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Article

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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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INTRODUCTION

Understanding the spatial aspects of species diversity is a key challenge in ecology (Gaston 2000). One well-known pattern is global latitudinal diversity, where species richness peaks in the tropics and declines towards the poles (Rosenzweig 1992). Variation in species richness along latitudinal gradients is a well-documented pattern (Yu et al. 2013) and similar patterns have been observed along elevation gradients (Rahbek 1995) and across taxonomic groups (Stevens 1992) and continents (Cavarzere & Silveira 2012) to provide striking patterns in diversity (Sanders & Rahbek 2012). Distribution patterns along elevation gradients have been noted in invertebrates (Sanders 2002; Sanders et al. 2003; Khan et al. 2011; Levanoni 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; 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; Joshi & Bhatt 2015; Montano-Centellas & Garitano-Zavala 2015), and herpetofauna (Hofer et al. 1999; Naniwadekar & Vasudevan 2007; Chettri et al. 2010; Srinivas 2011). In general, species richness along elevation gradients follows one of three patterns: monotonic decline (decreasing with elevation), a hump-shaped pattern peaking at middle elevations (mid-domain), and that increasing with elevation (Stevens 1992; Rahbek 1995). Among these, the most widely-observed patterns are monotonic decline and mid-domain peak (Rahbek 1995; McCain 2009).

Comprehensive data sets for bird communities living along elevation gradients are available for many sites (Colwell et al. 2004; Boyle et al. 2015). 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 widely accepted as a general pattern in different taxa (Stevens 1992; Rahbek 1995). Rahbek (1995), however, stated that this view of the relation between species richness and elevation is immature and that the compositional changes in bird communities along elevations are still not well understood (Terborgh 1971, 1977; Blake & Loiselle 2000; Jankowski et al. 2009; Acharya et al. 2011). Monotonic decline of species richness (Stevens 1992; Nor et al. 2001; Yu et al. 2013; Acharya & Vijayan 2015), mid-elevation peak (Rahbek 1995, 1997; Nor 2001; Rickart 2001; McCain 2004; Brehm et al. 2007; Das 2008; Acharya et al. 2011; Srinivas 2011; Joshi & Rautela 2014; Joshi & Bhatt 2015), monotonic increase in species richness (Sanders et al. 2003; Naniwadekar & Vasudevan 2007), and U-shaped pattern or mid-elevation depression (Raman et al. 2005) are widely observed patterns of species distribution along elevation gradients.

Understanding the association between species richness and elevation gradients is essential as it provides insights into the observed patterns and processes responsible for the relation, which in turn supports conservation efforts (Stevens 1992; Raman et al. 2005; Acharya et al. 2011). In view of this, the present study was carried out to document and describe the distribution pattern of bird communities along the elevation gradient in Sutlej River basin of Himachal Pradesh belonging to the western Himalayan part of India. The western part of Himalaya is an important area of regional endemism and is a priority region for conservation (Rahmani & Islam 2004). The study aims to provide comprehensive information on the species richness pattern from yet another important region of the western Himalaya, thereby contributing more information to the debatable topic of species distribution patterns along an elevation gradient.

METHODS

Study area

The Sutlej River basin in the western Himalayan mountain range (30.85–32.91^{0}N & 76.26–79.00^{0}E) is situated in the state of Himachal Pradesh (Fig. 1). The entire region 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 in the southwesterly direction, bisecting the state. The Sutlej River basin covers wide-ranging variations in elevation (498–6685 m), climate (tropical to temperate), and vegetation types (tropical forest to alpine pastures). The temperature varies from a minimum of -3.8°C in February during winter to a maximum of 31.9°C in May during summer. The average annual rainfall (June–September) is 1,035.1mm (Indian Meteorological Department 2012) and precipitation in the form of snow is recorded during winter from December to February. We stratified the study area into 16 elevation bands of 200m interval. Within each band, point counts were fixed in proportion to the availability of the area. ASTER

