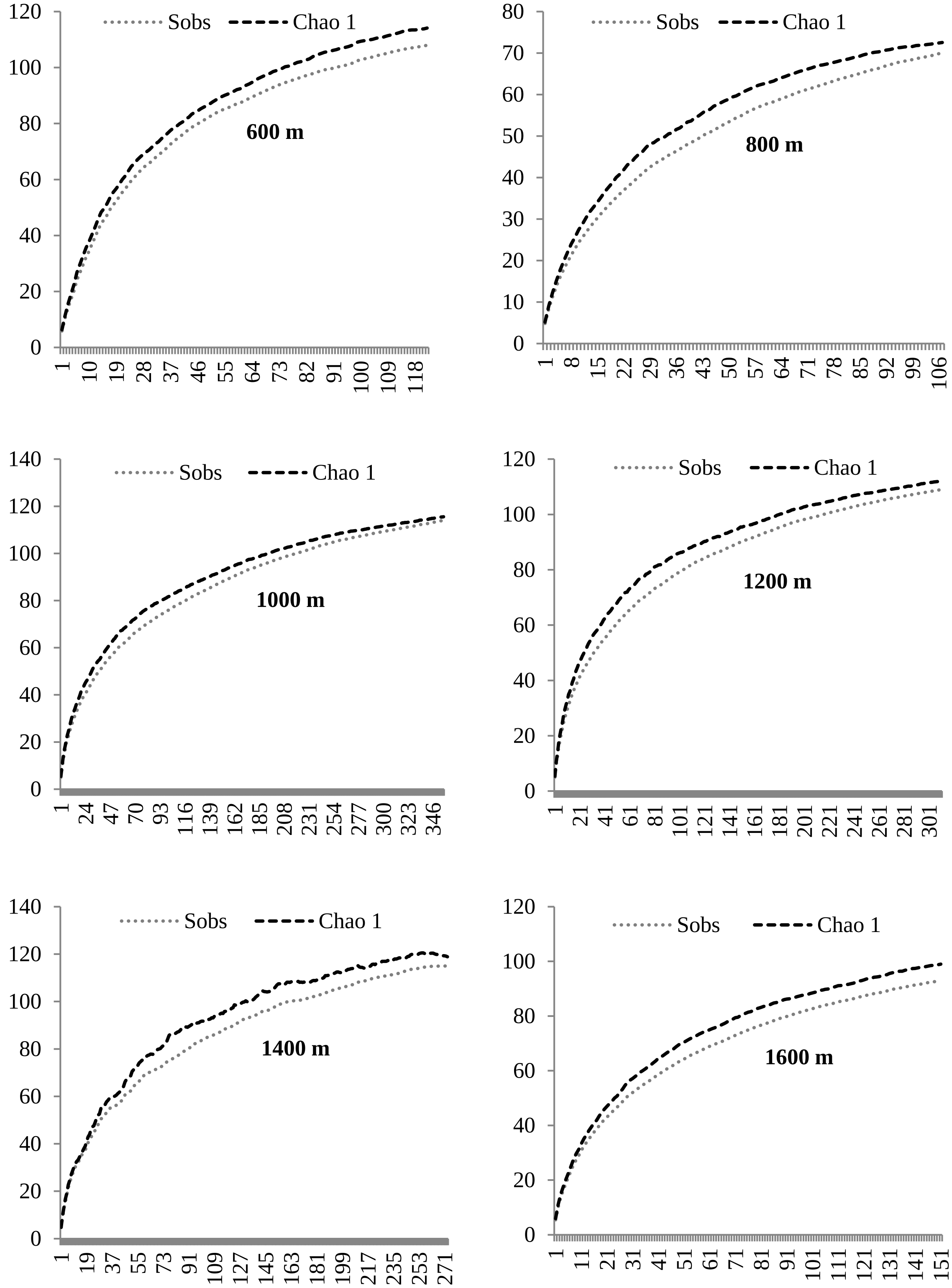


Figure 4.2a Species accumulation curves of birds in different elevational bands across Sutlej river basin, Himachal Pradesh. Horizontal Axis (Sampling Effort); Vertical Axis (Number of Species); Sobs – Species Observed


Sobs
Chao 1
600 m
800 m
1000 m
1200 m
1400 m
1600 m

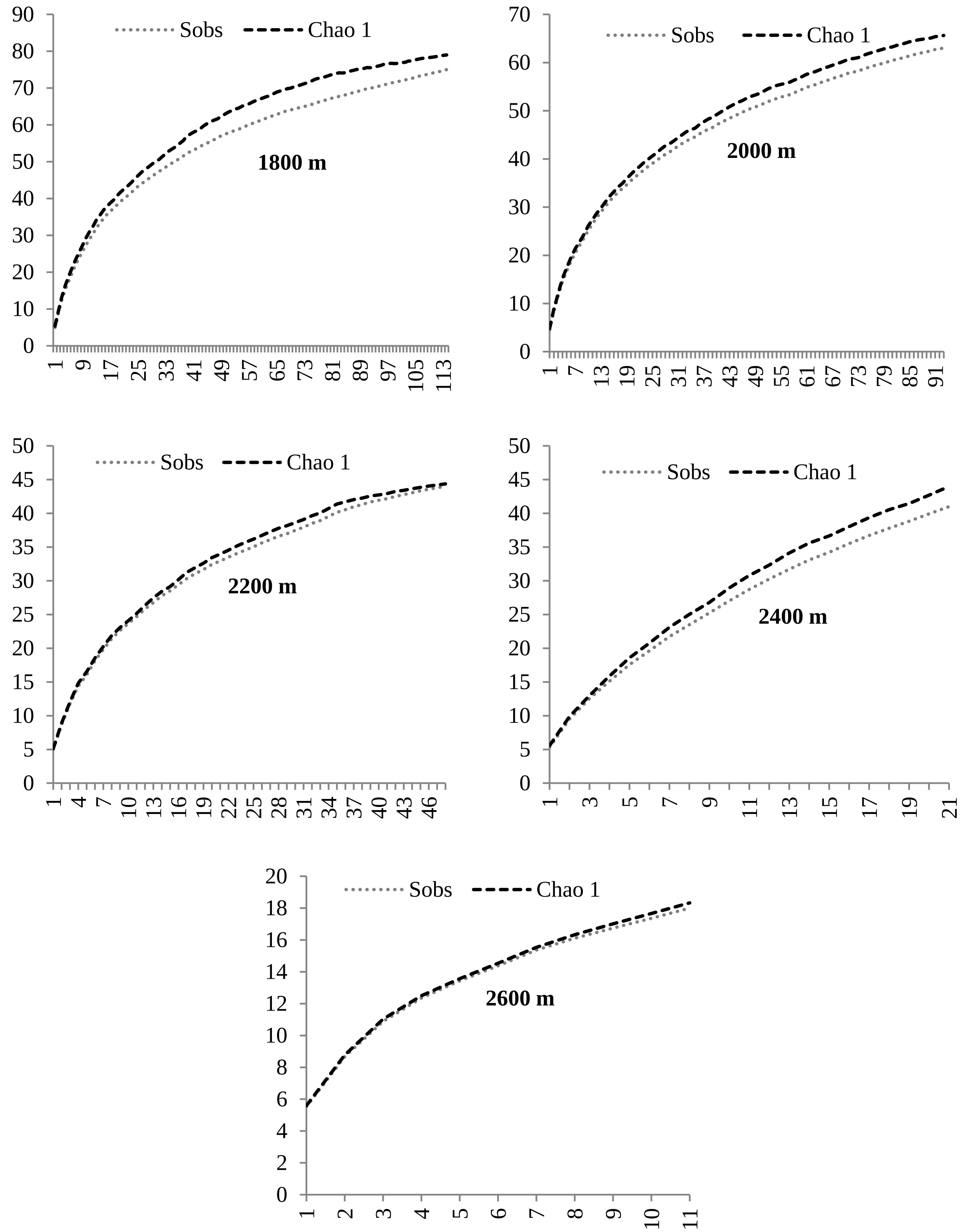


Figure 4.2b Species accumulation curves of birds in different elevational bands across Yamuna river basin, Uttarakhand. Horizontal Axis (Sampling Effort); Vertical Axis (Number of Species); Sobs – Species Observed

4.3.3. Sampling Effort and Species Richness in Relation to Area

The availability of area in Sutlej river basin showed a declining trend with increasing elevation (Figure 4.3a). The available area in each elevational band significantly correlated with sampling points ($r = 0.834$, $p < 0.000$), indicating that the sampling area and proportion of sampling points were sufficient. In addition the observed bird species richness ($r = 0.851$, $p < 0.000$) and estimated species richness ($r = 0.870$, $p < 0.000$) significantly correlated with area. Also, a significant correlation was observed between sampling points and bird species richness ($r = 0.958$, $p < 0.000$).

In contrast, in the Yamuna river basin, the largest area occurs above 1500 m to 2200 m and below 600 m to 800 m, after which it generally declines with increasing elevation. The land area availability shows a hump-shaped pattern peaking at middle elevation (Figure 4.3b). The available area in each elevational band significantly correlated with sampling points ($r = 0.66$, $p < 0.02$), indicating that the sampling area and proportion of sampling points were sufficient. The correlation of the area with observed species richness and estimated species richness showed a negative trend with no significant results. Whereas, sampling points and bird species richness showed low r-value. The results signify that higher elevation is having a larger area compared to lower regions but supporting very limited species richness, however lower elevation with less area supports more species.

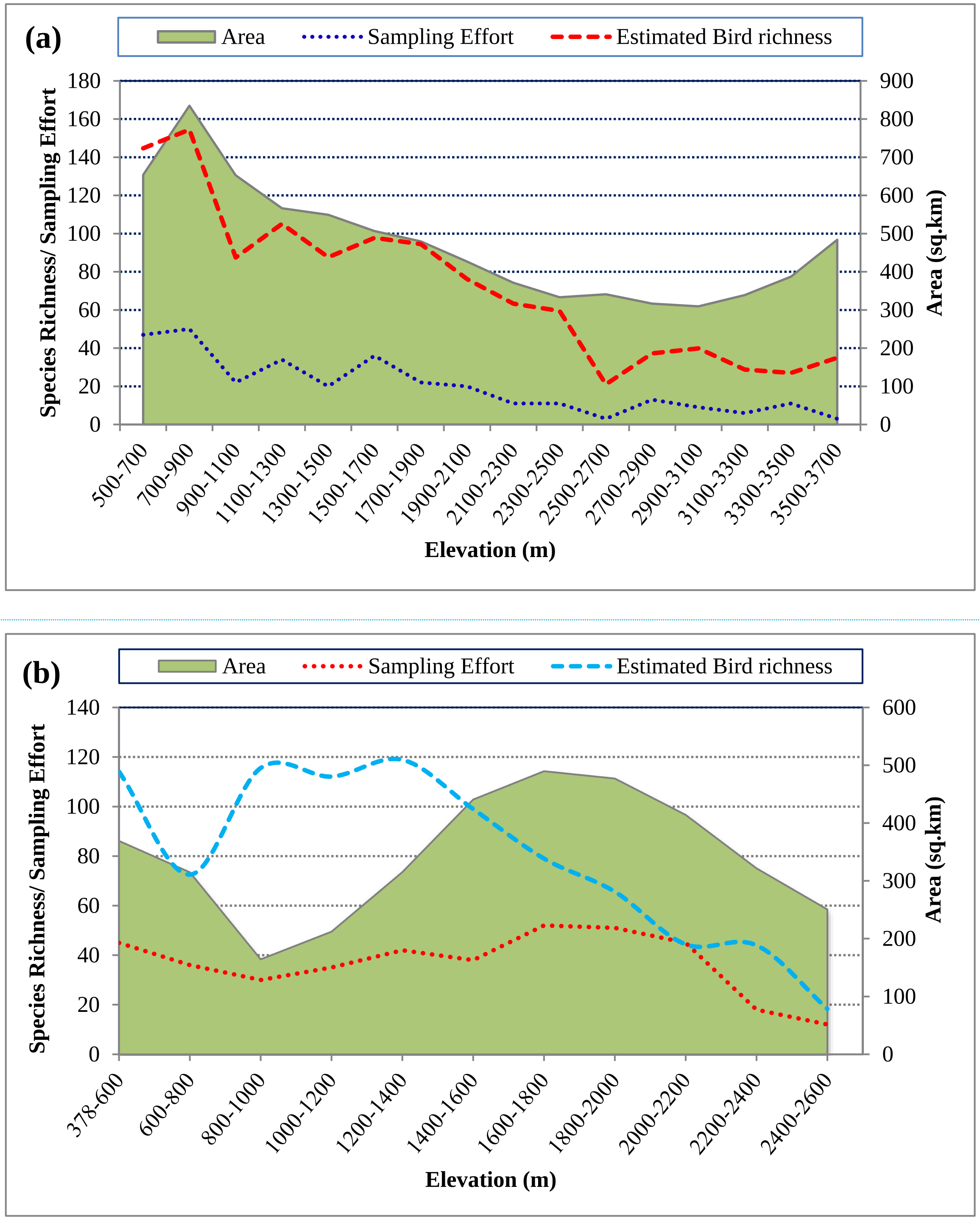


Figure 4.3 Plot showing the relationship between area, sampling effort and estimated species richness across the Sutlej (a) and Yamuna (b) river basin, Western Himalaya.

4.3.4. Trophic Groups

Food availability is one of the most important factors determining the species distributions along the elevation. The bird species found in the Sutlej river basin were classified into eight trophic groups based on their diets; all trophic groups were found along all the elevational gradients, except few groups such as frugivore (< 2500 m), nectarivore (< 2100 m) and piscivores (< 1300 m) were restricted with elevational gradients (Figure 4.4a). Bird species belonging to different trophic groups showed the significant variation along the elevational band (One-way ANOVA: $F = 95.63$, $p < 0.000$). The proportion of insectivorous bird group showed highest species richness with a peak at 700 m followed by granivorous birds. Among the groups, nectarivores and piscivores were observed as least number. The overall picture indicated that all the groups were distributed across the elevational gradient and except a few. However, all the trophic groups showed significant negative correlation with elevation ($p \leq 0.001$).

Based on their food preference of birds in Yamuna river basin also categorized into eight trophic groups observed all along the elevations except piscivorous, which were restricted below 1800 m (Figure 4.4b). The bird species belonging to different trophic groups showed the significant variation along the elevational band (one-way ANOVA; $F = 60.05$, $p < 0.000$). The insectivorous group dominated with highest species richness at middle elevation (1400 m), while other groups peaked between 1000 – 1800 m elevations. Carnivore, frugivore, insectivore, nectarivore, and omnivore showed significant negative correlation with elevation (Pearson correlation, $p \leq 0.03$), while other groups showed no significant correlation with elevation.

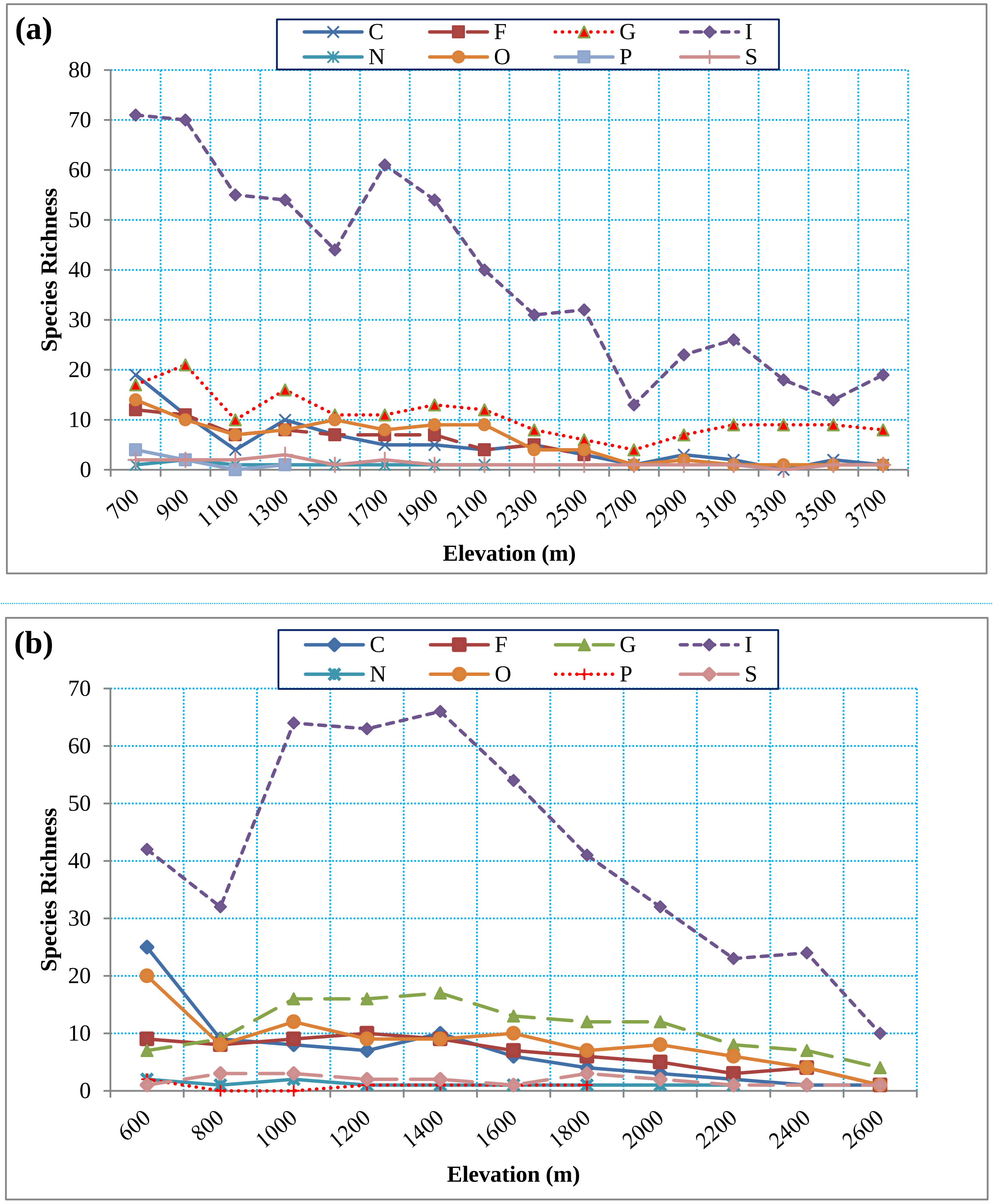


Figure 4.4 Graph showing the different trophic groups along elevation gradient from Sutlej (a) and Yamuna (b) river basins (C- Carnivores, F-Frugivores, G-Granivores, I-Insectivores, N-Nectarivores, O-Omnivores, P-Piscivores and S-Scavengers).

4.3.5. Species Turnover

There was a gradual increase in species turnover with elevation in the Sutlej river basin, with a low turnover rate observed for consecutive bands but a high turnover rate for distant bands (Table 4.2a). The high turnover rate was observed between 498-700 m and 2500-2700 m (0.83). The elevation band 498-700 m and 3300-3500 m, 498-700 m and 3500-3700 m, 700-900 and 2500-2700 m, 700-900 m, and 3300-3500 m showed more than 80% turnover. Among the consecutive band, the turnover rate was highest between 2300-2500 m and 2500-2700 m (0.54). The lowest species turnover rate was observed between 3100-3300 m and 3300-3500 m, and 3300-3500 m and 3500-3700 m (0.16). Maximum species sharing in distant bands was observed between 700-900 m and 1500-1700 m (82 species), and minimum between 498-700 and 2500-2700 m (Table 4.2a). The highest species sharing between consecutive bands was observed between 498-700 m and 700-900 m (108 species) and the lowest was observed between 2300-2500 m and 2500-2700 m. Species turnover rate between two consecutive elevational bands showed significant correlation ($r = 0.56$; $p < 0.000$).

Yamuna river basin also showed the gradual increases of species turnover with elevation. Species turnover rate was low between consecutive bands but was high between distant bands (Table 4.2b). The highest turnover among the consecutive band was between 2200-2400 m and 2400-2600 m (0.49) and lowest was between 800-1000 m and 1000-1200 m (0.13). The high turnover rate of distant bands was observed between 378-600 m and 2400-2600 m (0.76). The elevation band 378-600 m had a higher turnover rate (more than 60%) with many elevation bands (between 1800-2600 m). Band 800-1000 m and 2400-2600 m, 1000-1200 m and 2400-2600m, 1200-1400 m and 2400-2600 m showed more than 70% turnover. The highest species sharing in the distant band was observed between 378-600 and 1200-1400 m (65 species) and the consecutive band was between 800-1000 m and 1000-1200 m (97 species). Species turnover between two consecutive elevational bands showed significant correlation ($r = 0.64$; $p < 0.000$).

Table 4.2a Species turnover and shared species between different elevational bands across Sutlej river basin, Himachal Pradesh. (Turnover-Table is read by row to column; Shared Species – Column to row).

Elevation Band (m)	**498-700**	**700-900**	**900-1100**	**1100-1300**	**1300-1500**	**1500-1700**	**1700-1900**	**1900-2100**	**2100-2300**	**2300-2500**	**2500-2700**	**2700-2900**	**2900-3100**	**3100-3300**	**3300-3500**	**3500-3700**
498-700	-	0.20	0.33	0.30	0.32	0.34	0.36	0.46	0.56	0.62	**0.83**	0.72	0.75	0.77	**0.81**	**0.80**
700-900	108	-	0.27	0.23	0.28	0.27	0.30	0.41	0.51	0.57	**0.80**	0.70	0.76	0.77	**0.80**	0.79
900-1100	76	78	-	0.23	0.29	0.28	0.30	0.41	0.46	0.53	0.77	0.67	0.74	0.75	0.77	0.78
1100-1300	84	89	72	-	0.26	0.21	0.25	0.34	0.42	0.49	0.75	0.61	0.70	0.72	0.73	0.74
1300-1500	75	76	59	67	-	0.27	0.28	0.33	0.42	0.46	0.72	0.62	0.70	0.74	0.74	0.75
1500-1700	78	82	65	77	64	-	0.17	0.28	0.33	0.40	0.70	0.56	0.61	0.64	0.67	0.66
1700-1900	74	77	62	72	62	77	-	0.28	0.29	0.38	0.67	0.51	0.58	0.63	0.66	0.65
1900-2100	57	59	46	57	51	60	58	-	0.34	0.35	0.63	0.40	0.53	0.58	0.59	0.60
2100-2300	43	45	38	45	39	50	51	41	-	0.26	0.57	0.38	0.46	0.54	0.56	0.57
2300-2500	36	38	32	38	35	43	43	39	38	-	0.54	0.41	0.39	0.43	0.50	0.47
2500-2700	14	15	12	15	14	17	18	17	16	16	-	0.39	0.42	0.46	0.53	0.48
2700-2900	25	25	20	27	22	29	31	32	28	25	17	-	0.28	0.38	0.37	0.39
2900-3100	22	20	16	21	18	26	27	26	25	27	17	27	-	0.22	0.27	0.30
3100-3300	19	18	14	18	14	22	22	21	19	22	13	20	26	-	0.16	0.17
3300-3500	16	16	13	17	14	20	20	20	18	19	11	20	24	23	-	0.16
3500-3700	17	17	13	17	14	21	21	20	18	21	13	20	24	24	24	-

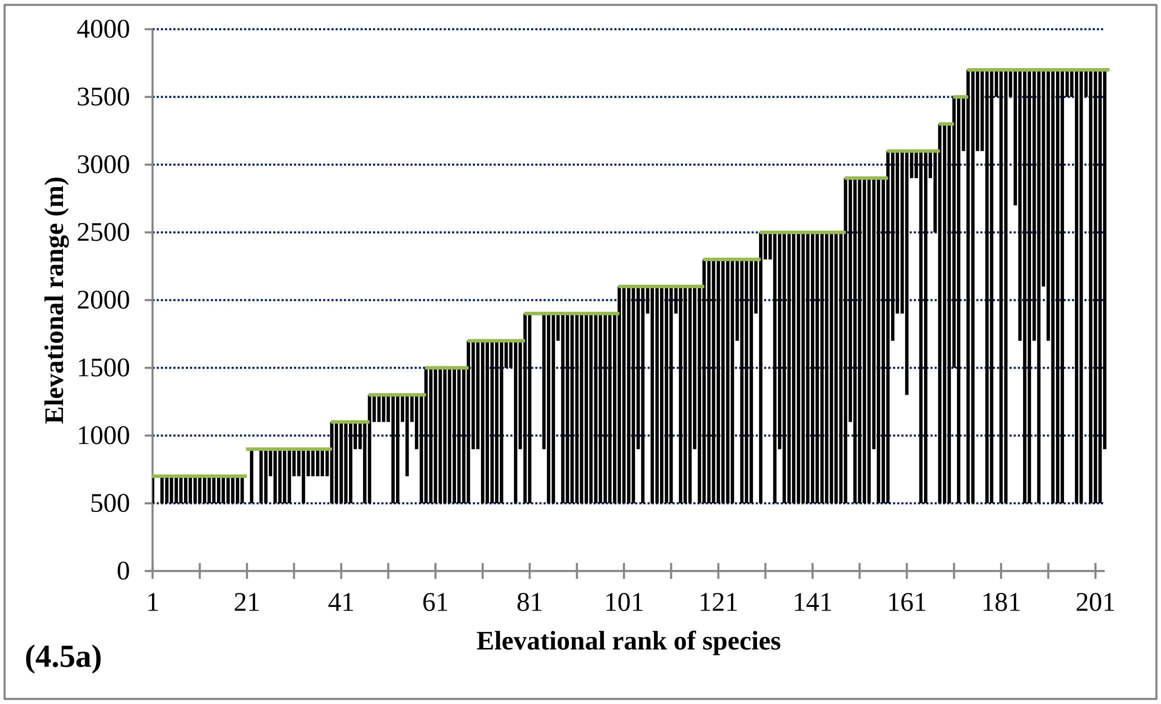
Table 4.2b Species turnover and shared species between different elevational bands across Yamuna river basin, Uttarakhand

Elevation Band (m)	**378-600**	**600-800**	**800-1000**	**1000-1200**	**1200-1400**	**1400-1600**	**1600-1800**	**1800-2000**	**2000-2200**	**2200-2400**	**2400-2600**
378-600	-	0.36	0.40	0.41	0.42	0.46	0.56	0.60	0.62	0.62	**0.76**
600-800	57	-	0.30	0.32	0.33	0.34	0.41	0.41	0.44	0.50	0.64
800-1000	67	64	-	0.13	0.17	0.24	0.34	0.40	0.51	0.56	**0.74**
1000-1200	64	61	97	-	0.16	0.21	0.32	0.41	0.50	0.52	**0.72**
1200-1400	65	62	95	94	-	0.18	0.30	0.39	0.47	0.51	**0.73**
1400-1600	54	54	79	80	85	-	0.21	0.32	0.39	0.42	0.68
1600-1800	40	43	62	63	67	66	-	0.28	0.33	0.36	0.63
1800-2000	34	39	53	51	54	53	50	-	0.25	0.37	0.56
2000-2200	29	32	39	38	42	42	40	40	-	0.25	0.45
2200-2400	28	28	34	36	38	39	37	33	32	-	0.49
2400-2600	15	16	17	18	18	18	17	18	17	15	-

4.3.6. Elevational Range Profile

Elevational range profile of the birds in the Sutlej river basin showed that most species occupied very narrow elevational ranges along the elevation gradient (Figure 4.5a). Among the total number of bird species recorded, 147 (72%) species were restricted within 2500 m elevation, whereas 56 species occurred above 2500 m, and 10 species occurred only above 3000 m. In addition, there were 27% (55 spp.) of bird species found in only a single elevational band, but 17 species occurred at the whole elevational gradient (Figure 4.5a). Elevational range sizes of the bird species showed that 34% (70 spp.) of the species used <500 m elevational ranges, whereas 15% (30 spp.) of species showed >2000 m elevational ranges, but only 8% (17 spp.) of species at the ranges of >3500 m (Figure 4.5b). The correlation between elevational range size with lower and upper limit of each species showed that the range size of low elevation species (*i.e.* those occurring below 2000 m) tended to decrease with elevation ($r = -0.383$, $p < 0.00$), whereas range sizes of high elevation (above 2000 m) species tended to increase with elevation ($r = 0.282$, $p < 0.01$).

In contrast to Sutlej, elevational range profile of Yamuna river basin showed that majority of the bird species recorded at above 1500 m elevation (Figure 4.6a). Forty species were restricted within 1000 m and six species restricted above 1500 m elevations, whereas 44% (79 spp.) of species occurred <1500 m, and remaining species at the ranges of >1500 m elevation. Also, there were 36 species of birds found in a single or double elevational band, but 15 species were found at all the elevational gradients (Figure 4.6a). However, the maximum bird species richness was found between 1000 – 1500 m elevational bands. The number of species declined with the increase in range size (Figure 4.6b). Around 32% (57 spp.) of species used very narrow elevational range sizes (< 500 m) and 10% of species used >2500 m elevational ranges (Figure 4.6b). The range sizes of low elevation species (below 1500 m) tended to decrease with elevation ($r = -0.128$, $p < 0.26$), whereas range sizes of high elevation (above 1500 m) species tended to increase with elevation ($r = 0.743$, $p < 0.00$).



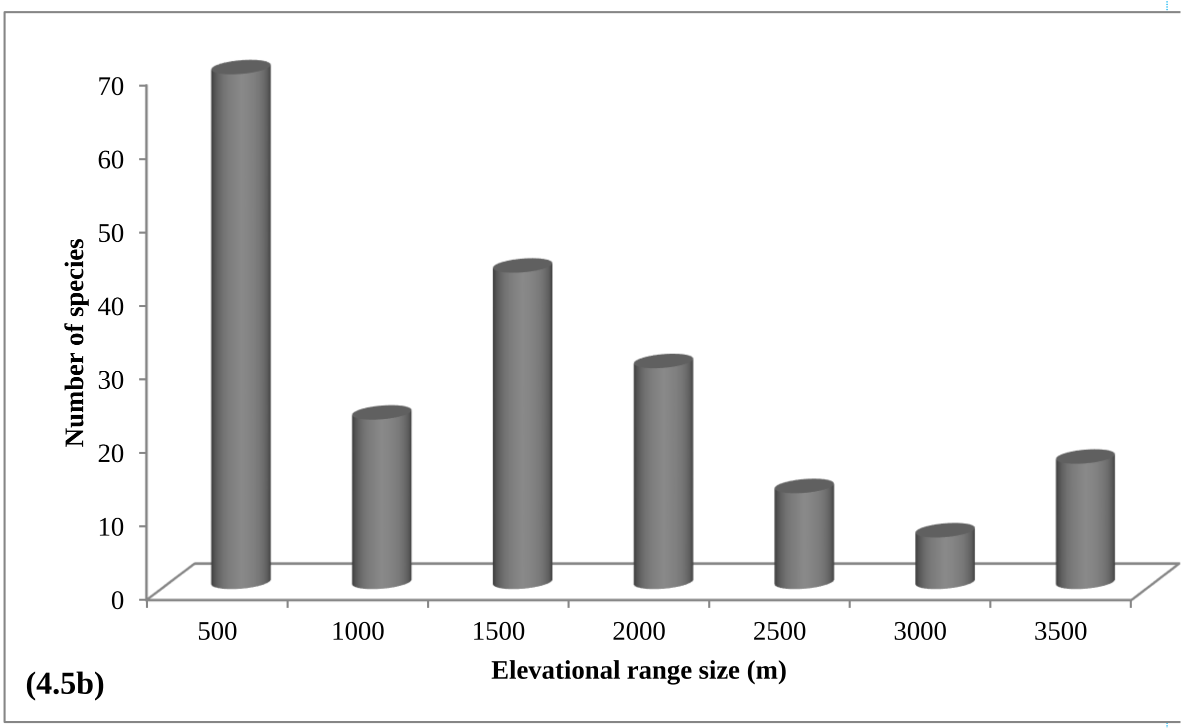


Figure (4.5a) Elevational range size of bird species (Vertical bars indicate maximum and minimum elevational limits of each species) and **(4.5b)** Elevational range-size utilization of bird species across the Sutlej river basin.

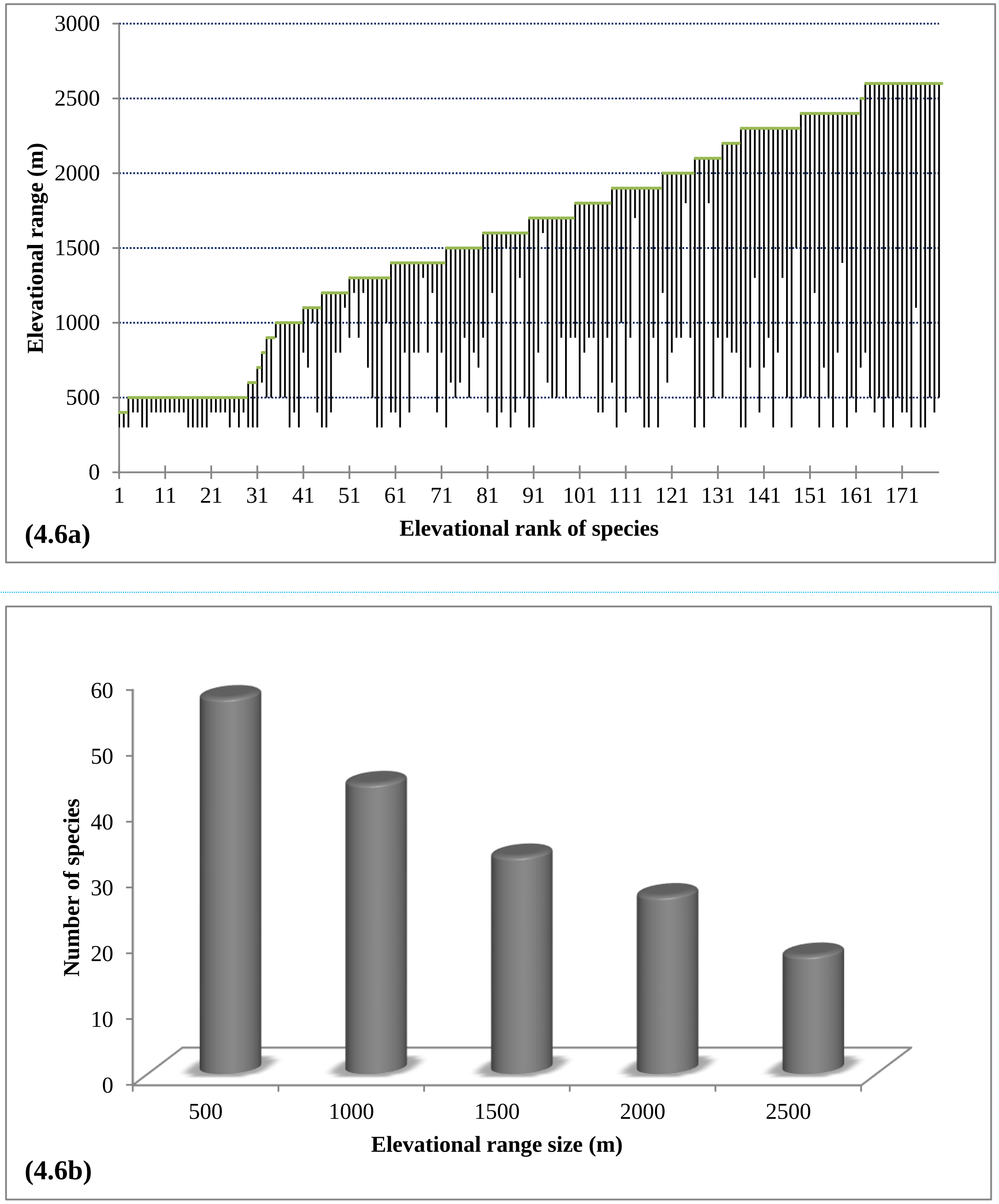


Figure (4.6a) Elevational range size and, (**4.6b)** Elevational range-size utilization of bird species across the Yamuna river basin.

4.3.7. Mid-Domain Null Model

Sutlej River Basin

MDE predictions were observed with very limited support in the Sutlej river basin. The observed species richness significantly declined with increasing elevations ($F_{(1,14)}$ = 93.52, p < 0.000; R^2 = 0.87; Figure 4.1a). The species distribution pattern showed a monotonic decline with an increase in elevation. A similar pattern was observed in the mid-domain effect, where the data revealed a poor fit to the MDE predictions. The range size of resident bird species showed only 12.5% (2 out of 16 points) of the empirical points occurring within the predicted range of null model (Figure 4.7a). The regression relationship between empirical species richness and the mean of the predicted richness was not significant ($F_{(1.14)}$ = 0.026, p = 0.87; R^2 = 0.002). The empirical species richness in lower elevation between 500 – 1500 m and higher elevation 2100 – 3700 m deviated from the MDE predicted richness.

MDE for overall bird species showed that out of 16 empirical points, only three points (19%) occurred within the prediction curve (Figure 4.7b). The empirical richness in the lower elevation (between 500 – 1300 m) and higher elevation (1900 – 3300 m) was observed away from the MDE predicted limits. Regression of empirical species richness and the mean of the predicted richness was not significant ($F_{(1.14)}$ = 0.001; p = 0.97; R^2 = 0.0001). A comparison of observed species richness and empirical species richness in different elevational categories showed that they were closely matched with each other. However, an abrupt turn down in observed species richness at the elevation ranges from 900 to 1100 and 1300 to 1700 m (Figure 4.7b).

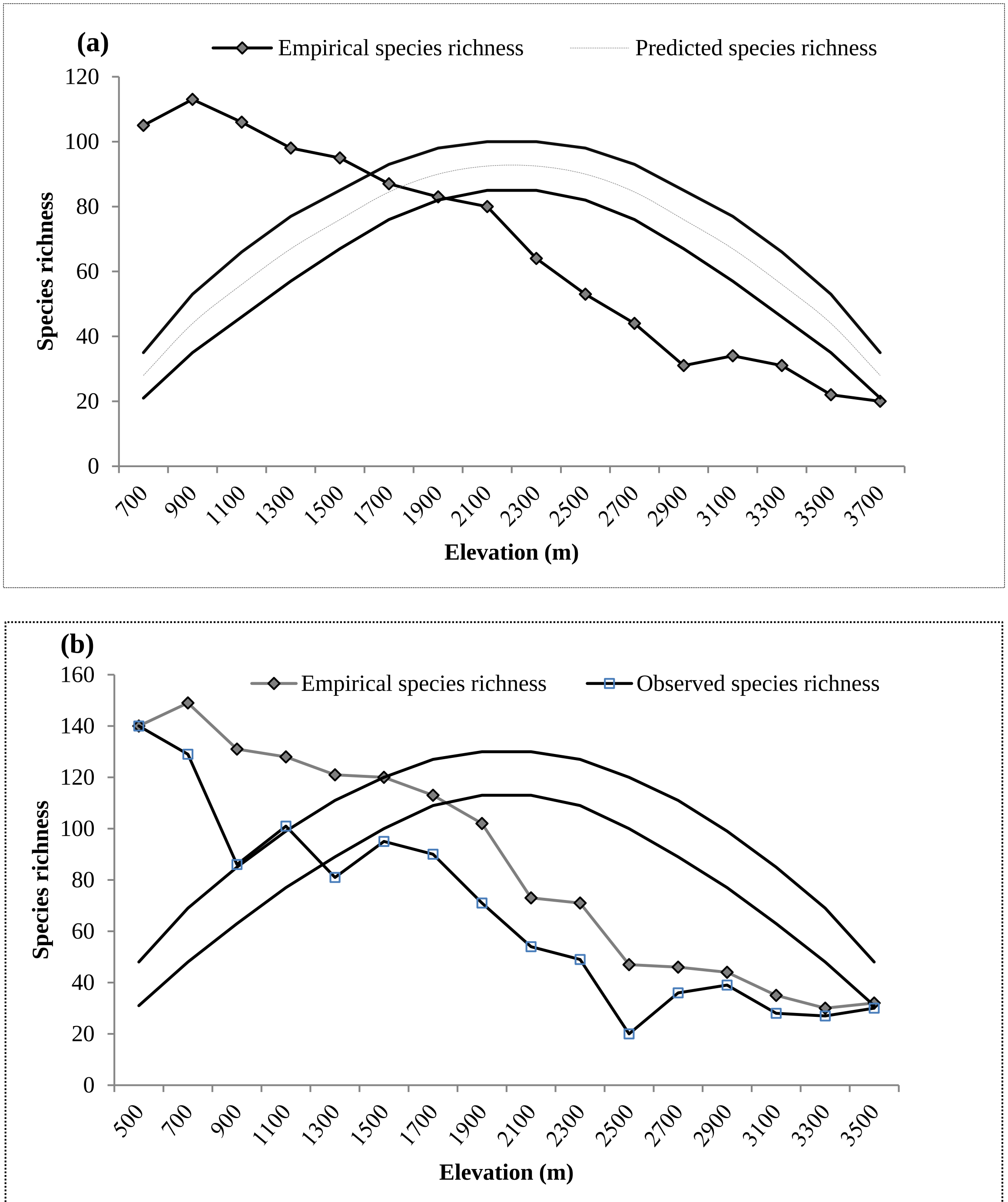


Figure 4.7 Plots showing the elevational patterns of bird species richness in the Sutlej river. (a) Resident birds (b) Overall species. Empirical species richness curves, predicted species richness, observed species richness, and the upper and lower 95% prediction curves sampled without replacement from programme Mid-Domain Null (50,000 simulations).