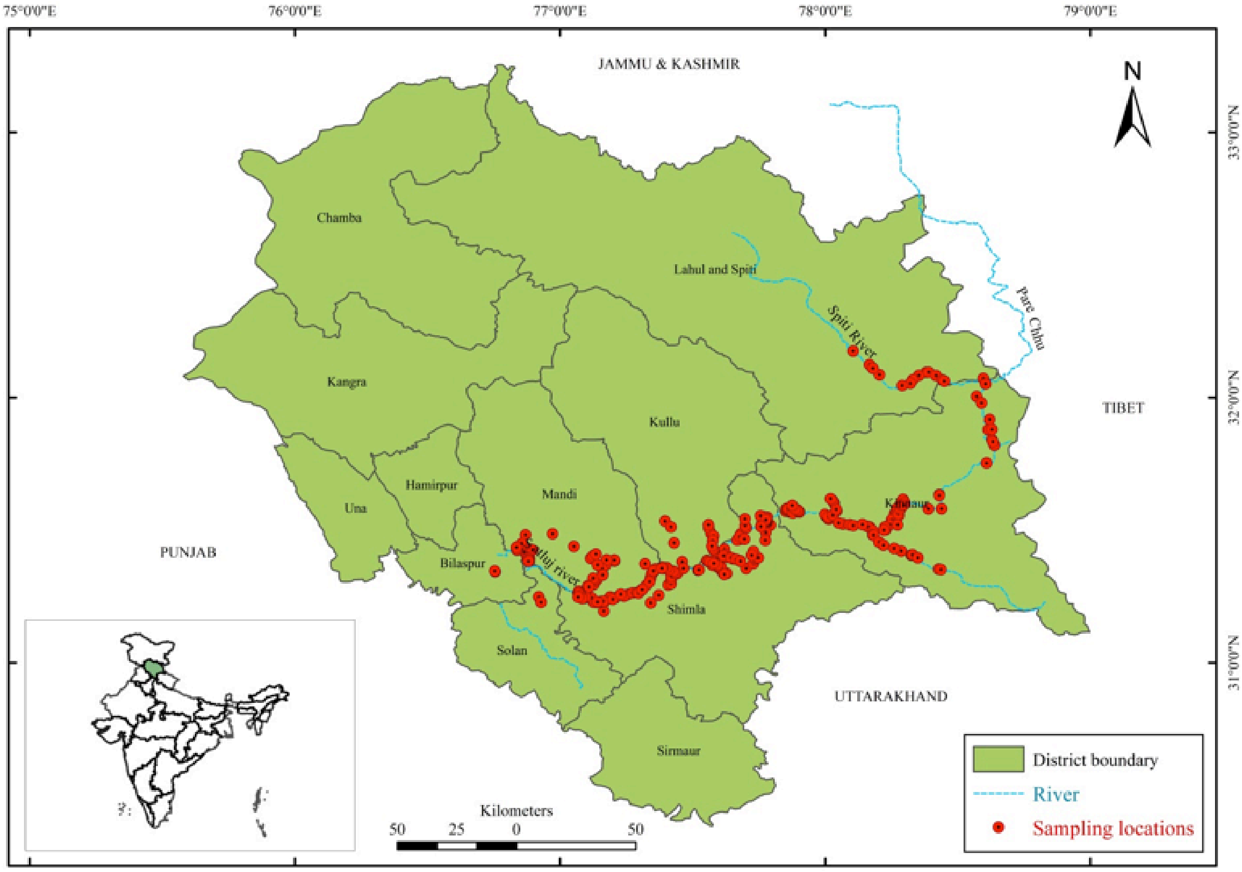

Figure 1. Map showing the sampling points at different elevations of Sutlej River basin, Himachal Pradesh

Global Digital Elevation Model (GDEM) was used to obtain the area available in each elevation band. A total of 318 sampling points were surveyed at different elevation bands (Table 1).