Yamuna River Basin

The observed species richness and interpolated species richness followed low plateau patterns along the elevational gradient in Yamuna river basin (Figure 4.8a & b). Both the species richness curve showed low-elevational peaks between 1000-1500 m, thereafter species richness decline with increasing elevation (Figure 4.8b). The 95 % prediction curves from 50,000 simulations of the mid-domain null model demonstrated a low fit to the predicted and empirical species richness. Whereas, resident birds showed only 18% (2 out of 11 points) of the empirical species richness occurred inside the predicted range (Figure 4.8a). The regression between empirical species richness and the mean of the predicted richness was not significant ($F_{(1.9)} = 4.078$, $p = 0.07$; $R^2 = 0.312$). Thus there were two clear peaks found at a middle elevation between 1500 m and 1700 m, rest of the empirical points almost close to the predicted domain. But only one empirical point from lower elevation (600 m) has highly deviated from the predicted domain.

Overall bird species richness also followed the same pattern, species richness of birds peaked at 1000-1500 m elevation further showed a declining trend with increase elevation (Figure 4.8b). Out of the 11 (18%) empirical points, two were found inside boundaries of the predicted domain, whereas deviations from the mid-domain boundaries noticed at 600 m, 1100 m, and 2300 m elevation. Regression of empirical species richness with mean of the predicted richness relationship was not significant ($F_{(1.9)} = 3.712$; $p = 0.08$; $R^2 = 0.292$).

The observed species richness and empirical species richness closely matched with each other. On the contrary, 27% (3/11 points) of the observed species richness spin within the predicted range boundaries than predicted richness (Figure 4.8 b). In general, it showed that the deviation between empirical and observed species richness association was not significant. The overall trend showed that considerable amount of species richness found above 800 m, after increase towards 1000 m and steady until 1500 m elevation thereafter the curve was declining to the increasing elevation. This pattern strongly indicated that there was a low plateau species richness followed in Yamuna river basin.

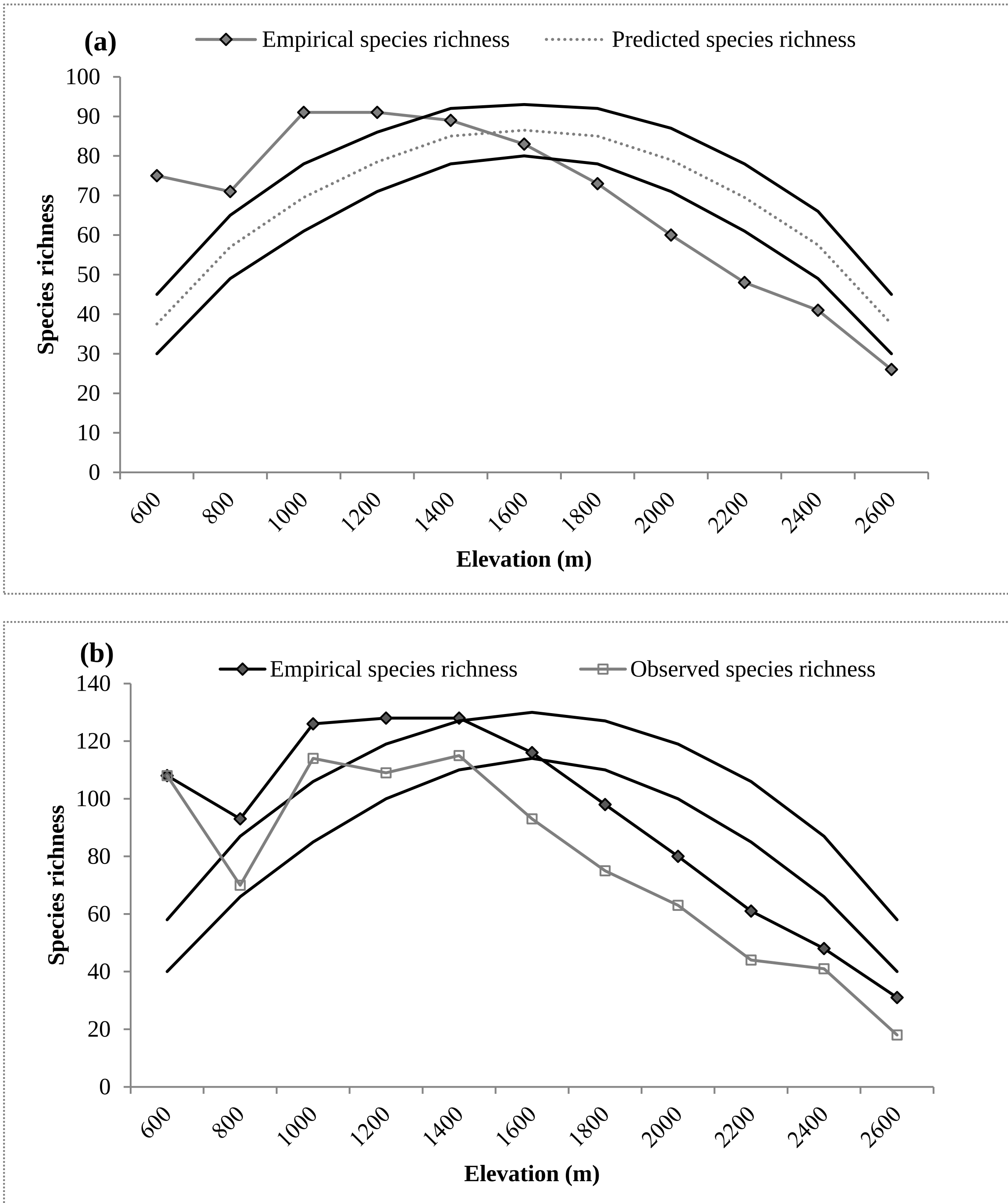


Figure 4.8 Plots showing the elevational patterns of bird species richness in the Yamuna river. (a) Resident birds (b) Overall species. Empirical species richness curves, predicted species richness, observed species richness, and the upper and lower 95% prediction curves sampled without replacement from programme Mid-Domain Null (50,000 simulations).

4.3.8 Factors Governing Species Distribution

Sutlej River Basin

Relationship of bird species richness with respect to various environmental factors is given in the Table 4.3a. Most of the environmental factors (except MDE, NDVI April, and February) significantly correlated with the estimated species richness. The mean annual temperature showed the highest r^2 value followed by other variables. The results of stepwise multiple regressions with seven selected factors in the first model showed that the mean annual temperature significantly correlated with estimated species richness (Table 4.4a). After removing mean annual temperature, the second model habitat variable NDVI March significantly correlated, and when the habitat variable was removed, the third model mean annual precipitation showed significant correlation with bird species richness.

Yamuna River Basin

The r^2 and related p-values for simple linear regression between estimated species richness and environmental factors are shown in Table 4.3b. The factors such as mean annual temperature, mean annual precipitation and NDVI (February, March, June) were all correlated strongly with the estimated species richness, whereas MDE richness, area and NDVI (December, October, May, September) were not significant. The mean annual temperature showed the highest r^2 value followed by NDVI February (Table 4.3b). In the stepwise regression first model, mean annual temperature was significantly correlated with estimated richness (Table 4.4b). After removing mean annual temperature the second model habitat variable NDVI February has significantly correlated, when the second model was excluded the third model mean annual precipitation correlated significantly. However, these results indicate that the mean annual temperature was the major factor influencing the distribution pattern of birds along an elevation gradient.

Table 4.3a Simple linear regression analyses of estimated species richness against ten environmental factors, Sutlej river basin.

S. No	Response variable	Predictor variable	r^2 values	*P* - values
1	Estimated species richness (Chao1)	MAT	**.850**	.000
2		NDVI March	**.847**	.000
3		MAP	**.805**	.000
4		Area	**.756**	.000
5		NDVI July	**.748**	.000
6		NDVI November	**.686**	.000
7		NDVI October	**.656**	.000
8		NDVI April	.152	.135
9		MDE	.031	.512
10		NDVI February	.015	.650

MAT, mean annual temperature; MAP, mean annual precipitation; NDVI, normalized difference vegetation index; MDE, mid-domain effect. Significant (*P*<0.000) r^2 values are shown in bold font.

Table 4.4a Explanatory variables estimate for the best-fit stepwise multiple regression models (Sutlej river basin).

Model	Variables	Selected Model	Part Correlation	Adjusted R^2±SE	F	P
1	MAT, NDVI March, MAP, Area, NDVI July, NDVI November, NDVI October	MAT	0.922	0.839±16.45	79.10	<0.000*
2	NDVI March, MAP, Area, NDVI July, NDVI November, NDVI October	NDVI March	0.920	0.836±16.61	77.25	<0.000*
3	Area, NDVI July, NDVI November, NDVI October	MAP	0.897	0.791±18.74	57.70	<0.000*

MAT, mean annual temperature; MAP, mean annual precipitation; NDVI, normalized difference vegetation index. Significant (*P*<0.000*) level.

Table 4.3b Simple linear regression analyses of estimated species richness against eleven factors, Yamuna river basin.

S. No	Response variable	Predictor variable	r^2 values	*P* - values
1		MAT	**0.730**	0.001
2		NDVI February	**0.673**	0.002
3		MAP	**0.638**	0.003
4		NDVI March	**0.605**	0.005
5		NDVI June	**0.440**	0.026
6	Estimated species richness (Chao1)	NDVI December	0.316	0.072
7		NDVI October	0.290	0.088
8		MDE	0.164	0.216
9		NDVI May	0.065	0.448
10		Area	0.034	0.585
11		NDVI September	0.010	0.774

MAT, mean annual temperature; MAP, mean annual precipitation; NDVI, normalized difference vegetation index; MDE, mid-domain effect. Bold numbers indicate significant r^2 values (*P*<0.00)

Table 4.4b Explanatory variables estimate for the best-fit stepwise multiple regression models (Yamuna river basin).

Model	Variables	Selected Model	Part Correlation	Adjusted R^2±SE	F	P
1	MAT, NDVI February, MAP, NDVI March, NDVI June	MAT	0.854	0.700±18.95	24.30	<0.001*
2	NDVI February, MAP, NDVI March, NDVI June	NDVI February	0.820	0.637±20.85	18.51	<0.002*
3	MAP, NDVI March, NDVI June	MAP	0.799	0.598±21.92	15.88	<0.003*

MAT, mean annual temperature; MAP, mean annual precipitation; NDVI, normalized difference vegetation index. Significant (*P*<0.00*) level.

4.4. DISCUSSION

4.4.1. Species Richness, Diversity, and Abundance

Directly plotting the number of bird species against the corresponding elevational gradient bands of the Sutlej (500-3700 m) and Yamuna (378-2600 m) river basin confirmed the generally observed pattern of a decline in species richness with increasing elevation (Rahbek, 1995). But in Yamuna river basin the species richness peaked at a lower elevation between 1000 m and 1400 m. Species richness of birds declining with elevation is reported from several other mountain areas, including the mountains of Peru (Terborgh, 1977; Patterson *et al*., 1998), Mexico (Navarro, 1992), Bolivia (Montano-Centellas & Garitano-Zavala, 2015), and multiple mountain areas (McCain, 2009). In addition, other taxonomic groups were also frequently documented with monotonic decline in species richness with elevation, e.g. amphibian (Fauth *et al*., 1989; Wiafe & Agyei, 2013), reptiles (Hofer *et al*., 1999; McCain, 2010; Chettri *et al*., 2010), and mammals (Graham, 1990; Patterson *et al*., 1998). This is mainly attributed to a declining trend in temperature, productivity, and the area towards higher elevations (Stevens, 1992; Rahbek, 1997; Lomolino, 2001).

Bird species richness and diversity of Sutlej river basin peaked at low elevation band between 500 m and 900 m and then decreased (Figure 4.1a). Regression between elevation and species richness and diversity resulted in very high r^2 value (Table 4.1a). This finding was consistent with previous studies on birds. For instance, species richness of birds in Eastern Andes of Peru (Terborgh, 1971; Terborgh & Weske, 1975), South America (Rahbek, 1997) and Eastern Madagascan (Hawkins, 1999) reported richness peaked at 500-1000 m elevation. Patterson *et al*., (1998) observed species richness peak at 500 m in Andes Mountains in southeastern Peru, and Mallet-Rodrigues *et al*., (2010) reported highest species richness found at 100-1000 m in Serra dos Orgaos Mountain in southeastern Brazil. This higher richness in lower elevation is due to some factors such as habitat complexity, availability of area and temperature (Terborgh, 1975; McCain, 2009; Yu *et al*., 2013).

Yamuna river basin, species richness, and diversity showed a peak at 1000-1400 m elevational band, even though the general pattern was a monotonic decline (Figure 4.1b).

The absence of species below 800 m would have resulted in high species richness in the consecutive band. The absence of species richness was caused possibly due to the intense human interference of the region. A few large-scale studies have found a peak in species richness between 1000 m and 1800 m elevation. Joshi and Rautela (2014), Joshi and Bhatt (2015) reported species richness and diversity peak at 1200-1400 m in a study carried out on birds in Doon valley, Uttarakhand having similar climatic conditions as that of Yamuna river basin. Breeding bird species in Hengduan Mountains in China reported species richness gradually increased with elevation, peaked at around 800-1800 m, and then decreased along the higher elevation *i.e.* around 6000 m (Wu *et al*., 2013). The distant diversity pattern of bird species is due to the severity of the climatic condition that may cause the species to specific elevation bands (Rahbek, 1995).

In Sutlej river basin abundance showed a monotonic decline with elevation. From lower to middle elevation (>500-2100 m) abundance decreased simultaneously with species richness along the elevation, but the sudden decline was noticed between 2300-2500 m with low abundance then increases (beyond 2700 m) with elevation (Table 4.1a). Decline numbers in this specific region (2300-2500 m) was possibly due to the intense human occupation. Although the number of species decreased with elevation, abundance showed a different pattern with more individuals in the higher elevations (>3500 m). Declines in species number with elevation have been reported that reduction of insect abundance, fruit and nectar production, and abundances of many small vertebrates (McCain, 2009). The high abundance was due to restricted distribution of three higher elevation species (*Columba rupestris*, *Columba leuconota* and *Pyrrhocorax pyrrhocorax*) with aggregation of many individuals.

Species richness and abundance of Yamuna river basin also showed a contrast pattern with elevation. Abundance and richness of species were different among elevational bands because elevation affects the condition of the physical environment (Stevens, 1992). Species abundance was high at lower elevation band (<600 m) then decreases moderately towards with elevation (Table 4.1b). The fluctuations in abundance may be caused by local movements within and among habitats at the same elevational bands (Loiselle & Blake, 1991). There were two abundance peaks found between 1200 m and 1400 m and beyond 2400 m. The high species abundance of the elevational bands indicates the possibility of resources such as habitat structure (for food availability and provides good shelter and nesting sites), competition, predation and climatic conditions (Cody, 1981; Loiselle & Blake, 1991; Stevens, 1992; Kattan & Beltran, 1999; Jayson & Mathew, 2000).

Species richness estimators are based on assumptions that the community being sampled is present at all times during sampling. However the sample is too low, approaching estimators yield higher values than the observed richness (Colwell & Coddington, 1994). In Sutlej and Yamuna river basin all non-parametric estimators showed higher values than observed species richness. The observed species richness obtained from point count corresponded well with a Chao1 estimate. The patterns of species richness across these elevational bands indicate that sampling was fairly complete, although few additional species remain to be documented in some of the elevational bands of Sutlej (elevational band 900 m, 2300 m, 2500 m, and 3700 m; Figure 4.2a) and Yamuna River Basin (band 2400 m and 2600 m; Figure 4.2b). This could be attributed to under sampling of this terrain in few elevational bands because of inaccessibility and landscape degradation (Pandit & Grumbine, 2012).

In a population with many rare species represented by singletons, the probability of encountering new species are higher or singletons may disappear only after more sampling (Walther & Moore, 2005). Sutlej river basin showed 17 singleton species in lower elevation, 10 singletons in middle and 8 singletons in higher elevation, likewise in Yamuna river basin found 15 singleton species in lower elevation and 7 singletons in higher elevation, which indicates the chances of more new species in these elevational bands. Detecting all species in natural communities may not be possible (Walther & Moore, 2005) and hence, the estimated richness using estimators provide as a useful tool for assessing the biodiversity of the area. As most of the species were detected during sampling, a little effort is needed to detect the missing species especially from lower elevation of Sutlej and Yamuna river basin.

4.4.2. Area

In McCain, 2007b, the shape of the species-area relationship was largely responsible for the high variability of area effects. A strong species richness-area relationship was expected when both variables show similar patterns along the elevational gradient. In the Sutlej river basin, the area declined monotonically with elevation, making an exceptional test system for evaluating the importance of area on species richness patterns. A positive relationship between species richness and area was demonstrated by correlation analyses and individual regression analyses (Table 4.3a). The results supported the species richness-area relationship and followed monotonic declining patterns with elevation (Figure 4.3a). Also, indicating that area was a crucial factor in determining species richness in Sutlej river basin.

The species-area relationship results in the present study (Sutlej) also support studies that have been conducted in other regions, such as the mammal species richness in western U.S.A (Rickart, 2001), South American tropical birds (Rahbek, 1997), and Colombian Andes birds (Kattan & Franco, 2004). Furthermore, Sanders (2002) stated that the amount of available area determines species richness along the elevational gradient. In the Sutlej river basin, although the lower elevational bands harbored a larger area, the climate was hot and humid, resulting in suitable habitat for most bird species.

Lower elevations on mountain ranges usually have larger areas than the higher elevations (Kattan & Franco, 2004). But in Yamuna river basin a large proportion of area have been found in higher elevations (1500 m to 2200 m, Figure 4.3b). The results of correlation analyses showed the negative relationship and regression analyses showed a very low r^2 value between species richness and area respectively (Table 4.3b). This results support McCain (2009) literature analyses at a global level, which stated no consistent support for the influence of area on bird species richness along elevation. Rosenzweig (1995) noted that when to sample a larger area might contribute more species. In contrast, the Yamuna river basin supports only less number of species with a larger area.

4.4.3. Trophic Groups

Instead of looking at the broad distribution pattern of avifauna, it is of interest to examine its dietary components to see whether they all respond similarly to the elevation gradient (Terborgh, 1977). Trophically distinct subdivisions of bird species of Sutlej and Yamuna river basin showed varied pattern along the elevation gradient (Figure 4.4a&b),

the variation in respect to their ecological requirements among different trophic groups (Kessler *et al*., 2001; Elkins, 2004). Both the Sutlej and Yamuna River Basin, species richness of insectivore birds showed the negative correlation with elevation, with the maximum diversity found at a lower elevation. Similar results were reported in earlier studies on birds (Terborgh, 1977; Loiselle & Blake, 1991). The diversity of insects is reported to peak at lower elevation due to less climatic conditions and complexity of vegetation, which increases their diversity and abundance ultimately increasing the diversity and population of birds (Loiselle & Blake, 1991). Insectivorous birds often constitute the most species-rich feeding guild among the subdivisions (Katuwal *et al*., 2016).

Fruit-eating bird species showed a declining trend with elevation but nectar-feeding species exhibits not much variation along an elevation in both the river basin. Terborgh (1977) observed declining pattern in frugivore species richness but found no significant variation in nectarivores with elevation. In addition, Sam *et al*. (2017) reported fruit feeding birds decline with elevation. The decline in species richness is probably due to fluctuation in the availability of fruits and flowers in higher elevation (Loiselle & Blake, 1991; Blake & Loiselle, 2000). Loiselle and Blake (1991) stated that when food turns scarce at one elevation site, birds migrate to resource abundant sites since the specific elevation with constant supplies of these resources attracts many species. This explanation appears reasonable because the availability of fruit crops is considerably more seasonal in lower elevation and also many plants bear fruits and flowers continuously for long periods. The results were consistent with similar other studies in Andes mountains (Terborgh, 1977) and Costa Rica mountains (Blake & Loiselle, 2000). Compare to insectivores, many of the frugivores and nectarivores are less common at higher elevations.

Granivorous birds also showed a declining trend with elevation in both the river systems (Figure 4.4a&b). Grain-eating birds were higher at lower elevation were dominated by agriculture land and open grassland which support more seed production (Girma *et al*., 2017). Compare to other trophic groups, granivores span all over the elevational gradient particularly the higher elevation. Due to the harsh climatic condition in higher elevation, other resources become scarce but dry grains exist even during harsh winter providing constant food to the birds.

Omnivores, carnivores, scavengers and piscivores birds showed monotonic decline along with an elevation gradient in both Sutlej and Yamuna river basin (Figure 4.4a&b). The above listed four trophic groups in Sutlej showed a significant negative correlation with elevation and had relatively higher richness at a lower elevation. Similarly, in Yamuna river basin, carnivores, and omnivores showed significant negative correlation with elevation and richness higher at a lower elevation but scavengers and piscivores showed no significant correlation with elevation. The highest abundance of omnivores in the lower elevation dominated by tropical hill forests was also supported with good availability of animal and plant source diet. Omnivore arises due to resource constraints and high energetic requirements (Mengesha *et al*., 2011) so that exploitation of broader ranges of food items would be beneficial.

The declining trend of carnivore species was consistent with earlier studies on raptors in Andes Mountain (Thiollay, 1996). The certain extent of lower elevation in Sutlej and Yamuna river basin occupied with grassy slopes, the majority of the carnivore species also preferred the grassland habitat because the abundance of small mammals are in grassland habitat than in forested habitats (Girma *et al*., 2017). The decline of carnivores could probably be explained by their specific habitat preference and food habit or lower survival capability at a higher elevation (Thiollay, 1996). Scavengers are free-ranging animals that move over a large area on a daily basis to intake food (Spiegel *et al*., 2013). Both the river basin scavenging birds showed increased movements along the elevation gradient but mostly found in the low and mid-elevation, indicating that availability of food resources. Due to the low abundance of wild ungulates in this region (Thakur, 2014), scavengers depends on domesticated animals for their food (Margalida *et al*., 2009), most of the human settlements are located in the low- and mid-elevation. According to Elkins (2004) statement that many species resort to food sources associated with humans.

Piscivores were the least abundant guilds in the Sutlej and Yamuna river basin. Fish-eating birds in Sutlej were found in the lower elevation (<1300 m) and in the Yamuna, they were restricted to low-and mid-elevation (<1800 m), indicating that availability of food resources was limited. These findings were consistent with similar other studies on the Himalayas which have reported richness of fishes peaking at lower

(500-600 m) and middle (1300 and 1500 m) elevation (Pandit & Grumbine, 2012). The recent literature surveys on Himalayan river studies reported the increased number of damming activities in Sutlej and Yamuna (Pandit & Grumbine, 2012). Due to the damming, the flow regimes alter the river regulation, which often results in the destruction and fragmentation of riverine ecosystems, ultimately restricting the fishes (Lovett, 1999; Grumbine & Pandit, 2013). This explanation appears reasonable because of the less fish prey, making the location more difficult to survive in this particular guild.

4.4.4. Species Turnover

Species turnover in Sutlej and Yamuna River Basin was observed high between distant elevation categories and low in consecutive ones (Table 4.2a&b). The low turnover rate in consecutive bands was due to the overlapping of vegetation and climatic conditions. Among the consecutive bands, the relatively high turnover rate was found in higher elevation in both the river basins. The highest turnover was observed in the Sutlej river basin between 2500-2700 m, where the Himalayan moist forest changes to a temperate forest, followed by another peak at 3300-3500 m, where the tree line is replaced by alpine vegetation. A transition from complex vegetation (temperate forest) to sub-alpine vegetation was observed in the Yamuna at 2400-2600 m. According to these results, species turnover along an elevation is largely linked to vegetation change, which is in agreement with previous studies on birds that found maximum turnover rates at vegetation ecotones (Terborgh, 1971; Navarro, 1992). Mallet-Rodrigues *et al*. (2015) were also reported that slight differences in the vegetation structure and floristic composition might have an important role in species replacement along elevation. The other possible explanation for this species turnover was climatic factors and historical isolation may influence the distributional limits of species along elevation gradient (Graham *et al*., 2005).

4.4.5. Elevational Range Profile

Species richness of birds in Sutlej river basin was greater within 2000 m elevation (116 species – 57%) and rest were found above 2000 m. The elevation range limits of each species varied in this region and showed very narrow ranges. Out of 203 species, 17 species occurred in all sampled elevation bands while 55 species found only in few elevation bands showing that their range sizes are narrow. Likewise in Yamuna river basin, most of the species showed narrow elevational ranges. Out of 179 species observed, 15 species were widely distributed to all elevational bands and 36 species occurred at one or two elevational bands. It is likely due to dispersal ability, particular habitat associations, interspecific competition, or environmental tolerance that range sizes are extremely limited in both river basins (Jankowski *et al*., 2010; Laurance *et al*., 2011). It is consistent with the previous study conducted in the Eastern Himalayan mountain (Acharya *et al*., 2011) which found that most of the species are habitat specialists, either restricted to a handful of sites or a single vegetation zone.

Species with broader elevation ranges are mostly tended to be insectivorous or granivorous in both river basins (Terborgh, 1977). However, the insectivore birds such as *Coracias benghalensis*, *Pitta brachyuran, Yuhina flavicollis, Leiothrix lutea* and granivore birds such as *Perdicula asiatica*, *Spilopelia senegalensis, Chalcophaps indica* in Sutlej and Yamuna insectivore birds such as *Merops leschenaultia*, *Regulus regulus*, *Picoides canicapillus*, *Phylloscopus chloronotus*, *Garrulax striatus* and granivore birds such as *Petronia xanthocollis*, *Francolinus pondicerianus*, *Carduelis spinoides* were observed only at low elevation bands (<2000 m). Stevens (1992) stated that the relationship between latitudinal and elevation differences experienced by the organisms along the geographical gradients is due to the breadth of climatic conditions. A species with a narrow elevation range will have less climatic tolerance, and thus will be vulnerable to extinction due to global warming (Colwell *et al*., 2008; McCain, 2009; Laurance *et al*., 2011). For instance, broader elevation range species can migrate upward or downward in response to climatic change and could maintain their viable population sizes (Laurance *et al*., 2011).

4.4.6. Mid-Domain Effect (MDE)

Birds of the Sutlej and Yamuna river basin showed high species richness at low-elevation and after decreased with elevation. This finding was consistent with a similar study on birds in Andes Mountains (Terborgh, 1977). The influence of geometric constraints on species ranges is considered as an important explanation for a mid-elevational peak in species richness (Rahbek & Graves, 2001; McCain, 2004; Acharya *et al*., 2011). The analyses of MDE null model did not follow the significant fit to the 95% prediction limits of the simulation curve in both river basins (Figure 4.7 & 4.8). MDE regressions found the very low R^2 value between empirical species richness and mean predicted richness. The results indicate that the elevational pattern of species was not consistent with MDE (McCain, 2009). However, the species richness along the elevation gradient was greater in three distinct peaks was observed in Sutlej (1000 m, 2200 m, and 3200 m) and Yamuna (600 m, 1100 m, and 1500 m) river basin respectively. This pattern reflects that the species richness of birds in both river basins was highly patchy.

Thus, the studies revealed that species richness of birds declined monotonically with increasing elevation. The monotonic decline in species richness along the elevational gradient has commonly been reported in various taxa and regions (Terborgh, 1977; Rahbek 1995, 2005; Patterson *et al*., 1998; Lessig 2008; Mallet-Rodrigues *et al*., 2015). However, in contrast, few studies in Himalayas observed high species richness at middle elevation than higher and lower elevations (Raza 2006; Acharya *et al*., 2011; Joshi *et al*., 2012; Joshi & Rautela 2014; Joshi & Bhatt, 2015) although they found very little support for the MDE (Acharya *et al*., 2011). Lack of mid-elevation peak in species richness indicates that the geometric constraints have a relatively low influence on the bird species richness pattern in the Sutlej and Yamuna river basin of western Himalaya.

In resident birds, 19% of Sutlej and 18% of Yamuna, empirical species richness fells within 95% null model and it might be influenced by the geometric constraints than in other bands. For Sutlej overall bird species, geometric constraints influence between 1600 – 1800 m and > 3500 m elevation, whereas observed species richness fells 1000 m, 1200 m, and 3500 m elevation of the null model. Similarly for Yamuna overall bird species, geometric constraints influence between 1500 m and 1700 m, whereas observed species richness fells 900 m, 1300 m, and 1500 m elevation of the null model. The sudden decline in both resident and overall bird species richness above >2000 m in Sutlej and > 1500 m in the Yamuna is in concurrence with increasing elevation and it is due to sparse forest cover and harsh climatic conditions (Singh *et al*., 2015).

These changes in climatic conditions could be a cause for the decline of species richness above the transition zone in Sutlej (>2000 m) and Yamuna (>1500 m) river basin (Xu *et al*., 2009).

4.4.7. Environmental Factors

Sanders and Rahbek (2012) summarized a number of factors proposed to explain elevational distribution patterns of species richness along the elevation gradient, and some of the most frequently tested are climate, area, geometric constraints, productivity, disturbance, habitat heterogeneity and evolutionary history (Rahbek, 1995; Sanders, 2002; McCain, 2009; McCain & Grytnes, 2010; Acharya *et al*., 2011). In the present study, I tested spatial factors, climatic factors and habitat variables for both river basins, and found the strong explanatory power of the environmental factors. The potential correlates of species richness in separation of one another using simple linear regressions, I found that species of birds in Sutlej and Yamuna river basin were positively and strongly correlated with mean annual temperature, NDVI, mean annual precipitation, and area, whereas the area was not correlated with Yamuna river basins (Table 4.3a&b). The other main driver spatial factor MDE did not correlate with any of the river basins. This results support McCain (2009) previous study, stated that MDE is a not the main driver of elevational distribution of bird diversity.

Further, the combination of climatic, spatial and productivity variables was also tested with step-wise multiple regression models. The emerged monotonic decline in species richness was primarily influenced by temperature as evidenced by the multiple regression models for both Sutlej and Yamuna river basins (Table 4.4a&b). This observed result is corresponding with most previous studies on birds (Acharya *et al*., 2011; Mallet-Rodrigues *et al*., 2015; Pan *et al*., 2016). Stevens (1992) reported similar results in various taxa, explained that species richness along the elevational gradient was influenced by the climatic factors followed by habitat variables. In addition, vast literature analyses at a global scale revealed that elevational diversity of species is strongly influenced by climatic factors for birds and other taxonomic groups (McCain 2005, 2007a, 2009, 2010; McCain & Grytnes, 2010). The reasonable explanations for climatic influences, temperature are the major factor of productivity and may govern species diversity through its effect on productivity (McCain & Grytnes, 2010). On the contrary, other regional studies in the Himalayas had observed that the vegetation composition (Raza 2006; Joshi *et al*., 2012) and vegetation structure (Joshi & Rautela 2014; Joshi & Bhatt 2015) determined the species richness in a gradient rather than elevation and other climatic factors. These studies had covered a part of the elevation range and they had not considered wide-elevational range as followed in the present study and Acharaya *et al*. (2011). This might be the reason for the no influence of climatic variables on bird species distribution in other studies (Joshi *et al*., 2012). McCain and Grytnes (2010) reported that gradual increase of climate warms and climatic patterns change will affect the mountain communities and clearly shifting the plants and animals from their natural habitat. Elevational gradients serve as baselines for evaluation of population declines, range shifts and extinction risks of biodiversity.

4.5. SUMMARY

The distribution pattern of birds along the elevation gradient of Sutlej and Yamuna river basin was studied. The number of bird species present along the elevational bands decreases with increasing elevation in both the river basins. At 700 m, 140 species were detected and 30 at 3700 m in Sutlej, whereas in Yamuna 108 species at 600 m and 18 at 2600 m elevation band. Species diversity also followed the similar decreasing pattern along the elevation gradient peaked at 700 m in Sutlej and 1400 m elevation in the Yamuna. The relationship between elevation and bird abundance was found highest at lower (700 m) and higher (3500 m) elevation in Sutlej, and the Yamuna peaked at 600 m and further random fluctuations were observed.

According to the findings, Chao1 is the best estimator for species richness estimates since it produces a high estimated value with a low standard deviation. The accumulation curves for all elevational bands reached asymptote except for Sutlej river basin at 900 m, 2300 m, 2500 m and 3700 m and Yamuna river basin at 2400 m, 2600 m. The lacks of estimated species richness in these specific elevational bands were indicating the need for more sampling. Availability of area determines the species richness along an elevation gradient, larger areas support a greater number of species. This explanation confirmed in Sutlej found a decreasing area with increasing elevation, observed the highest number of species in lower elevation, in contrast to Yamuna river basin increases area with increasing elevation supports only less number of species with a larger area.

Food availability is one of the most important factors influencing the elevational distribution of species. Bird species segregated into eight trophic groups based on their diet in both Sutlej and Yamuna river basin. Insectivore birds were dominating and found the highest number of lower elevation followed by granivorous birds in both river basins. The entire trophic diversity showed declining pattern with elevation. These findings were indicating that food in form of insects, fishes, animals, fruits, seeds, and flowers was available in quantity at lower elevations.

Species turnover rate was high between distant elevation categories and found low in consecutive ones in both the river basins. In all the species of Sutlej, the turnover rate was less than 40% in the consecutive elevation band and 30% in the Yamuna. Comparatively, high turnover was observed between 2300-2500 m and 2500-2700 m and shared species between 498-700 m and 700-900 m among adjacent bands in Sutlej river basin. Likewise in Yamuna river basin, high turnover was observed between 2200-2400 m and 2400-2600 m and shared species between 800-1000 m and 1000-1200 m among adjacent bands.

Elevational ranges of each species varied in Sutlej and Yamuna river basin, most of the species showed very narrow elevational ranges. Only 17 species of Sutlej and 15 species of Yamuna were widely distributed across all the elevational bands. Most of the higher elevational birds extended ranges towards lower elevation and species distributed in lower elevation were restricted to one or two elevational bands. Species with broader ranges were mostly tending to be insectivorous or granivorous in Sutlej and Yamuna river basin. Among other species with wide elevational ranges, populations are continuous, and gene flow appears enough to overcome any trend that exists for elevational variation.

The trends in bird distribution occurring along the elevation gradient of Sutlej and Yamuna river basin were observed monotonic decline with increasing elevation. Mid-Domain Null Model for Sutlej river basin showed that divergence of species richness occurred between 500-1400 m and 2000-3400 m, where the empirical species richness was higher than the simulated richness. Similarly, in Yamuna river basin, empirical richness was higher than the simulated richness and deviated between 400-1300 m and 1900-2600 m. Both the river basin showed a low R^2 value between empirical and simulated richness indicates that the geometric constraints did not influence the distribution pattern of birds.

Numbers of factors have been proposed to explain elevational distribution pattern of species along the elevational gradient; such as spatial factors (area, geometric constraints), environmental factors (climate, productivity, habitat heterogeneity) and evolutionary history. The mid-domain null model indicated that no influence of geometric constraints on species distribution in the Sutlej and Yamuna river basin. The climatic and habitat factors caused the distribution pattern of birds in both the river basins. The crucial factor for the elevational distribution of species was temperature, it determines the spatial and temporal arrangements of bird species.

Chapter 5

CHAPTER 5

CHANGES IN BIRD COMMUNITIES IN RESPONSE TO HYDRO-ELECTRIC POWER PROJECTS

5.1. INTRODUCTION

Rivers and their natural surrounding habitats are among the most diverse, dynamic and complex ecosystems in the world (Dynesius & Nilsson, 1994). This ecosystem supports large portion of its biodiversity and also acting as important corridors for the distribution and movement of plants and animals (Naiman *et al*., 1993; Dynesius & Nilsson, 1994). Among the river associated organisms, birds are the most evident, with specialized characters evolved to exploit the resources and habitat conditions provided by rivers (Ormerod & Tyler, 1993). But, in recent years the river ecosystems have become increasingly vulnerable to developmental activities like construction of hydro-electric dams resulting in the degradation and fragmentation of riverine habitats (Grumbine & Xu, 2011; Pandit & Grumbine, 2012). The impact also causes changes in the river geomorphology and hydrology causing impairment of the ecological integrity of rivers through elimination of species and loss of ecosystem services (Richter *et al*., 2003; Sinha *et al*., 2019).

Although hydropower is an important energy option for developing countries that help to meet their power demands and reduce global carbon emissions, the damage caused during construction and operation of Hydro Electric Projects (HEPs) to the river associated biodiversity is huge and often irreplaceable. In a meta-analysis, it was found that by 2025 the deforestation rate due to the dam construction would likely to extirpate 22 angiosperms and 7 vertebrate taxa. In addition, the disturbances due to the dam construction and alteration of riverine habitats might reduce the tree species richness by 35%, tree density by 42% and basal area by 30% in the dense forests (Pandit & Grumbine, 2012). Furthermore, the clearing of vegetation cover for construction of roads, installation of power lines, and expansion of human population in formerly natural areas are reported to cause habitat loss and fragmentation (Small & Hunter, 1988, Sisk *et al*., 1994).

Himalayan rivers are mostly perennial, and discharge patterns are strongly influenced by seasonal monsoonal precipitation and glaciers (Singh *et al*., 2015). Large discharge of water to the rivers from the Himalaya provides ideal conditions for hydropower development (Erlewein, 2013). The GOI had announced an ambitious Plan to generate 50,000 MW through HEPs by 2020 and proposed to construct of 292 new dams in various Himalayan river systems (Pandit & Grumbine, 2012). A total of 292 dams were proposed in Himalayan Rivers, which includes 109 in the Brahmaputra, 89 in the Ganga and 94 in the Indus river and, the state Sikkim is expected to get more HEPs in future followed by Uttarakhand and Himachal Pradesh. Currently, Uttarakhand and Himachal Pradesh contributes maximum to the total hydro-electric power generation from the Indian Rivers. In Himachal Pradesh, the government has identified that 18,820 MW of power could be generated from the rivers in this state and so far they established power projects of 6,085 MW and 4,435 MW under construction and nearly 8,299 MW would be developed. Similarly, 18,175 MW is the identified capacity for Uttarakhand state, which includes 2,980.1 MW of existing, 1,926.0 MW of construction and 13,269.0 MW to be established (Agrawal *et al*., 2010).