Table 1. Area availability and sampling effort in Sutlej River basin

Elevation band	Area (km^2)	Sampling points	Sampling replication
500-700	653.65	47	188
700-900	834.93	50	200
900-1100	652.74	22	87
1100-1300	566.20	34	136
1300-1500	549.23	20	80
1500-1700	506.60	36	144
1700-1900	479.71	22	88
1900-2100	426.88	20	80
2100-2300	371.42	11	43
2300-2500	333.42	11	44
2500-2700	340.98	3	12
2700-2900	316.68	13	50
2900-3100	309.35	9	33
3100-3300	338.79	6	18
3300-3500	387.30	11	26
3500-3700	483.80	3	10

Bird sampling

The present study was conducted from June 2012 to April 2013. To assess the difference in the richness and abundance of birds along the elevation gradient, point count method (Gaston 1975) was followed. A minimum of 1km distance (calculated using QGIS 2.12.1) was maintained between the consecutive points. In each point count, a single observer recorded every bird seen inat 10min intervals (Ralph et al. 1995; Raman 2003) within the fixed distance of 50m radius. The number of individuals and species were recorded based on both visual and vocal estimation. The sampling was avoided in inaccessible areas and at point count stations with evidence of human settlement. The surveys were carried out 30min after dawn and 30min before sunset on days with suitable weather conditions. The point counts were conducted from 0600 to 1100 hr in the morning and 1500 to 1800 hr in the evening. The probability of twice counts was minimized by excluding flocks that appeared in the same direction. To enhance the probability of detecting elusive or rare species, point counts varied between one to four replications in each season (summer, winter, & rainy season). Thus, a total of 1,239 point counts were conducted throughout the study. The average species richness of sampling replications has been used for analyses. The migratory status and taxonomic system used in this study followed Grimmett et al. (2011).

Habitat variables

We extracted temperature, precipitation, and other 19 bioclimatic variables from the WORLDCLIM database for the analysis. The database presents climatic data from 1950–2000 (50 years) at a spatial resolution of 1km (Hijmans et al. 2005). We used normalized differential vegetation index (NDVI) values from 2012 and 2013 to measure primary productivity, downloaded from Google Earth Engine (LANDSAT 7 with 32 days interval: https://earthengine.google.com/datasets/).

Analysis

We used non-parametric estimator (Chao 1) to calculate the estimated species richness using the statistical software program EstimateS 9.1 (Colwell & Coddington 1994; Colwell 2016). A precise estimate of observed and estimated species richness for a sampling interval was assumed if the species accumulation curve approached a plateau (Chao et al. 2005). Linear regression analysis (Sokal & Rohlf 1995) was performed against observed species richness with elevation to assess the species distribution pattern.

We performed Monte Carlo simulation using the software Mid-Domain Null model (McCain 2004) for testing geometric phenomena or mid-domain patterns of species ranges. The computed action simulates species richness curves based on empirical ranges or range midpoints within a bounded domain. It is based on the analytical–-stochastic models (Colwell & Hurtt 1994). The species ranges are randomly shuffled within a bounded geographical domain and resulting peak species richness at intermediate elevation (Colwell & Lees 2000). To test the geometric boundary 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 200m elevation increases). Linear regression was applied between empirical species richness and the average of the predicted number of species to assess the model fit.

We used simple linear regression model to explore the effect of each explanatory variable that could support the bird species richness along an elevation gradient. The explanatory variables such as mean annual temperature, mean annual precipitation, area, NDVI for July, October, November, February, March & April, and MDE predicted richness were regressed with estimated species richness (Chao 1). Among the environmental variables, temperature, precipitation, and area were highly correlated, similar to the habitat variables NDVI for July, November, and March. These highly correlated variables were selected for stepwise multiple regression analysis to identify the best explanatory variables that predicted the estimated species richness along elevation. In the set of variables, we selected estimated species richness as dependent variable and others as independent variables. In each successive step, the model with significant results was dropped and tried with other variables to find the next significant one.

We examined the elevation range profile for each species occurring at all elevations, whether the species utilized all intermediate elevation or was stuck between elevation maximum and minimum limits (Patterson et al. 1998). We then performed Pearson correlation to test the relationship between the range size of each species against the lower and upper limits of its elevation ranges. Regression and correlation analysis were performed in statistics software package SPSS 17.0 (Chicago, IL, USA).