Western Himalaya has been recognized as one of the four biodiversity hotspots in India for its rich biodiversity with large proportion of endemic animals and plants (Myers *et al*., 2000). It is situated at the tri-junction of the Afrotropical, Indo-Malayan and Palaearctic realms, all of which support rich biodiversity. The Himalayas lies in the global biodiversity hotspots and home for many plants and animals which include 980 species of birds (Conservation International, 2019). The presence of 11 endemic bird species in the Western Himalaya, it is identified as an Endemic Bird Areas by Birdlife International (2019). Also the region comes under Important Bird Areas network. Considering the uniqueness of the area for conserving several threatened and range-restricted animals and plants, several patches of forests has been identified and prioritized under various categories of protected areas (Gaston *et al*., 1983).

The world's riverine ecosystems hold around 60 river bird species representing 16 different families (Buckton & Ormerod, 2002). Among all species, at continent level, Asia has the greatest species richness (28 species) and sub-continental level Himalayas with 13 species. These species range from those totally dependent the river channel (e.g. redstarts and dippers) or to those which occupy and use riparian habitats more opportunistically (e.g. wagtail and whistling-thrush). Inspite of high diversity and richness of river associated birds, the studies that address the effect these HEPs on the distribution and abundance of birds have not been explored in Himalayan rivers. In this context, the present study attempts to answer the following questions: Does the species richness, diversity and composition of river birds differ between river stretches affected by HEPs at different stages of development? In addition, to discover which species were most affected by HEPs and to address the species-specific differences in abundance between these sites.

5.2. METHODS

5.2.1 Study Design

The study areas were categorized into existing HEP sites (active hydro-power projects), construction sites (sites which are under construction) and proposed sites (no hydro-power projects /natural riverine systems). Depending on the level of disturbance, hydropower project areas were classified as moderately disturbed (the Existing Project site), highly disturbed (the Construction site) and undisturbed (the Proposed Project site). Overall, 29 sites were surveyed along the Sutlej river that includes ten each from existing and under construction projects, and nine from proposed project sites. Similarly, in Yamuna river 46 sites, which includes nine existing projects, six construction projects and 31 proposed projects were studied.

The sampling points chosen from the stratified elevational bands were the HEP sites located at Sutlej and Yamuna rivers. Further analysis, sampling points were taken within the 5 km radius of each HEP site. If the points taken from the proposed HEP sites, it considered as a proposed HEP site points likewise for existing and under construction HEP sites for both rivers. The distance between two sampling points kept at a minimum of 1 km.

5.2.2 Bird Surveys

Point count method was followed to understand the effect of different stages HEPs on birds in Sutlej and Yamuna rivers (detailed notes on methodology was given in

Chapter 3, Section 3.2.1.). A total of 182 and 340 point count stations were established in the HEP and proposed sites of the Sutlej and Yamuna rivers respectively. In Sutlej river, 51 points in the proposed sites, 68 in construction sites and 63 in proposed sites were sampled. In Yamuna river, 67 points in existing sites, 69 in under construction sites and 204 in proposed sites were studied.

Depending on the nature of their association with the riverine system, river-associated birds were categorized as either river exclusive (obligate) or non-exclusive (non-obligate). River obligate were defined as species that (i) exclusively occur along streams or river channels or within the river corridor, during significant part of their breeding or non-breeding life cycle and (ii) feed on production wholly or partly originating from the river channel (Buckton & Ormerod, 2002; Sinha *et al.*, 2019). Non-obligate species feeding and roosting on habitats such as inland water bodies, ponds and lakes besides inhabiting river banks.

5.2.3 Statistical Analysis

The following analyses were done to explore the diversity and pattern of species richness of the observed bird assemblages (i.e. existing sites, construction sites and proposed sites) in Sutlej and Yamuna river.

(1) Species richness, abundance, Shannon diversity index (H') and Evenness (E) details are provided in Chapter 3, Section 3.2.2.

(2) Mean abundance of birds for all the three HEP sites were calculated as the total number of individuals divided by the number of sampling points.

(3) SIMPER (Similarity Percentage) test was performed to assess the bird species which are primarily responsible for an observed difference between groups of samples. The SIMPER test ranks species based on its percentage of contribution to difference between groups.

(4) To assess the difference in species composition between HEP sites, Non-metric Multi Dimensional Scaling (nMDS) analysis was performed using Bray-Curtis similarity measure. nMDS ordinates the sampling sites by their similarity in species composition, and to place the sampling points in a two dimensional coordinate system.

5.3. RESULTS

5.3.1. Bird richness and abundance

Totally, 141 species belonging to 49 families and 178 species belonging to 50 families were recorded in and around the HEP sites along the Sutlej and Yamuna rivers respectively. In both the river systems, the family Muscicapidae (17 species in Sutlej and 18 in Yamuna) dominated the species composition followed by family Accipitridae (Table 5.1.).

Among the recorded species in Sutlej, four species fall under various threat categories of IUCN (one Critically Endangered species: Red-headed Vulture; two Endangered species: Egyptian Vulture and Pallas's Fish-eagle; one Vulnerable species: Common Pochard) (IUCN, 2019). The mean abundance of threatened and near-threatened birds was observed more in existing sites (6.27) followed by proposed sites (5.10). Under construction sites had relatively less abundance of threatened species. Among the threatened birds, Pallas's Fish-eagle and near-threatened birds Bearded Vulture and Himalayan Griffon was recorded in all the project sites, while other species were recorded either in one or two sites. Himalayan Griffon was the most common near-threatened species in all the HEP sites but its abundance was 50% lesser in the construction sites compared to the existing sites (Table 5.2).

Of the recorded bird species in Yamuna river, four species fall under various threat categories of IUCN (Endangered: Egyptian Vulture and Pallas's Fish-eagle; Vulnerable: Common Pochard and Asian Woollyneck). In addition, six species fall under the Near-threatened category of IUCN (Table 5.3). Mean abundance of threatened birds recorded in existing HEP sites was higher than proposed and construction sites respectively. The near-threatened species Bearded Vulture, Himalayan Griffon and Alexandrine Parakeet were recorded in all the project sites, while other species were recorded either in one or two sites (Table 5.3). In both the river systems, the threatened species Common Pochard was recorded only from the existing HEP sites and not from other sites.

Table 5.1 Family-wise representation of bird species number and percentage in Sutlej and Yamuna River

S. No.	Family	Sutlej River Total Number of Species (%)	Yamuna River Total Number of Species (%)
1	Phasianidae	5 (3.55)	5 (2.81)
2	Anatidae	1 (0.71)	9 (5.06)
3	Podicipedidae	1 (0.71)	2 (1.12)
4	Columbidae	5 (3.55)	7 (3.93)
5	Apodidae	3 (2.13)	3 (1.69)
6	Cuculidae	2 (1.42)	3 (1.69)
7	Rallidae	-	1 (0.56)
8	Ciconiidae	-	2 (1.12)
9	Ardeidae	1 (0.71)	7 (3.93)
10	Phalacrocoracidae	1 (0.71)	2 (1.12)
11	Recurvirostridae	-	1 (0.56)
12	Charadriidae	1 (0.71)	2 (1.12)
13	Scolopacidae	-	1 (0.56)
14	Laridae	-	2 (1.12)
15	Strigidae	2 (1.42)	2 (1.12)
16	Accipitridae	10 (7.09)	9 (5.06)
17	Bucerotidae	1 (0.71)	-
18	Upupidae	1 (0.71)	1 (0.56)
19	Meropidae	1 (0.71)	2 (1.12)
20	Coraciidae	1 (0.71)	-
21	Alcedinidae	2 (1.42)	3 (1.69)
22	Megalaimidae	1 (0.71)	3 (1.69)
23	Picidae	3 (2.13)	7 (3.93)
24	Falconidae	1 (0.71)	1 (0.56)
25	Psittacidae	4 (2.84)	4 (2.25)
26	Pittidae	1 (0.71)	-
27	Aegithinidae	1 (0.71)	-
28	Campephagidae	2 (1.42)	3 (1.69)
29	Laniidae	1 (0.71)	3 (1.69)

S. No.	Family	Sutlej River Total Number of Species (%)	Yamuna River Total Number of Species (%)
30	Oriolidae	-	1 (0.56)
31	Dicruridae	3 (2.13)	4 (2.25)
32	Rhipiduridae	1 (0.71)	2 (1.12)
33	Monarchidae	1 (0.71)	1 (0.56)
34	Corvidae	9 (6.38)	8 (4.49)
35	Paridae	5 (3.55)	2 (1.12)
36	Hirundinidae	4 (2.84)	6 (3.37)
37	Aegithalidae	1 (0.71)	1 (0.56)
38	Alaudidae	-	1 (0.56)
39	Cisticolidae	5 (3.55)	5 (2.81)
40	Pycnonotidae	3 (2.13)	3 (1.69)
41	Sylviidae	6 (4.26)	3 (1.69)
42	Timaliidae	7 (4.96)	9 (5.06)
43	Zosteropidae	1 (0.71)	1 (0.56)
44	Sittidae	2 (1.42)	1 (0.56)
45	Certhiidae	1 (0.71)	-
46	Sturnidae	3 (2.13)	4 (2.25)
47	Turdidae	2 (1.42)	7 (3.93)
48	Muscicapidae	17 (12.06)	18 (10.11)
49	Cinclidae	1 (0.71)	1 (0.56)
50	Chloropseidae	1 (0.71)	-
51	Nectariniidae	1 (0.71)	2 (1.12)
52	Passeridae	2 (1.42)	3 (1.69)
53	Prunellidae	1 (0.71)	-
54	Estrildidae	-	1 (0.56)
55	Motacillidae	5 (3.55)	3 (1.69)
56	Fringillidae	4 (2.84)	4 (2.25)
57	Emberizidae	3 (2.13)	2 (1.12)
Overall species		**141**	**178**

Table 5.2 Mean abundance of Threatened and Near-threatened bird species recorded in the different stages of the HEP sites of Sutlej River (CR-Critically Endangered; EN-Endangered; VU-Vulnerable; NT-Near-threatened; IUCN, 2019).

Species	IUCN	Existing HEP sites	Under Construction HEP sites	Proposed HEP sites
Red-headed Vulture *Sarcogyps calvus*	CR	0.02	-	-
Egyptian Vulture *Neophron percnopterus*	EN	-	0.01	-
Pallas's Fish-eagle *Haliaeetus leucoryphus*	EN	0.06	0.01	0.05
Common Pochard *Aythya ferina*	VU	0.12	-	-
Bearded Vulture *Gypaetus barbatus*	NT	0.06	0.06	0.06
Himalayan Griffon *Gyps himalayensis*	NT	6.00	2.91	4.97
Pallid Harrier *Circus macrourus*	NT	0.02	-	0.02
Alexandrine Parakeet *Psittacula eupatria*	NT	-	0.88	-
Overall		**6.27**	**3.88**	**5.10**

Mean abundance; the total number of individuals /the number of sampling points

Table 5.3 Mean abundance of Threatened and Near-threatened bird species recorded in the different stages of the HEP sites of Yamuna River

Species	IUCN	Existing HEP sites	Under Construction HEP sites	Proposed HEP sites
Egyptian Vulture *Neophron percnopterus*	EN	-	0.03	0.02
Pallas's Fish-eagle *Haliaeetus leucoryphus*	EN	-	0.01	-
Common Pochard *Aythya ferina*	VU	5.30	-	-
Asian Woollyneck *Ciconia episcopus*	VU	0.03	-	-
Painted Stork *Mycteria leucocephala*	NT	0.49	-	-
River Lapwing *Vanellus duvaucelii*	NT	1.27	-	-
Bearded Vulture *Gypaetus barbatus*	NT	0.04	0.03	0.04
Himalayan Griffon *Gyps himalayensis*	NT	1.22	1.46	2.08
Cinereous Vulture *Aegypius monachus*	NT	-	-	0.01
Alexandrine Parakeet *Psittacula eupatria*	NT	0.49	0.03	0.08
Overall		**8.85**	**1.57**	**2.23**

Mean abundance; the total number of individuals /the number of sampling points

5.3.2. Diversity Index

Shannon diversity index value for Sutlej river was relatively higher in the construction sites (3.58) compared to proposed and existing HEP sites (Table 5.4.). However, the evenness value was higher in existing project sites (0.33) than the construction and proposed sites (Table 5.4). In Yamuna river, Shannon diversity and evenness values were higher in existing project sites (H'=3.85; E=0.33) compared to other sites (Table 5.5).

Table 5.4 Shannon diversity (H') and Evenness (E) indices of birds in different stages of the HEP sites in Sutlej River

Project Status	Shannon Diversity (H')	Evenness (E)
Existing HEP sites	3.40	0.33
Under Construction HEP sites	3.58	0.29
Proposed HEP sites	3.38	0.31

Table 5.5 Shannon diversity (H') and Evenness (E) indices of birds in different stages of the HEP sites in Yamuna River

Project Status	Shannon Diversity (H')	Evenness (E)
Existing HEP sites	3.85	0.33
Under Construction HEP sites	3.48	0.30
Proposed HEP sites	3.68	0.27

5.3.3. Species Richness and Abundance in Sutlej and Yamuna River

Both mean abundance and species richness of birds in Sutlej and Yamuna rivers were higher in the existing sites compared to other sites (Figure 5.1 & 5.2). Similarly in both the rivers, the mean abundance and richness were lower in the proposed sites. The richness and abundance of birds in construction sites of Yamuna was much lesser than the Sutlej river and this indicates that the composition of birds in Yamuna river was most altered or affected by the construction associated activities.

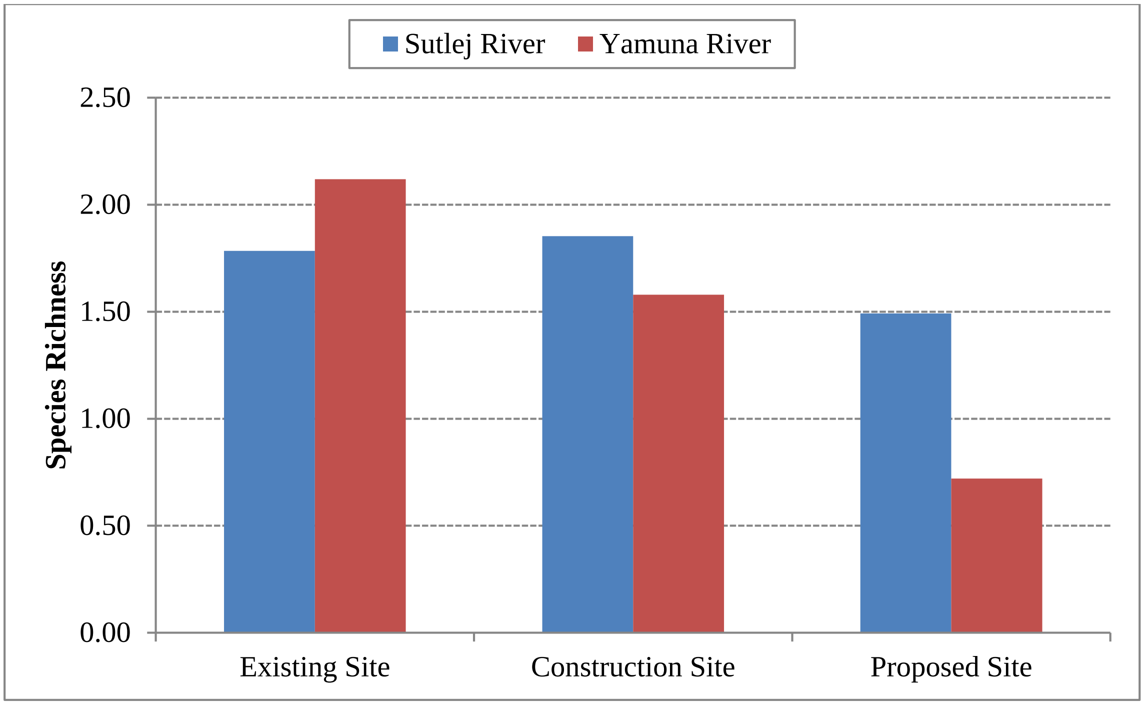


Figure 5.1 Species richness (species richness per point) of different stages of the HEP sites in Sutlej and Yamuna River

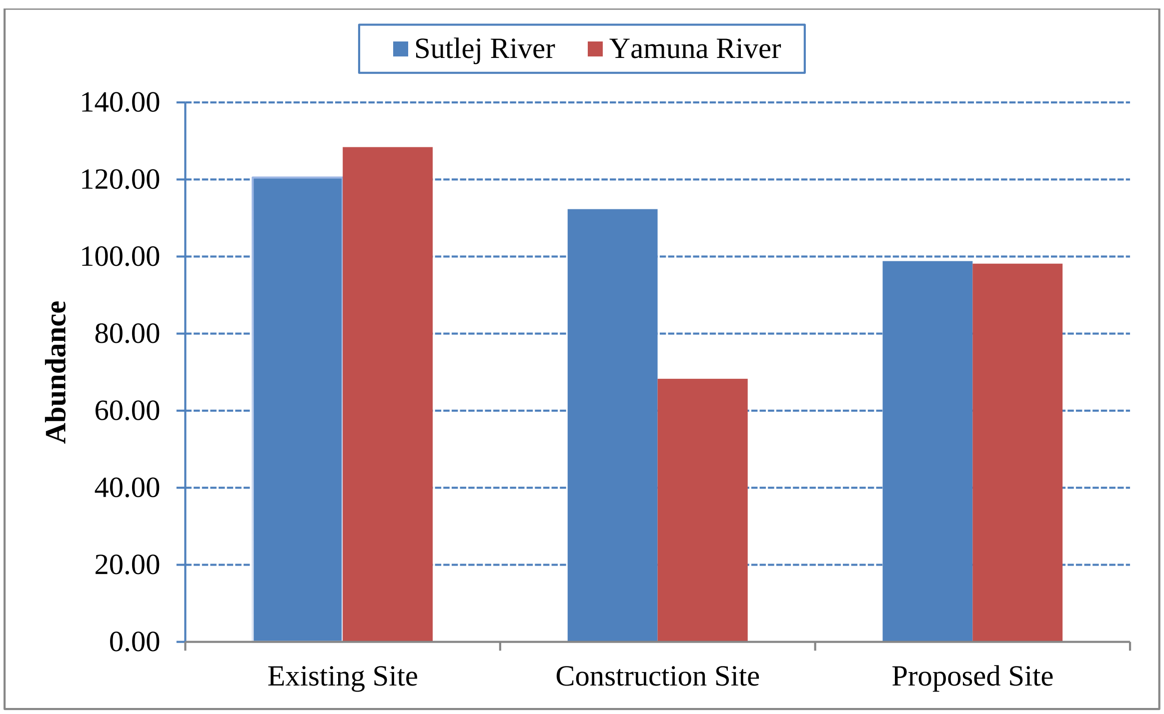


Figure 5.2 Bird abundance (number of individuals per point) of different stages of the HEP sites in Sutlej and Yamuna River

5.3.4. Changes in Bird Composition

The non-metric multi-dimensional scaling (nMDS) was applied to understand the similarity in bird composition across different distance categories (1km, 2km and above 2 to 5km) from the existing and construction HEP sites. The nMDS plot for existing project sites (Stress=0.28; R^2=0.41) and construction sites (Stress=0.25; R^2=0.56) of Sutlej river and Yamuna river shows that the species composition within 1 km band was a subset of the other two bands but produces a unique composition (Figure 5.3 & 5.4 and Figure 5.5 & 5.6). Further, it is clear that the species composition of birds within 1 km radius from existing and under construction HEP sites is completely different from the other two radius bands (2km and above 2 to 5km).