RESULTS

Species richness

A total of 203 bird species, including 147 residents and 56 non-residents, were recorded across 16 elevation bands during the study period. The number of species detected in each elevation band varied from 20 to 140. The bird species richness was highest at around 700m elevation in the Sutlej River basin. The species accumulation curves across all the bands almost reached an asymptote, except in the elevation gradient above 2100–2500 m and 3500–3700 m (Fig. 2). The observed species richness corresponded well with the estimated Chao 1 ($r = 0.99$, $p < 0.000$).

Mid-domain analysis

Mid-domain effect (MDE) predictions were not observed in Sutlej River basin ($F_{(1,14)} = 93.52$, $p < 0.0001$; $R^2 = 0.87$; Fig. 3). The observed species richness, however, significantly declined with increasing elevation along all elevation gradients. The species distribution pattern in the Sutlej River basin showed a monotonic decrease in species richness with increasing elevation. A similar pattern was observed in the MDE, where the data revealed poor fit to the MDE predictions. The range size of resident bird species showed that only 12.5% of the empirical points occurred inside the predicted range of MDE null model (Fig. 4). The regression relationship between empirical species richness and the mean of the predicted richness is insignificant ($F_{(1.14)} = 0.026$, $p = 0.87$, $R^2 = 0.002$). MDE for all the bird species was also insignificant ($F_{(1.14)} = 0.001$; $p = 0.97$; $R^2 = 0.0001$) and 81% (13/16) of the empirical points fell out of the predicted limits (Fig. 5).

In simple linear regression, estimated species richness (Chao 1) was significantly correlated with mean temperature ($F_{(1.14)} = 79.10$, $p = 0.000$, $R^2 = 0.85$). Other environment factors such as MDE predicted richness and habitat variables such as NDVI for October, February, and April were insignificant. In the stepwise regression first model, the annual mean temperature was significantly correlated with estimated richness (Table 2). After removing the temperature, the second model habitat variable, NDVI March, was significantly correlated and the third model precipitation and area together showed a significant correlation.

Variation in empirical species richness in different elevation bands matched closely with the observed species richness. Abrupt turndown in species richness at elevation ranges 900–1,100 m and 1,300–1,700 m, however, was closely associated with predicted range boundaries (Fig. 5). It shows that the deviation of MDE prediction between empirical and observed species richness slightly goes wrong in Sutlej River basin.

Elevation range profile

The elevation range profile for birds in Sutlej River basin recorded a higher number of species (72% of species) occurring below 2500m elevation gradients. A total of 55 bird species was restricted to very narrow elevation range size (200m), 10 species were restricted above 3,000m (Table 3), and 17 species were spread all over the gradients (Fig. 6). A total of 77 (38%) bird species were below 600m elevation range and 19 species occurred above 3,000m elevation range. The elevation range size of low elevation species, those occurring below 2,000m (upper limit: $r = 0.825$, $p < 0.0001$; lower limit: $r = -0.383$, $p < 0.0001$), and high elevation species, those occurring above 2000m (upper limit: $r = 0.282$, $p < 0.01$; lower limit, $r = -0.813$, $p < 0.0001$), was positively correlated with upper limit and negatively correlated with lower limit. The range size of low elevation species, however, was inclined to decrease with elevation and that of high elevation species to increase with elevation.

DISCUSSION

In Sutlej River basin, we found a clear association between bird species richness and the factor (temperature) influencing the species distribution across the elevation bands. The MDE analysis also showed the decreasing trend of species richness along the alelevation gradients. In addition, species range size revealed that most of the species have a narrow elevation range within the sampled elevation gradients.

Species richness

Previous studies along Sutlej River basin examined a section of the elevation gradient for assessing the avian communities (Gaston 1993; Thakur et al. 2006; Mattu & Thakur 2006; Miller et al. 2008; Jayapal & Ramesh 2009; Kulkarni & Goswami 2012). This is the first study along an elevation gradient (498–3700 m) to document the distribution pattern of bird species along the Sutlej River basin. The species richness and abundance obtained from point count corresponded with Chao 1 estimate. The patterns of species richness across these elevation bands indicate that our sampling effort was fairly complete, although some new species were still recorded in few of the bands (2100–and2500 m & >3500m). This could be attributed to undersampling of the terrain in a few elevation bands due to inaccessibility and landscape degradation (Pandit & Grumbine 2012).