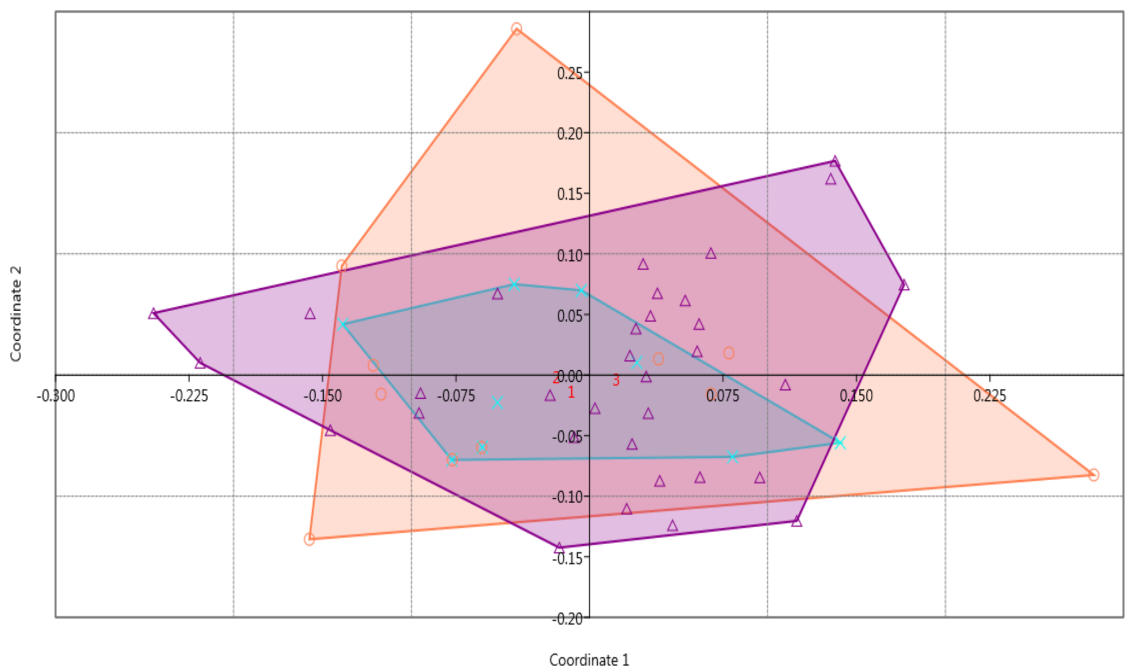


Figure 5.3 nMDS plots showing the species composition of birds in different distance bands from the Existing project sites of Sutlej River (X - sampling points within 1km distance; O – points from 1-2km; △ - points from 2-5km)

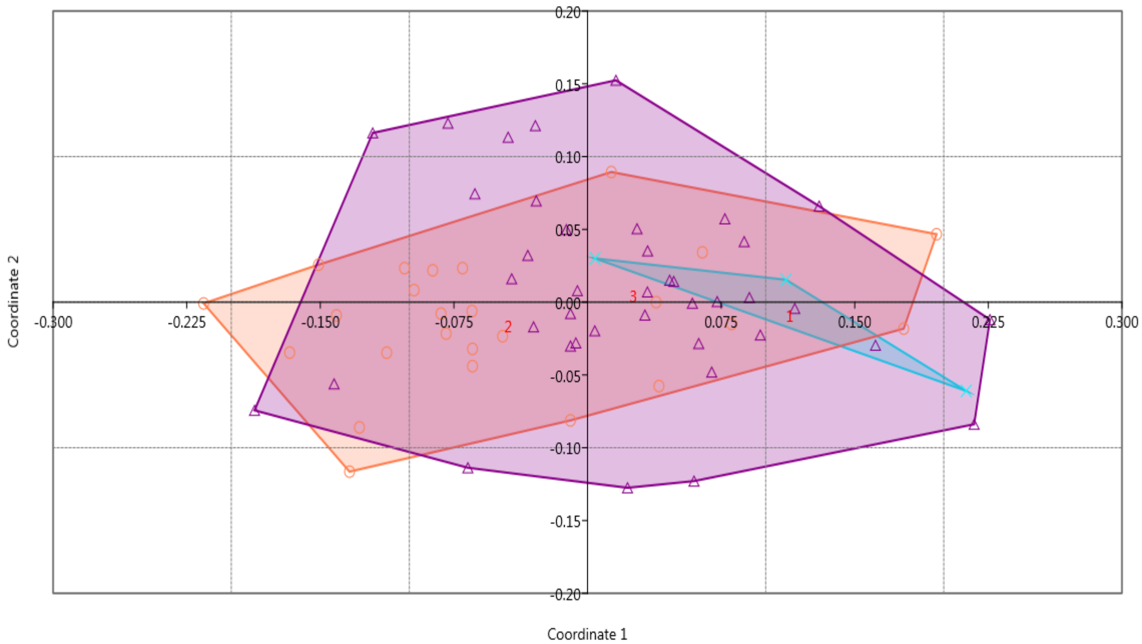


Figure 5.4 nMDS plots showing the species composition of birds in different distance bands from the construction sites of Sutlej River

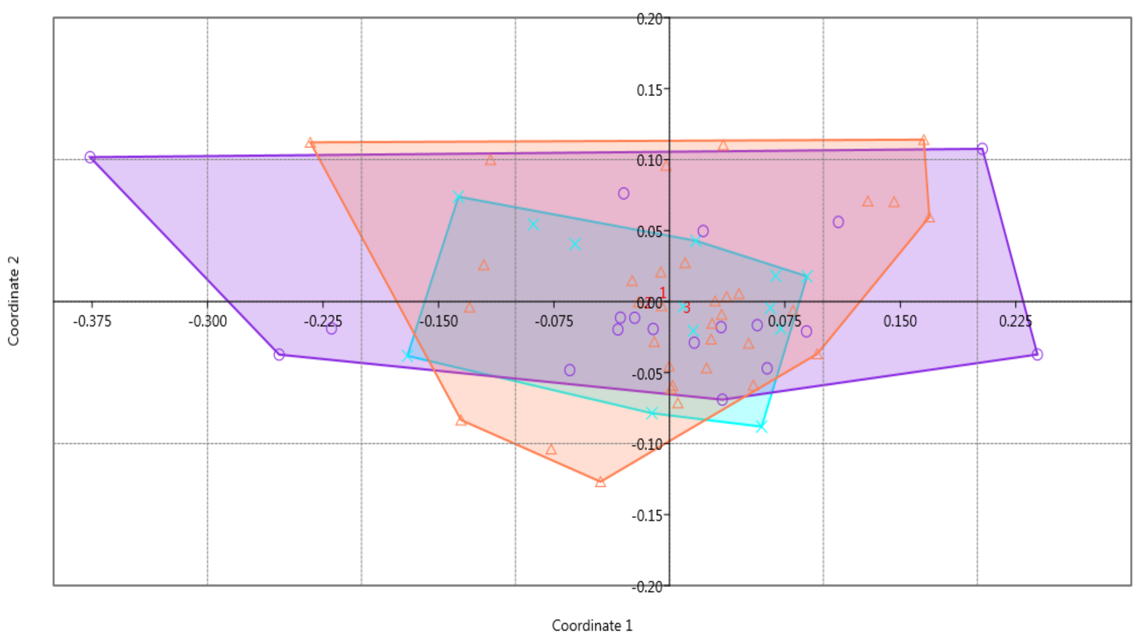


Figure 5.5 nMDS plots showing the species composition of birds in different distance bands from the Existing project sites of Yamuna River (X - sampling points within 1km distance; O – points from 1-2km; △ - points from 2-5km)

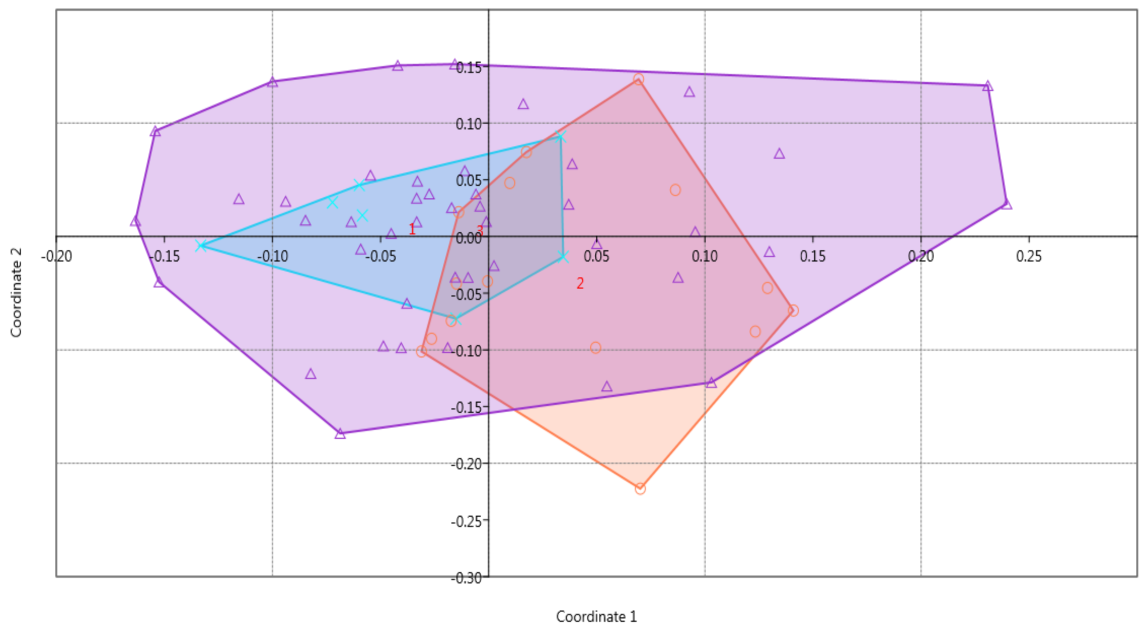


Figure 5.6 nMDS plots showing the species composition of birds in different distance bands from Construction sites of Yamuna River

5.3.5. Species Composition

The dissimilarity in bird species composition in all the HEP sites of Sutlej and Yamuna river were assessed by using SIMPER test. In Sutlej, the overall dissimilarity in species composition between different stages of HEP sites was explained mainly by Himalayan Bulbul (10.99%), Fire-fronted Serin (8.05%) and Large-billed Crow (7.71%) (Table 5.6). In Yamuna, Himalayan Bulbul (10.96%), Large-billed Crow (7.19%) and House Sparrow (7.07%) were the major contributors to the dissimilarity in species composition between the stages of HEPs (Table 5.7).

Table 5.6 Bird species with percent of contribution for the difference in species composition in HEP sites of Sutlej River

Common Name	Average Dissimilarity	Percentage of Contribution	Cumulative Percentage	Mean Construction sites	Mean Existing sites	Mean Proposed sites
Himalayan Bulbul	7.201	10.99	10.99	18.1	8.16	9.32
Fire-fronted Serin	5.28	8.055	19.04	2.29	14.3	4.56
Large-billed Crow	5.056	7.714	26.75	12.9	17.4	15.9
House Sparrow	4.283	6.535	33.29	5.41	6.12	6.7
Rock Dove	3.902	5.954	39.24	5.56	6.51	7.29
Himalayan Griffon	3.247	4.954	44.2	2.91	6	4.97
Streaked Laughingthrush	2.25	3.432	47.63	3.79	4.51	4.02

Table 5.7 Bird species with percent of contribution for the difference in species composition in HEP sites of Yamuna River

Common Name	Average Dissimilarity	Percentage of Contribution	Cumulative Percentage	Mean Construction sites	Mean Existing sites	Mean Proposed sites
Himalayan Bulbul	7.83	10.96	10.96	12.7	9.43	11.8
Large-billed Crow	5.143	7.197	18.15	6	7.6	5.35
House Sparrow	5.055	7.073	25.23	6.16	4.1	3.51
Red-vented Bulbul	2.779	3.889	29.12	2.49	2.46	2.54
Oriental White-eye	2.753	3.852	32.97	2.25	2.99	2.57
Little Swift	2.222	3.11	36.08	1.09	4.91	0.641
Plumbeous Water-redstart	2.192	3.067	39.14	2.7	2.27	2.38

5.3.6. Richness and Abundance of River Associated Birds

A total of 34 river associated bird species belonging to 14 families was recorded from Sutlej river, of which 17 species were recorded from various stages of HEPs areas (Table 5.8). In Yamuna river, 42 species belonging to16 families was recorded. Among them, 20 species were found in the different stages of HEPs areas (Table 5.9). The major contribution to the river bird community along the river Sutlej was from the family Ardeidae with six species, followed by Motacillidae (five species), Alcedinidae and Muscicapidae (four species). In river Yamuna, the major contribution was from the family Anatidae with nine species, followed by Ardeidae (seven species) and Muscicapidae (four species).

Amongst the three stages of HEPs in Sutlej, the overall mean abundance of birds and mean number of sightings was relatively more in existing HEP sites (Mean Abundance (MA)=14.80; Mean number of Sightings (MS)=7.08) and proposed HEP sites (MA=13.52; MS=6.57) than the under construction HEP sites (MA=12.00; MS=6.29) (Table 5.8). The obligate species Blue Whistling-thrush, non-obligate species Plumbeous Water-redstart and White-capped Water-redstart were the most abundant and frequently encountered in the proposed and existing project sites. In construction sites, obligate species Plumbeous Water-redstart was abundant followed by non-obligate species Blue Whistling-thrush and obligate species White-capped Water-redstart (Table 5.8).

In river Yamuna, mean bird abundance was higher in existing HEP sites (20.82) followed by proposed HEP sites (9.60). The mean number of bird sightings were more in proposed HEP sites (5.50) followed by existing HEP sites (4.76) (Table 5.9). The obligate species Plumbeous Water-redstart mean abundance was higher in proposed and construction sites, followed by non-obligate species Blue Whistling-thrush. Existing project sites was dominated by non-obligate species Great Cormorant followed by Blue Whistling-thrush and obligate species Plumbeous Water-redstart (Table 5.9).

Table 5.8 Number of bird species sightings and abundance from the different HEPs sites of Sutlej River, Obligate and Non-obligate river birds are indicated by symbols * and # respectively.

Common Name	IUCN	Mean number of sightings (Sightings/point)			Mean abundance (Individuals/point)		
		Under Construction HEP sites	Existing HEP sites	Proposed HEP sites	Under Construction HEP sites	Existing HEP sites	Proposed HEP sites
Crested Kingfisher*	LC	-	-	0.03	-	-	0.05
Plumbeous Water-redstart*	LC	1.79	2.02	1.97	3.78	4.31	4.21
White-capped Water-redstart*	LC	1.13	1	1.08	2.12	1.86	2.11
Little Forktail*	LC	0.04	0.02	0.05	0.04	0.02	0.05
Spotted Forktail*	LC	0.04	0.14	0.08	0.04	0.22	0.10
Brown Dipper*	LC	0.12	0.25	0.22	0.21	0.63	0.56
Little Grebe#	LC	-	0.02	0.02	-	0.10	0.08
Indian Pond-heron#	LC	0.01	-	-	0.01	-	-
Great Cormorant#	LC	0.09	0.02	0.02	0.13	0.02	0.02
Red-wattled Lapwing#	LC	0.01	-	-	0.04	-	-
Pallas's Fish-eagle#	EN	0.01	0.04	0.03	0.01	0.06	0.05
White-breasted Kingfisher#	LC	0.12	-	-	0.13	-	-
Blue Whistling-thrush#	LC	2.28	2.63	2.32	3.68	5.10	4.30
White Wagtail#	LC	0.12	0.14	0.11	0.50	0.43	0.37
White-browed Wagtail#	LC	0.18	0.18	0.10	0.51	0.53	0.27
Yellow Wagtail#	LC	0.03	0.24	0.13	0.06	0.63	0.38
Grey Wagtail#	LC	0.31	0.39	0.43	0.72	0.90	1.00

Table 5.9 Number of bird species sightings and abundance from the different HEPs sites of Yamuna River

Common Name	IUCN	Mean number of sightings (Sightings/point)			Mean abundance (Individuals/point)		
		Under Construction HEP sites	Existing HEP sites	Proposed HEP sites	Under Construction HEP sites	Existing HEP sites	Proposed HEP sites
Crested Kingfisher*	LC	0.01	0.07	0.03	0.01	0.07	0.04
Plumbeous Water-redstart*	LC	1.25	1.06	1.70	2.70	2.27	3.54
White-capped Water-redstart*	LC	0.52	0.40	0.61	0.97	0.81	1.10
Little Forktail*	LC	0.06	0.03	0.03	0.07	0.04	0.03
Spotted Forktail*	LC	0.14	0.07	0.08	0.19	0.10	0.09
Brown Dipper*	LC	0.13	0.09	0.19	0.26	0.16	0.40
Indian Pond-heron#	LC	-	0.09	0.005	-	0.24	0.01
Cattle Egret#	LC	-	0.15	-	-	0.87	-
Little Egret#	LC	-	0.15	-	-	1.69	-
Little Cormorant#	LC	-	0.09	-	-	2.22	-
Great Cormorant#	LC	0.09	0.16	0.10	0.14	7.10	0.18
River Lapwing#	NT	-	0.16	0.005	-	1.27	0.005
Red-wattled Lapwing#	LC	0.01	0.15	0.02	0.01	0.34	0.04
Pallas's Fish-eagle#	EN	0.01	-	-	0.01	-	-
Pied Kingfisher#	LC	-	0.10	0.005		0.15	0.005
White-breasted Kingfisher#	LC	0.04	0.12	0.08	0.04	0.13	0.09
Blue Whistling-thrush#	LC	1.59	1.46	2.36	2.23	2.27	3.35
White Wagtail#	LC	0.04	0.15	0.03	0.16	0.40	0.12
White-browed Wagtail#	LC	0.04	0.04	0.05	0.14	0.12	0.14
Grey Wagtail#	LC	0.13	0.19	0.20	0.25	0.55	0.47

5.4. DISCUSSION

There are important habitats for river associated birds along the Himalayan rivers in India. But the developmental activities like Hydro Electric Projects along the river system have had negative effects on riverine birds and its habitats (Jolli, 2012). Such a loss or effect may drive the birds and its associated biodiversity to move/disappear from the riverine system, which is less suitable for them. In addition, the effect of HEPs on birds may be species-species in some cases where some species shows decreasing trend while other species tend to become increase more abundantly (Blair, 1996). At the same time, if HEP sites stabilized (after construction), once again the birds may re-colonize, which is not documented. This is first attempt in Western Himalayas to study the effect of HEPs on birds and it would provide baseline information for the better management of the HEP sites and the biodiversity of riverine systems.

In Sutlej, the higher bird species richness and diversity was observed in highly disturbed area. This is due to the dominance of generalists and open habitat preferring species in highly disturbed sites (Larsen, *et al*., 2010; Jolli, 2012). The results indicating that the vegetation of the area was not completely destroyed and still there are some patches of the forest left over which appear to support the insects and other food resources in good amount to sustain the high species richness and diversity. In Yamuna, bird species richness and diversity was found high in existing sites. These existing sites are slowly recovering after installation of the power projects and become stabilized and vegetation reappear leads to increase the population of birds. Furthermore, the existing sites are highly prohibited by HEPs peoples, and the public is not permitted inside since the disturbance is reduced. Bird species richness as an indicator of habitat quality can be misleading, where degraded habitats can be occupied by generalist species thereby raising the overall species richness (Magguran, 2016). Hence, it is suggested to consider species composition to mirror habitat quality and habitat degradation (Magguran, 2016). In the present study species composition of birds was different in various stages of HEP sites.

Based on patterns of detection of birds along Sutlej and Yamuna river, it was found that the structure and composition of bird species responded to changes in the riparian habitats. In both Sutlej and Yamuna river, the bird composition was not similar within the existing and construction sites. The species composition of birds within 1km radius was a subset of 2km and 5km radius point count sites and it indicates different pattern of composition although within 2 and 5 km radius. This shows that the species composition around the HEP sites were completely different from other different bands. Generalist species like Himalayan Bulbul, Large-billed Crow and House Sparrow were present abundantly in all the distance categories of construction and existing sites of both rivers. However the IUCN red listed species were not found in the closest distance (within 1km) of the construction sites, contrary to construction sites the existing sites of both rivers support the quite number of red listed species within 1km distance categories. The species such as Pallas's Fish-Eagle, Common Pochard, Bearded Vulture and Himalayan Griffon recorded from existing dam sites of the Sutlej river and, Asian Woollyneck, Painted Stork, Common Pochard, River Lapwing, Bearded Vulture, Himalayan Griffon from the Yamuna river. Also the existing hydro-electric dam supports many water birds such as Cormorants, Grebes, Egrets, Herons, Kingfishers, Pochards, Ducks, Gulls and Terns. These high species richness in dam sites was due to the increase in the abundance of certain fish and aquatic invertebrates (Negi & Punetha, 2017).