Table 2. Results of step-wise multiple regressions between estimated species richness (Chao 1) and explanatory variables to predict the most significant factor supporting the species distribution patterns

	Variables	Selected model	Part correlation	Adjusted R^2±SE	F	p
1	Temperature, precipitation, area, MDE predicted richness, NDVI (July, November & March)	Temperature	0.922	0.839±16.45	79.10	<0.000
2	Precipitation, area, MDE predicted richness, NDVI (July, November & March)	NDVI March	0.920	0.836±16.61	77.25	<0.000
3	Precipitation, area, MDE predicted richness, NDVI (July & November)	Precipitation area	0.406 0.341	0.909±12.39	75.52	<0.001

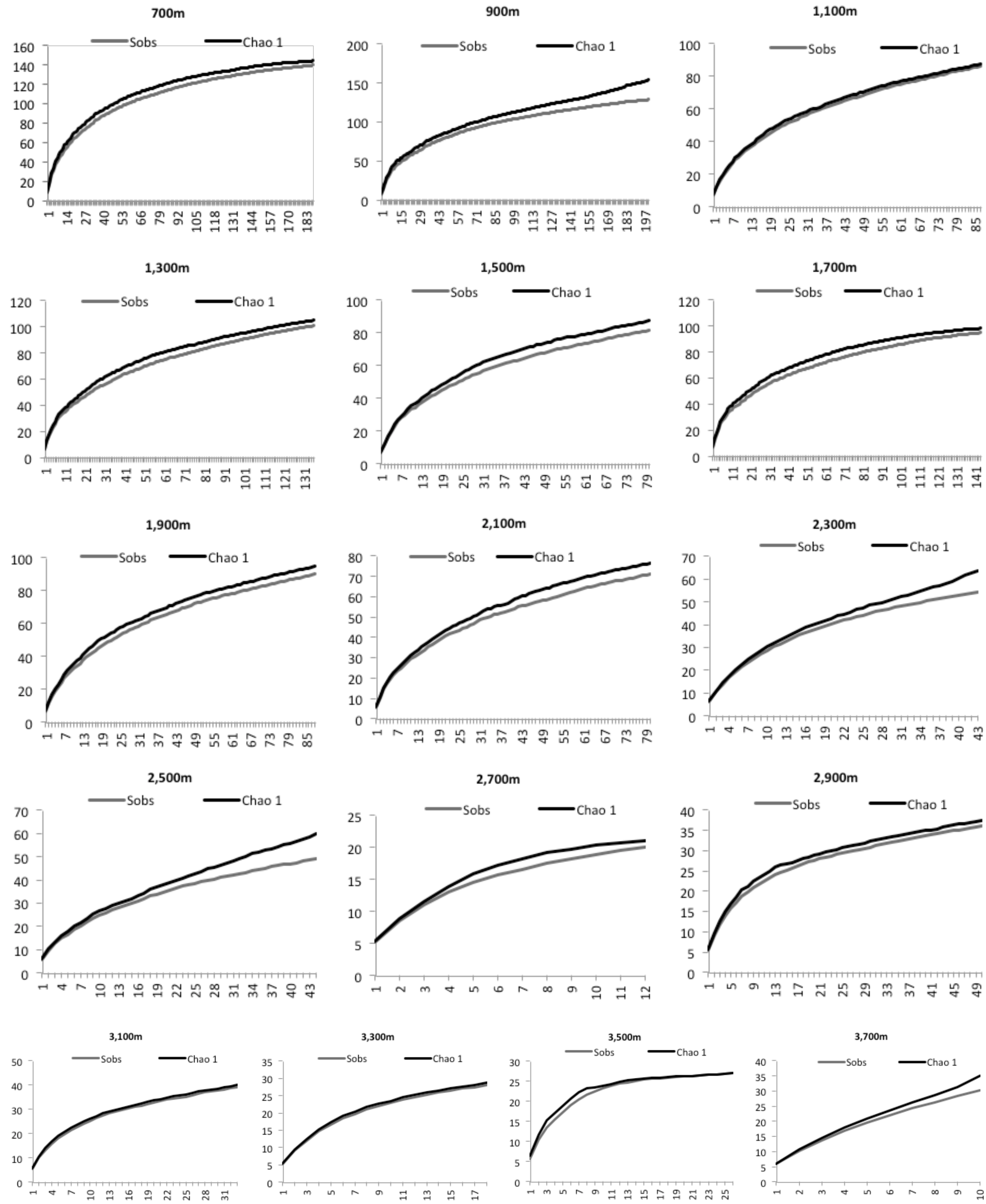

Figure 2. Estimates of species richness for birds - curves based on abundance detected in various elevation bands across Sutlej River basin, Himachal Pradesh
Horizontal axis - sampling effort, vertical axis - number of species, Sobs - species observed

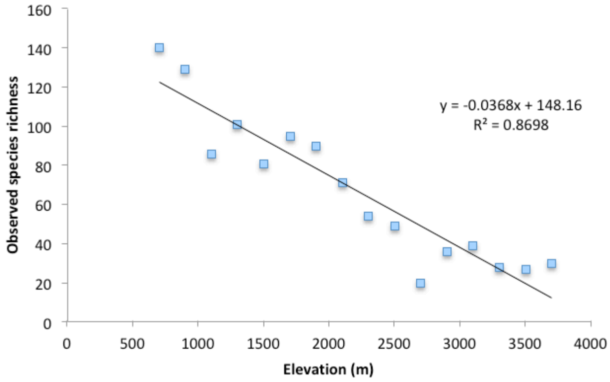