River birds can serve as potential indicators of human impact on the environment (Larsen *et al*., 2010). The removal of riverine habitat is likely to affect a number of river associated birds, notably Crested Kingfisher, Plumbeous Water-redstart, White-capped Water-redstart, Little Forktail, Spotted Forktail and Brown Dipper. All these species use riparian habitat for shelter and food. Plumbeous Water-redstart and White-capped Water-redstart were the most common species in the Sutlej and Yamuna rivers and are most widespread species generally on fast-flowing rivers. In both rivers, all these river birds avoided using construction sites with intensive land-use and change in water quality while White-capped Water-redstart from Sutlej and Little Forktail, Spotted Forktail from Yamuna river were comparatively higher in construction sites indicating the wider adaptation on a landscape changes on river processes. These findings are in agreement with the previous studies that, the change of water quality on few birds are often favors (Ormerod & Tyler, 1993). Among the recorded river birds, Crested Kingfisher had less number of sightings and hence in abundance was very low in both rivers. However, in Sutlej this species was sighted only in undisturbed area and avoided using disturbed area indicating the effects of HEPs on the species.

5.5. SUMMARY

The results pointed out that habitat disturbance had affected the species richness, abundance, diversity and composition of avifauna along both Sutlej and Yamuna rivers. The construction and existing sites were species richness and evenness becomes similar because other species takes up the place once the site is disturbed, but habitat specific species are getting affected. Especially, exclusive river birds are the most vulnerable to river modification. The fragmentation of rivers into small stretches with or without permanent runoff water flow has started to severely affect the riverine habitats. The decline of the fish fauna, other invertebrates and habitat degradation in the dried up rivers leads to relocate the riverine species.

The HEPs have some negative and positive effect on the bird composition of the Sutlej and Yamuna rivers. The avoidance of river birds in the disturbed site of HEPs clearly indicating the alteration of habitats by construction activities and clearance of vegetation has contributed to this low richness of river birds. Although further work is required for the assessment and use of river birds for ecological monitoring in both Sutlej and Yamuna rivers.

CHAPTER 6

CONCLUSION

Understanding the spatial variation in bird communities is one of the most challenging tasks in ecology (Gaston, 2000). The species diversity along the latitudinal gradient is well known (Rosenzweig, 1992). The latitudinal gradient thought of as a microcosm of elevational gradients (Rahbek, 1995). Despite having noticeable pattern of bird diversity along elevational gradient, birds they have not received as much attention as latitudinal gradients (Sanders & Rahbek, 2012). Therefore, planning a conservation effort in montane ecosystems requires a thorough understanding of bird distribution, diversity patterns and structure of bird communities. (Chettri *et al*., 2001; Raman *et al*., 2005; Acharya *et al*., 2011). As a result, this study was carried out along two major river basins in western Himalaya, such as the Sutlej and Yamuna; to describe the structure of bird communities at various elevations, identify the factors that govern species distribution and richness along the different elevation gradient. In addition, this study also investigated changes in bird communities in response to hydro-electric power projects.

Bird surveys were carried out between 498 m to 3,700 m asl in Sutlej, and 378 m to 2,600 m asl in the Yamuna river basin. Point count method was used to count the birds. A fixed point count stations were established at every 1 km interval, and birds were counted within 50 m fixed radial distance. During each observation species and their numbers were recorded. A total of 318 and 429 permanent sampling points were laid in the Sutlej and Yamuna river basins respectively. The points were sampled four times a year, in the summer, monsoon, post-monsoon, and in the winter. Though the study was conducted throughout the year, in Sutlej zone IV and Yamuna zone III could not be sampled in the winter due to heavy snowfall.

In total, 241 bird species belonging to 59 families were recorded in the river basins (203 species from the Sutlej and 179 species from the Yamuna). In comparison to other elevation zones, the lower elevation zone I in the Sutlej and Yamuna river basin had a highest species richness and diversity. Of the total bird species recorded about 37% and 34% species were found in specific elevation zone in Sutlej and Yamuna, respectively. In addition, 22 species in the Sutlej and 62 species in the Yamuna river basin were utilize entire elevation zones. The most abundant species in the Sutlej and Yamuna river basins were Himalayan bulbul, Large-billed crow, and House sparrow. Although Snow Pigeons were relatively abundant and restrict to higher elevation zone IV of Sutlej. Surprisingly, the near-threatened Himalayan griffon was found in all elevational zones of the Sutlej and Yamuna river basins.

Species richness and diversity differed significantly across season, with higher species richness and diversity at zone I in Sutlej and Yamuna river basins during summer. Overall, species richness was high during summer in both river basins, whereas diversity was observed maximum in Sutlej during summer and in Yamuna during winter.

In sum, bird species showed a monotonic decline with increasing elevation along the elevational gradient of Sutlej and Yamuna river basin, declining approximately at the elevational range of 1500 m in both river basins. Combinations of factors are likely to account for most variations in the observed richness pattern of birds. This observed richness pattern has been strongly and positively correlated with the climatic variables – atmospheric temperature - in both river basins. Species abundance correlated significantly with elevational band support more species at the lower elevations. Area consistent with species richness was confirmed in Sutlej river basin but the Yamuna it was a failure to explain. Species of different trophic guilds showed a monotonic response to elevation. Turnover rate observed high between distant elevations categories compare to consecutive ones. In addition, the small range sizes of resident birds occur along the whole elevation gradient suggest that conservation efforts should consider the entire gradient rather than just lower elevations.

The HEPs had a negative impact on the richness, abundance, diversity and composition of bird species in the Sutlej and Yamuna river basin. The avoidance of riverine birds in the disturbed site of HEPs clearly indicating the alteration of habitats by construction activities and clearance of vegetation which has contributes to this low richness of riverine birds. Exclusive river birds are the most vulnerable to habitat modification and fragmentation. The increased disturbance of riverine habitat affects flow patterns and the invertebrates community, which in turn affects the bird species. Therefore, additional research is required to evaluate the use of riverine habitat by birds for ecological monitoring in both the Sutlej and Yamuna rivers.

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Appendices

Appendix 1. Checklist of birds recorded during the study from the Sutlej River, Himachal Pradesh. The classification follows Grimmett *et al*. (2011)

Family	Common Name	Scientific Name	IUCN	Resident Status
Phasianidae	Indian Peafowl	*Pavo cristatus*	LC	R
	Chukar	*Alectoris chukar*	LC	R
	Jungle Bush-quail	*Perdicula asiatica*	LC	R
	Black Francolin	*Francolinus francolinus*	LC	R
	Grey Francolin	*Francolinus pondicerianus*	LC	R
	Red Junglefowl	*Gallus gallus*	LC	R
	Cheer Pheasant	*Catreus wallichii*	VU	R
	Kalij Pheasant	*Lophura leucomelanos*	LC	R
Anatidae	Common Pochard	*Aythya ferina*	VU	WV
Podicipedidae	Little Grebe	*Tachybaptus ruficollis*	LC	R
Columbidae	Rock Dove	*Columba livia*	LC	R
	Hill Pigeon	*Columba rupestris*	LC	R
	Snow Pigeon	*Columba leuconota*	LC	R
	Oriental Turtle-dove	*Streptopelia orientalis*	LC	LM
	Eurasian Collared-dove	*Streptopelia decaocto*	LC	R
	Eastern Spotted Dove	*Spilopelia chinensis*	LC	R
	Laughing Dove	*Spilopelia senegalensis*	LC	R
	Grey-capped Emerald Dove	*Chalcophaps indica*	LC	R
Apodidae	White-throated Needletail	*Hirundapus caudacutus*	LC	SV
	Himalayan Swiftlet	*Aerodramus brevirostris*	LC	R
	Pacific Swift	*Apus pacificus*	LC	SV
	Little Swift	*Apus affinis*	LC	R
Cuculidae	Greater Coucal	*Centropus sinensis*	LC	R
	Western Koel	*Eudynamys scolopaceus*	LC	R
Rallidae	Common Moorhen	*Gallinula chloropus*	LC	R
Ardeidae	Indian Pond-heron	*Ardeola grayii*	LC	R
	Cattle Egret	*Bubulcus ibis*	LC	R
	Grey Heron	*Ardea cinerea*	LC	WV
	Great White Egret	*Ardea alba*	LC	R
	Intermediate Egret	*Ardea intermedia*	LC	R

Family	Common Name	Scientific Name	IUCN	Resident Status
	Little Egret	*Egretta garzetta*	LC	R
Phalacrocor-acidae	Little Cormorant	*Microcarbo niger*	LC	R
	Great Cormorant	*Phalacrocorax carbo*	LC	PV
Recurvirostridae	Black-winged Stilt	*Himantopus himantopus*	LC	WV
Charadriidae	Little Ringed Plover	*Charadrius dubius*	LC	R
	Red-wattled Lapwing	*Vanellus indicus*	LC	R
Scolopacidae	Common Sandpiper	*Actitis hypoleucos*	LC	SV
	Wood Sandpiper	*Tringa glareola*	LC	WV
	Marsh Sandpiper	*Tringa stagnatilis*	LC	WV
Strigidae	Asian Barred Owlet	*Glaucidium cuculoides*	LC	R
	Spotted Owlet	*Athene brama*	LC	R
Accipitridae	Black-winged Kite	*Elanus caeruleus*	LC	R
	Bearded Vulture	*Gypaetus barbatus*	NT	R
	Egyptian Vulture	*Neophron percnopterus*	EN	SV
	Crested Serpent-eagle	*Spilornis cheela*	LC	R
	Red-headed Vulture	*Sarcogyps calvus*	CR	R
	Himalayan Griffon	*Gyps himalayensis*	NT	R
	Black Eagle	*Ictinaetus malaiensis*	LC	R
	Bonelli's Eagle	*Aquila fasciata*	LC	R
	Hen Harrier	*Circus cyaneus*	LC	WV
	Pallid Harrier	*Circus macrourus*	NT	WV
	Shikra	*Accipiter badius*	LC	R
	Pallas's Fish-eagle	*Haliaeetus leucoryphus*	VU	R
	Black Kite	*Milvus migrans*	LC	R
Bucerotidae	Indian Grey Hornbill	*Ocyceros birostris*	LC	R
Upupidae	Common Hoopoe	*Upupa epops*	LC	R
Meropidae	Asian Green Bee-eater	*Merops orientalis*	LC	R
	Chestnut-headed Bee-eater	*Merops leschenaulti*	LC	SV
Coraciidae	Indian Roller	*Coracias benghalensis*	LC	R
Alcedinidae	Common Kingfisher	*Alcedo atthis*	LC	R
	Crested Kingfisher	*Megaceryle lugubris*	LC	R
	Pied Kingfisher	*Ceryle rudis*	LC	R

Family	Common Name	Scientific Name	IUCN	Resident Status
	White-breasted Kingfisher	*Halcyon smyrnensis*	LC	R
Megalaimidae	Great Barbet	*Psilopogon virens*	LC	R
	Brown-headed Barbet	*Psilopogon zeylanicus*	LC	R
	Blue-throated Barbet	*Psilopogon asiaticus*	LC	R
Picidae	Himalayan Flameback	*Dinopium shorii*	LC	R
	Lesser Yellownape	*Picus chlorolophus*	LC	R
	Grey-faced Woodpecker	*Picus canus*	LC	R
	Scaly-bellied Woodpecker	*Picus squamatus*	LC	R
	Great Slaty Woodpecker	*Mulleripicus pulverulentus*	VU	R
	Grey-capped Woodpecker	*Picoides canicapillus*	LC	R
	Brown-fronted Woodpecker	*Leiopicus auriceps*	LC	R
Falconidae	Common Kestrel	*Falco tinnunculus*	LC	R
Psittacidae	Slaty-headed Parakeet	*Psittacula himalayana*	LC	R
	Plum-headed Parakeet	*Psittacula cyanocephala*	LC	R
	Alexandrine Parakeet	*Psittacula eupatria*	NT	R
	Rose-ringed Parakeet	*Psittacula krameri*	LC	R
Pittidae	Indian Pitta	*Pitta brachyura*	LC	SV
Aegithinidae	Common Iora	*Aegithina tiphia*	LC	R
Campephagidae	Long-tailed Minivet	*Pericrocotus ethologus*	LC	LM
	Scarlet Minivet	*Pericrocotus flammeus*	LC	R
Laniidae	Bay-backed Shrike	*Lanius vittatus*	LC	R
	Long-tailed Shrike	*Lanius schach*	LC	LM
	Grey-backed Shrike	*Lanius tephronotus*	LC	SV
Oriolidae	Black-hooded Oriole	*Oriolus xanthornus*	LC	R
Dicruridae	Black Drongo	*Dicrurus macrocercus*	LC	R
	Ashy Drongo	*Dicrurus leucophaeus*	LC	SV
	Hair-crested Drongo	*Dicrurus hottentottus*	LC	R
Rhipiduridae	Yellow-bellied Fantail	*Rhipidura hypoxantha*	LC	WV
	White-throated Fantail	*Rhipidura albicollis*	LC	R
	White-browed Fantail	*Rhipidura aureola*	LC	R
Monarchidae	Asian Paradise-flycatcher	*Terpsiphone paradisi*	LC	SV
Corvidae	Black-headed Jay	*Garrulus lanceolatus*	LC	R

Family	Common Name	Scientific Name	IUCN	Resident Status
	Gold-billed Magpie	*Urocissa flavirostris*	LC	R
	Blue Magpie	*Urocissa erythrorhyncha*	LC	R
	Rufous Treepie	*Dendrocitta vagabunda*	LC	R
	Grey Treepie	*Dendrocitta formosae*	LC	R
	Spotted Nutcracker	*Nucifraga caryocatactes*	LC	R
	Red-billed Chough	*Pyrrhocorax pyrrhocorax*	LC	R
	Yellow-billed Chough	*Pyrrhocorax graculus*	LC	R
	House Crow	*Corvus splendens*	LC	R
	Large-billed Crow	*Corvus macrorhynchos*	LC	R
Paridae	Dark-grey Tit	*Parus rufonuchalis*	LC	R
	Rufous-vented Tit	*Parus rubidiventris*	LC	R
	Great Tit	*Parus major*	LC	R
	Green-backed Tit	*Parus monticolus*	LC	R
	Black-lored Tit	*Parus xanthogenys*	LC	R
	Black-crested Tit	*Parus melanolophus*	LC	R
Remizidae	Fire-capped Tit	*Cephalopyrus flammiceps*	LC	SV
Hirundinidae	Plain Martin	*Riparia paludicola*	LC	R
	Barn Swallow	*Hirundo rustica*	LC	SV
	Wire-tailed Swallow	*Hirundo smithii*	LC	SV
	Red-rumped Swallow	*Hirundo daurica*	LC	SV
	Asian House-martin	*Delichon dasypus*	LC	SV
Aegithalidae	Black-throated Tit	*Aegithalos concinnus*	LC	R
Alaudidae	Oriental Skylark	*Alauda gulgula*	LC	SV
	Ashy-crowned Sparrow-lark	*Eremopterix griseus*	LC	R
Cisticolidae	Zitting Cisticola	*Cisticola juncidis*	LC	R
	Striated Prinia	*Prinia crinigera*	LC	R
	Grey-breasted Prinia	*Prinia hodgsonii*	LC	R
	Jungle Prinia	*Prinia sylvatica*	LC	R
	Ashy Prinia	*Prinia socialis*	LC	R
	Plain Prinia	*Prinia inornata*	LC	R
Pycnonotidae	Himalayan Bulbul	*Pycnonotus leucogenys*	LC	R
	Red-vented Bulbul	*Pycnonotus cafer*	LC	R

Family	Common Name	Scientific Name	IUCN	Resident Status
	Asian Black Bulbul	*Hypsipetes leucocephalus*	LC	R
Sylviidae	Common Tailorbird	*Orthotomus sutorius*	LC	R
	Chestnut-headed Tesia	*Tesia castaneocoronata*	LC	R
	Tickell's Leaf-warbler	*Phylloscopus affinis*	LC	SV
	Pale-rumped Warbler	*Phylloscopus chloronotus*	LC	LM
	Greenish Warbler	*Phylloscopus trochiloides*	LC	LM
	Grey-hooded Warbler	*Phylloscopus xanthoschistos*	LC	R
	Whistler's Warbler	*Seicercus whistleri*	LC	LM
Timaliidae	Black-chinned Babbler	*Stachyris pyrrhops*	LC	R
	Yellow-eyed Babbler	*Chrysomma sinense*	LC	R
	Large Grey Babbler	*Turdoides malcolmi*	LC	R
	Jungle Babbler	*Turdoides striata*	LC	R
	Streaked Laughingthrush	*Garrulax lineatus*	LC	R
	Variegated Laughingthrush	*Garrulax variegatus*	LC	R
	Red-billed Leiothrix	*Leiothrix lutea*	LC	R
	White-browed Shrike-babbler	*Pteruthius flaviscapis*	LC	R
	Rufous Sibia	*Heterophasia capistrata*	LC	R
	Whiskered Yuhina	*Yuhina flavicollis*	LC	R
Zosteropidae	Oriental White-eye	*Zosterops palpebrosus*	LC	R
Reguliidae	Goldcrest	*Regulus regulus*	LC	R
Sittidae	Chestnut-bellied Nuthatch	*Sitta castanea*	LC	R
	White-cheeked Nuthatch	*Sitta leucopsis*	LC	R
	Wallcreeper	*Tichodroma muraria*	LC	WV
Certhiidae	Bar-tailed Treecreeper	*Certhia himalayana*	LC	LM
Sturnidae	Common Myna	*Acridotheres tristis*	LC	R
	Bank Myna	*Acridotheres ginginianus*	LC	R
	Jungle Myna	*Acridotheres fuscus*	LC	R
	Asian Pied Starling	*Sturnus contra*	LC	R
Turdidae	Blue Whistling-thrush	*Myophonus caeruleus*	LC	R
	White-collared Blackbird	*Turdus albocinctus*	LC	R
	Grey-winged Blackbird	*Turdus boulboul*	LC	R

Family	Common Name	Scientific Name	IUCN	Resident Status
Muscicapidae	Orange-flanked Bush-robin	*Tarsiger cyanurus*	LC	R
	Oriental Magpie-robin	*Copsychus saularis*	LC	R
	Indian Robin	*Saxicoloides fulicatus*	LC	R
	Blue-capped Redstart	*Phoenicurus caeruleocephala*	LC	R
	Black Redstart	*Phoenicurus ochruros*	LC	PV
	White-winged Redstart	*Phoenicurus erythrogastrus*	LC	LM
	Blue-fronted Redstart	*Phoenicurus frontalis*	LC	LM
	Plumbeous Water-redstart	*Rhyacornis fuliginosa*	LC	R
	White-capped Water-redstart	*Chaimarrornis leucocephalus*	LC	R
	Grandala	*Grandala coelicolor*	LC	R
	Little Forktail	*Enicurus scouleri*	LC	R
	Spotted Forktail	*Enicurus maculatus*	LC	R
	Common Stonechat	*Saxicola torquatus*	LC	LM
	Pied Bushchat	*Saxicola caprata*	LC	LM
	Grey Bushchat	*Saxicola ferreus*	LC	R
	Variable Wheatear	*Oenanthe picata*	LC	WV
	Blue-capped Rock-thrush	*Monticola cinclorhynchus*	LC	SV
	Chestnut-bellied Rock-thrush	*Monticola rufiventris*	LC	R
	Blue Rock-thrush	*Monticola solitarius*	LC	SV
	Ultramarine Flycatcher	*Ficedula superciliaris*	LC	SV
	Slaty-blue Flycatcher	*Ficedula tricolor*	LC	SV
	Verditer Flycatcher	*Eumyias thalassinus*	LC	SV
	Rufous-bellied Niltava	*Niltava sundara*	LC	LM
Cinclidae	White-throated Dipper	*Cinclus cinclus*	LC	R
	Brown Dipper	*Cinclus pallasii*	LC	R
Chloropseidae	Golden-fronted Leafbird	*Chloropsis aurifrons*	LC	R
Nectariniidae	Purple Sunbird	*Nectarinia asiatica*	LC	SV
	Crimson Sunbird	*Aethopyga siparaja*	LC	R
Passeridae	House Sparrow	*Passer domesticus*	LC	R

Family	Common Name	Scientific Name	IUCN	Resident Status
	Russet Sparrow	*Passer rutilans*	LC	R
Estrildidae	Scaly-breasted Munia	*Lonchura punctulata*	LC	R
Prunellidae	Robin Accentor	*Prunella rubeculoides*	LC	R
	Black-throated Accentor	*Prunella atrogularis*	LC	WV
Motacillidae	White Wagtail	*Motacilla alba*	LC	PV
	White-browed Wagtail	*Motacilla madaraspatensis*	LC	R
	Citrine Wagtail	*Motacilla citreola*	LC	WV
	Yellow Wagtail	*Motacilla flava*	LC	WV
	Grey Wagtail	*Motacilla cinerea*	LC	LM
	Paddyfield Pipit	*Anthus rufulus*	LC	R
Fringillidae	Fire-fronted Serin	*Serinus pusillus*	LC	R
	Yellow-breasted Greenfinch	*Carduelis spinoides*	LC	SV
	Common Rosefinch	*Carpodacus erythrinus*	LC	PV
	Red-mantled Rosefinch	*Carpodacus rhodochlamys*	LC	WV
Emberizidae	Crested Bunting	*Melophus lathami*	LC	SV
	Chestnut-breasted Bunting	*Emberiza stewarti*	LC	LM
	Rock Bunting	*Emberiza cia*	LC	R

Appendix 2. Checklist of birds recorded during the study from the Yamuna River, Uttarakhand. The classification follows Grimmett *et al*. (2011)

Family	Common Name	Scientific Name	IUCN	Resident Status
Phasianidae	Indian Peafowl	*Pavo cristatus*	LC	R
	Black Francolin	*Francolinus francolinus*	LC	R
	Grey Francolin	*Francolinus pondicerianus*	LC	R
	Red Junglefowl	*Gallus gallus*	LC	R
	Kalij Pheasant	*Lophura leucomelanos*	LC	R
Anatidae	Ruddy Shelduck	*Tadorna ferruginea*	LC	WV
	Red-crested Pochard	*Netta rufina*	LC	WV
	Common Pochard	*Aythya ferina*	VU	WV
	Tufted Duck	*Aythya fuligula*	LC	WV
	Northern Shoveler	*Spatula clypeata*	LC	WV
	Gadwall	*Mareca strepera*	LC	WV
	Indian Spot-billed Duck	*Anas poecilorhyncha*	LC	R
	Mallard	*Anas platyrhynchos*	LC	WV
	Common Teal	*Anas crecca*	LC	WV
Podicipedidae	Little Grebe	*Tachybaptus ruficollis*	LC	R
	Great Crested Grebe	*Podiceps cristatus*	LC	WV
Columbidae	Rock Dove	*Columba livia*	LC	R
	Hill Pigeon	*Columba rupestris*	LC	R
	Snow Pigeon	*Columba leuconota*	LC	R
	Oriental Turtle-dove	*Streptopelia orientalis*	LC	LM
	Eurasian Collared-dove	*Streptopelia decaocto*	LC	R
	Eastern Spotted Dove	*Stigmatopelia chinensis*	LC	R
	Wedge-tailed Green-pigeon	*Treron sphenurus*	LC	R
Apodidae	White-throated Needletail	*Hirundapus caudacutus*	LC	SV
	Alpine Swift	*Tachymarptis melba*	LC	SV
	Little Swift	*Apus affinis*	LC	R
Cuculidae	Greater Coucal	*Centropus sinensis*	LC	R
	Western Koel	*Eudynamys scolopaceus*	LC	R
	Common Hawk-cuckoo	*Hierococcyx varius*	LC	R
Rallidae	Common Coot	*Fulica atra*	LC	R

Family	Common Name	Scientific Name	IUCN	Resident Status
Ciconiidae	Painted Stork	*Mycteria leucocephala*	NT	R
	Asian Woollyneck	*Ciconia episcopus*	VU	R
Ardeidae	Indian Pond-heron	*Ardeola grayii*	LC	R
	Cattle Egret	*Bubulcus ibis*	LC	R
	Grey Heron	*Ardea cinerea*	LC	WV
	Purple Heron	*Ardea purpurea*	LC	R
	Great White Egret	*Ardea alba*	LC	R
	Intermediate Egret	*Ardea intermedia*	LC	R
	Little Egret	*Egretta garzetta*	LC	R
Phalacrocoracidae	Little Cormorant	*Microcarbo niger*	LC	R
	Great Cormorant	*Phalacrocorax carbo*	LC	PV
Recurvirostridae	Black-winged Stilt	*Himantopus himantopus*	LC	WV
Charadriidae	River Lapwing	*Vanellus duvaucelii*	NT	R
	Red-wattled Lapwing	*Vanellus indicus*	LC	R
Scolopacidae	Wood Sandpiper	*Tringa glareola*	LC	WV
Laridae	Black-headed Gull	*Larus ridibundus*	LC	WV
	Common Gull-billed Tern	*Gelochelidon nilotica*	LC	WV
Strigidae	Asian Barred Owlet	*Glaucidium cuculoides*	LC	R
	Spotted Owlet	*Athene brama*	LC	R
Accipitridae	Bearded Vulture	*Gypaetus barbatus*	NT	R
	Egyptian Vulture	*Neophron percnopterus*	EN	SV
	Crested Serpent-eagle	*Spilornis cheela*	LC	R
	Himalayan Griffon	*Gyps himalayensis*	NT	R
	Cinereous Vulture	*Aegypius monachus*	NT	WV
	Changeable Hawk-eagle	*Nisaetus cirrhatus*	LC	R
	Shikra	*Accipiter badius*	LC	R
	Pallas's Fish-eagle	*Haliaeetus leucoryphus*	VU	R
	Black Kite	*Milvus migrans*	LC	R
Upupidae	Common Hoopoe	*Upupa epops*	LC	R
Meropidae	Asian Green Bee-eater	*Merops orientalis*	LC	R
	Chestnut-headed Bee-eater	*Merops leschenaulti*	LC	SV

Family	Common Name	Scientific Name	IUCN	Resident Status
Alcedinidae	Crested Kingfisher	*Megaceryle lugubris*	LC	R
	Pied Kingfisher	*Ceryle rudis*	LC	R
	White-breasted Kingfisher	*Halcyon smyrnensis*	LC	R
Megalaimidae	Great Barbet	*Psilopogon virens*	LC	R
	Brown-headed Barbet	*Psilopogon zeylanicus*	LC	R
	Blue-throated Barbet	*Psilopogon asiaticus*	LC	R
Picidae	Himalayan Flameback	*Dinopium shorii*	LC	R
	Lesser Yellownape	*Picus chlorolophus*	LC	R
	Grey-faced Woodpecker	*Picus canus*	LC	R
	Scaly-bellied Woodpecker	*Picus squamatus*	LC	R
	Grey-capped Woodpecker	*Picoides canicapillus*	LC	R
	Brown-fronted Woodpecker	*Leiopicus auriceps*	LC	R
	Rufous-bellied Woodpecker	*Dendrocopos hyperythrus*	LC	R
Falconidae	Common Kestrel	*Falco tinnunculus*	LC	R
Psittacidae	Slaty-headed Parakeet	*Psittacula himalayana*	LC	R
	Plum-headed Parakeet	*Psittacula cyanocephala*	LC	R
	Alexandrine Parakeet	*Psittacula eupatria*	NT	R
	Rose-ringed Parakeet	*Psittacula krameri*	LC	R
Campephagidae	Small Minivet	*Pericrocotus cinnamomeus*	LC	R
	Long-tailed Minivet	*Pericrocotus ethologus*	LC	LM
	Scarlet Minivet	*Pericrocotus flammeus*	LC	R
Laniidae	Bay-backed Shrike	*Lanius vittatus*	LC	R
	Long-tailed Shrike	*Lanius schach*	LC	LM
	Grey-backed Shrike	*Lanius tephronotus*	LC	LM
Oriolidae	Eurasian Golden Oriole	*Oriolus oriolus*	LC	SV
Dicruridae	Black Drongo	*Dicrurus macrocercus*	LC	R
	Ashy Drongo	*Dicrurus leucophaeus*	LC	SV
	Bronzed Drongo	*Dicrurus aeneus*	LC	R
	Hair-crested Drongo	*Dicrurus hottentottus*	LC	R
Rhipiduridae	Yellow-bellied Fantail	*Rhipidura hypoxantha*	LC	LM
	White-throated Fantail	*Rhipidura albicollis*	LC	R
Monarchidae	Asian Paradise-flycatcher	*Terpsiphone paradisi*	LC	SV

Family	Common Name	Scientific Name	IUCN	Resident Status
Corvidae	Black-headed Jay	*Garrulus lanceolatus*	LC	R
	Gold-billed Magpie	*Urocissa flavirostris*	LC	R
	Blue Magpie	*Urocissa erythrorhyncha*	LC	R
	Rufous Treepie	*Dendrocitta vagabunda*	LC	R
	Grey Treepie	*Dendrocitta formosae*	LC	R
	Spotted Nutcracker	*Nucifraga caryocatactes*	LC	R
	House Crow	*Corvus splendens*	LC	R
	Large-billed Crow	*Corvus macrorhynchos*	LC	R
Paridae	Great Tit	*Parus major*	LC	R
	Green-backed Tit	*Parus monticolus*	LC	R
Hirundinidae	Plain Martin	*Riparia paludicola*	LC	R
	Eurasian Crag-martin	*Hirundo rupestris*	LC	SV
	Barn Swallow	*Hirundo rustica*	LC	SV
	Wire-tailed Swallow	*Hirundo smithii*	LC	SV
	Red-rumped Swallow	*Hirundo daurica*	LC	R
	Asian House-martin	*Delichon dasypus*	LC	SV
Aegithalidae	Black-throated Tit	*Aegithalos concinnus*	LC	R
Alaudidae	Oriental Skylark	*Alauda gulgula*	LC	SV
Cisticolidae	Striated Prinia	*Prinia crinigera*	LC	R
	Grey-breasted Prinia	*Prinia hodgsonii*	LC	R
	Jungle Prinia	*Prinia sylvatica*	LC	R
	Ashy Prinia	*Prinia socialis*	LC	R
	Plain Prinia	*Prinia inornata*	LC	R
Pycnonotidae	Himalayan Bulbul	*Pycnonotus leucogenys*	LC	R
	Red-vented Bulbul	*Pycnonotus cafer*	LC	R
	Asian Black Bulbul	*Hypsipetes leucocephalus*	LC	R
Sylviidae	Pale-rumped Warbler	*Phylloscopus chloronotus*	LC	LM
	Greenish Warbler	*Phylloscopus trochiloides*	LC	LM
	Grey-hooded Warbler	*Phylloscopus xanthoschistos*	LC	R
Timaliidae	Rusty-cheeked Scimitar-babbler	*Pomatorhinus erythrogenys*	LC	R
	Black-chinned Babbler	*Stachyris pyrrhops*	LC	R

Family	Common Name	Scientific Name	IUCN	Resident Status
	Jungle Babbler	*Turdoides striata*	LC	R
	Striated Laughingthrush	*Garrulax striatus*	LC	R
	Streaked Laughingthrush	*Garrulax lineatus*	LC	R
	Variegated Laughingthrush	*Garrulax variegatus*	LC	R
	Chestnut-crowned Laughingthrush	*Garrulax erythrocephalus*	LC	R
	Rufous Sibia	*Heterophasia capistrata*	LC	R
	Whiskered Yuhina	*Yuhina flavicollis*	LC	R
Zosteropidae	Oriental White-eye	*Zosterops palpebrosus*	LC	R
Reguliidae	Goldcrest	*Regulus regulus*	LC	R
Sittidae	Wallcreeper	*Tichodroma muraria*	LC	WV
Sturnidae	Common Myna	*Acridotheres tristis*	LC	R
	Jungle Myna	*Acridotheres fuscus*	LC	R
	Chestnut-tailed Starling	*Sturnus malabaricus*	LC	SV
	Asian Pied Starling	*Sturnus contra*	LC	R
Turdidae	Blue Whistling-thrush	*Myophonus caeruleus*	LC	R
	Plain-backed Thrush	*Zoothera mollissima*	LC	R
	Eurasian Scaly Thrush	*Zoothera dauma*	LC	SV
	Long-billed Thrush	*Zoothera monticola*	LC	SV
	White-collared Blackbird	*Turdus albocinctus*	LC	R
	Chestnut Thrush	*Turdus rubrocanus*	LC	R
	Black-throated Thrush	*Turdus atrogularis*	LC	WV
Muscicapidae	Orange-flanked Bush-robin	*Tarsiger cyanurus*	LC	R
	Oriental Magpie-robin	*Copsychus saularis*	LC	R
	Indian Robin	*Saxicoloides fulicatus*	LC	R
	Blue-capped Redstart	*Phoenicurus caeruleocephala*	LC	R
	Blue-fronted Redstart	*Phoenicurus frontalis*	LC	LM
	Plumbeous Water-redstart	*Rhyacornis fuliginosa*	LC	R
	White-capped Water-redstart	*Chaimarrornis leucocephalus*	LC	R
	Little Forktail	*Enicurus scouleri*	LC	R
	Spotted Forktail	*Enicurus maculatus*	LC	R

Family	Common Name	Scientific Name	IUCN	Resident Status
	Common Stonechat	*Saxicola torquatus*	LC	SV
	Pied Bushchat	*Saxicola caprata*	LC	R
	Grey Bushchat	*Saxicola ferreus*	LC	R
	Blue-capped Rock-thrush	*Monticola cinclorhynchus*	LC	SV
	Chestnut-bellied Rock-thrush	*Monticola rufiventris*	LC	R
	Blue Rock-thrush	*Monticola solitarius*	LC	WV
	Verditer Flycatcher	*Eumyias thalassinus*	LC	SV
	Rufous-bellied Niltava	*Niltava sundara*	LC	LM
	Grey-headed Canary-flycatcher	*Culicicapa ceylonensis*	LC	SV
Cinclidae	Brown Dipper	*Cinclus pallasii*	LC	R
Nectariniidae	Purple Sunbird	*Nectarinia asiatica*	LC	SV
	Crimson Sunbird	*Aethopyga siparaja*	LC	R
Passeridae	House Sparrow	*Passer domesticus*	LC	R
	Russet Sparrow	*Passer rutilans*	LC	R
	Chestnut-shouldered Petronia	*Petronia xanthocollis*	LC	R
Estrildidae	Scaly-breasted Munia	*Lonchura punctulata*	LC	R
Motacillidae	White Wagtail	*Motacilla alba*	LC	PV
	White-browed Wagtail	*Motacilla madaraspatensis*	LC	R
	Grey Wagtail	*Motacilla cinerea*	LC	LM
Fringillidae	Fire-fronted Serin	*Serinus pusillus*	LC	R
	Yellow-breasted Greenfinch	*Carduelis spinoides*	LC	SV
	Common Rosefinch	*Carpodacus erythrinus*	LC	WV
	European Goldfinch	*Carduelis carduelis*	LC	R
Emberizidae	Crested Bunting	*Melophus lathami*	LC	LM
	Rock Bunting	*Emberiza cia*	LC	R

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ARTICLE

The pattern of bird distribution along the elevation gradient of the Sutlej River basin, western Himalaya, India

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Abstract: We examined the species richness of birds along the elevation gradient of the Sutlej River basin in Himachal Pradesh in the western Himalaya of India. Birds were sampled at 318 sites categorized into 16 elevation bands ranging from 498 to 3700 m between June 2012 and April 2013. A total of 203 bird species were recorded. Species richness showed a monotonic decline with increasing elevation, with 27% of species recorded within a narrow elevation range. We tested the roles of explanatory variables such as environment (temperature, precipitation, area, & Mid-domain Effect (MDE) richness) and habitat (Normalized Differential Vegetation Index (NDVI): July, November & March) on the observed distribution pattern. The observed species richness pattern was strongly correlated with temperature, while three other variables—precipitation, area, and MDE richness—contributed negligibly to the observed pattern. The present study indicates that climatic conditions and vegetation are the major contributors for determining species richness along the Sutlej River basin. Thus, a customized approach is crucial for conservation of species in the elevation range.

Keywords: Bird distribution, elevation range size, hydro-electric projects, India, mid-domain, monotonic decline, Sutlej River basin, western Himalaya.

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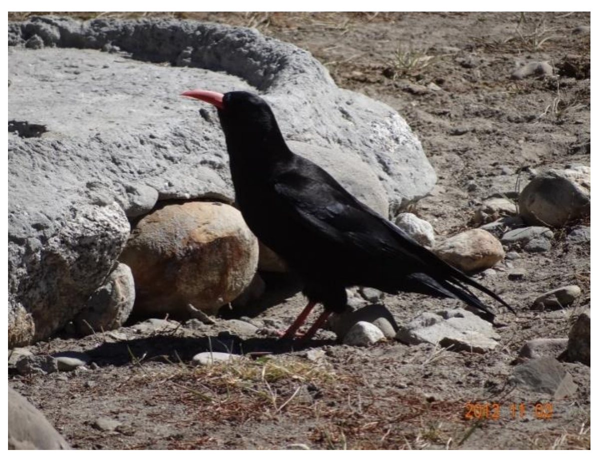
Alexandrine Parakeet *Psittacula eupatria*

Himalayan Griffon *Gyps himalayensis*

Egyptian Vulture *Neophron percnopterus*

Crested Kingfisher *Megaceryle lugubris*

Chukar *Alectoris chukar*



Red-billed Chough *Pyrrhocorax pyrrhocorax*

Plate 2. Some of the threatened and least concern birds recorded from Sutlej River

Bearded Vulture *Gypaetus barbatus*

Cinereous Vulture *Aegypius monachus*

Painted Stork *Mycteria* leucocephala

Common Kestrel *Falco tinnunculus*

Himalayan Bulbul *Pycnonotus leucogenys*

Plumbeous Water-redstart *Rhyacornis fuliginosa*

Plate 3. Some of the threatened and least concern birds recorded from Yamuna River

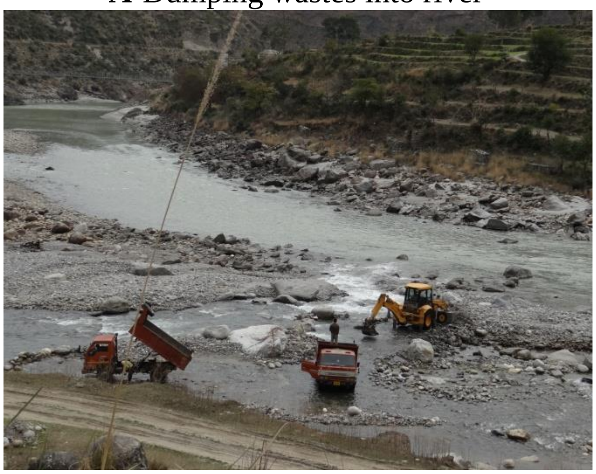
Plate 1. View of Sutlej River (A), Himachal Pradesh and Yamuna River (B), Uttarakhand

Plate 4. View of hydro power projects, Sutlej River: A-Constructing phase, B-Existing project

Plate 5. View of Hydro power dam (A) and Water line for hydro project (B), Yamuna River

A-Dumping wastes into river

B-Dumping soil into river



C-Removing sand from river

D-Removing sand for dam construction

E-Wood lopping

F-Forest fire

Plate 6. Anthropogenic activities in Sutlej (A, B & C) and Yamuna River (D, E & F)