Figure 3. Elevation variation of observed bird species richness in Sutlej River basin

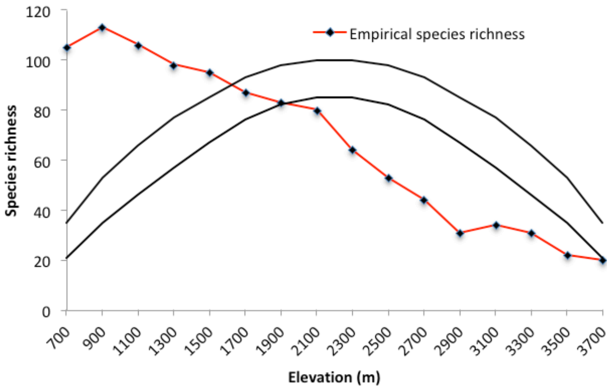

Figure 4. Mid-domain analysis for resident birds

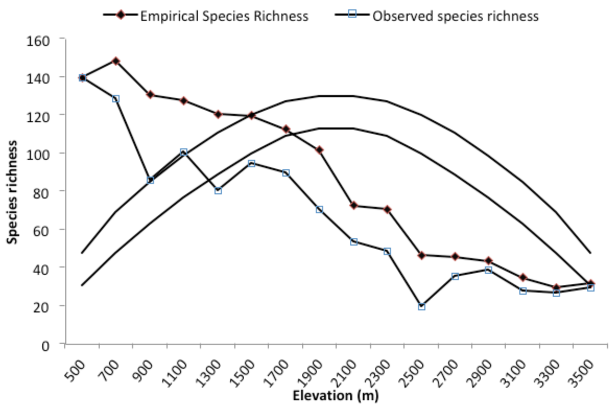

Figure 5. Mid-domain analysis for overall birds

Mid-domain analysis

The bird species richness along the elevation gradient was greater in three distinct peaks: 500–700 m, 1500–1700 m, and 3300–3500 m. This pattern reflects that the species richness of birds in Sutlej River basin is highly patchy. The present study, however, revealed that species richness of birds declined monotonically with increasing elevation. The monotonic decline in species richness along the elevation gradient has commonly been reported in various taxa and regions (Rahbek 1995, 2005; Patterson et al. 1998; Lessig 2008). In contrast, a few studies in the Himalaya 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 geometric constraints have a relatively low influence on the bird species richness pattern in the Sutlej River basin and western Himalaya.

The effect of climatic and productivity variables on the distribution pattern of birds in this river basin was tested. The monotonic decline in species richness was influenced by temperature as evidenced by the step-wise multiple regression model (Table 2). This observed result corresponds with Acharya et al. (2011) and Stevens (1992), where the species richness along the elevation gradient was influenced by climatic factors followed by habitat variables. In contrast, other studies in the Himalaya observed that the vegetation composition (Raza 2006; Joshi et al. 2012) and structure (Joshi & Rautela 2014; Joshi & Bhatt 2015) determined the species richness in a gradient, rather than the elevation and other climatic factors. These studies covered a part of the elevation range and did not consider a wide-elevation range as that followed in the present study and by Acharaya et al. (2011). This might be the reason for the absence of the influence of climatic variables on bird species distribution in other studies (Joshi et al. 2012).

In resident birds, 19% of observed species richness fells within 95% null model, which might be influenced by the geometric constraints than in other bands. For overall bird species, geometric constraints influenced between 1600 and 1800 m and >3500m elevation, whereas observed species richness fell between 900 and 1700 m and >3500m elevation of null model. The sudden decline in both resident and overall bird species richness above 2000m is in concurrence with increasing elevation and is due to sparse forest cover and harsh climatic conditions. These changes in climatic conditions could be a cause for the decline of species richness above the transition zone (>2000m) in Sutlej River basin.

Elevation range profile

Species richness of birds in Sutlej River basin was greater within 2000m elevation (116 species, 57%) and rest were found above 2000m. The elevation range limits of each species varied in this study area and

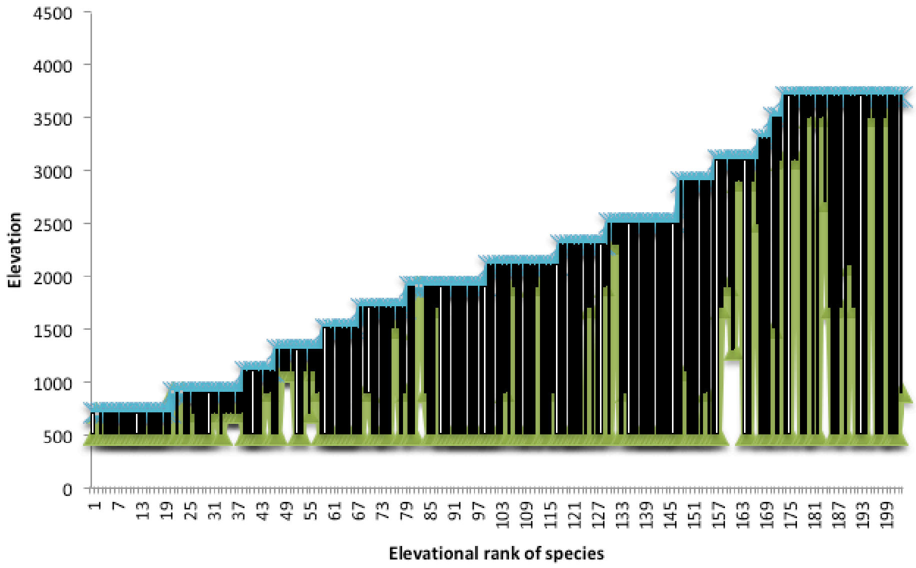

Figure 6. Elevation range profiles of birds in Sutlej River basin

showed very narrow ranges. Out of the 203 species, 17 species occurred in all sampled elevation bands while 55 species were found only in few elevation bands showing that their range sizes are narrow. Several factors such as habitat structure, inter-specific competition, and environmental tolerance (Jankowski et al. 2010; Laurance et al. 2011) would have driven the species into narrow elevation bands.

Species with broader elevation ranges were insectivorous or granivorous. The insectivorous birds such as Indian Roller *Coracias benghalensis*, Indian Pitta *Pitta brachyura*, Whiskered Yuhina *Yuhina flavicollis* & Red-billed Leiothrix *Leiothrix lutea* and granivorous birds such as Jungle Bush-quail *Perdicula asiatica*, Laughing Dove *Spilopelia senegalensis*, and Emerald Dove *Chalcophaps indica* were observed only at low elevation bands (<2000m). Stevens (1992) stated that the relationship between latitude and elevation differences experienced by the organisms along geographic gradients is due to the breadth of climatic conditions. Species that have narrow elevation ranges tend to have less climatic tolerance and thus are vulnerable to extinction due to global warming (Colwell et al. 2008; 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).

This is the first study in the western Himalaya to assess the distribution pattern of birds along a broad elevation gradient (500–3500 m). Our observation revealed that the bird species richness was significantly greater at a lower elevation than at mid- and high elevation, showing a monotonic decline in species richness. This observed pattern is strongly correlated with the climatic variable, atmospheric temperature, in Sutlej River basin. A large proportion of resident birds occurs in a narrow elevation range, indicating the necessity of sustainable conservation efforts. One of the major threats to the birds in Sutlej River basin is the hydropower projects that are reducing the green cover of the mountains, which perhaps is driving away species from their native elevation ranges (especially 600–1600 m) (Pandit & Grumbine 2012). Hence, a highly customized approach is crucial for the conservation of this entire elevation range.

REFERENCES

Acharya, B., N.J. Sanders, L. Vijayan & B. Chettri (2011). Elevational gradients in bird diversity in the eastern Himalaya: an evaluation of distribution patterns and their underlying mechanisms. *PLoS One* 6(12): e29097; https://doi.org/10.1371/journal.pone.0029097

Acharya, B.K. & L. Vijayan (2015). Butterfly diversity along the elevation gradient of eastern Himalaya, India. *Ecological Research* 30(5): 909–919.

Ali, S. & S.D. Ripley (1983). *Handbook of the Birds of India and Pakistan, Compact Edition*. University Press, Bombay, India, 737pp.

ASTER Global Digital Elevation Model (GDEM). Area availability. Available at http://www.gdem.aster.ersdac.or.jp/index.jsp

Bhardwaj, M., V.P. Uniyal, A.K. Sanyal & A.P. Singh (2012). Butterfly communities along an elevational gradient in the Tons valley, western Himalayas: implications of rapid assessment for insect conservation. *Journal of Asia-Pacific Entomology* 15: 207–217.

Blake, J.G. & B.A. Loiselle (2000). Diversity of birds along an elevational gradient in the Cordillera Central, Costa Rica. *Auk* 117: 663–686.

Boyle, W.A., B.K. Sandercock & K. Martin (2016). Patterns and drivers of intraspecific variation in avian life history along elevational gradients: a meta-analysis. *Biological Reviews* 91(2): 469–482.

Brehm, G., R.K. Colwell & J. Kluge (2007). The role of environment and mid-domain effect on moth species richness along a tropical elevational gradient. *Global Ecology and Biogeography* 16: 205–219.

Table 3. Narrow elevation range size of species and restricted species of birds in Sutlej River basin

Common name	Scientific name	Narrow elevation range size (200m)	Restricted (above 3000m)
Indian Peafowl	*Pavo cristatus*	+	
Jungle Bush-quail	*Perdicula asiatica*	+	
Cheer Pheasant [E, VU]	*Catreus wallichii*	+	
Common Pochard [VU]	*Aythya ferina*	+	
Little Grebe	*Tachybaptus ruficollis*	+	
Hill Pigeon	*Columba rupestris*		+
Snow Pigeon	*Columba leuconota*		+
Grey-capped Emerald Dove	*Chalcophaps indica*	+	
Pacific Swift	*Apus pacificus*	+	
Common Moorhen	*Gallinula chloropus*	+	
Indian Pond-heron	*Ardeola grayii*	+	
Cattle Egret	*Bubulcus ibis*	+	
Grey Heron	*Ardea cinerea*	+	
Great White Egret	*Ardea alba*	+	
Intermediate Egret	*Ardea intermedia*	+	
Little Egret	*Egretta garzetta*	+	
Little Cormorant	*Microcarbo niger*	+	
Black-winged Stilt	*Himantopus himantopus*	+	
Little Ringed Plover	*Charadrius dubius*	+	
Red-wattled Lapwing	*Vanellus indicus*	+	
Wood Sandpiper	*Tringa glareola*	+	+
Marsh Sandpiper	*Tringa stagnatilis*	+	
Spotted Owlet	*Athene brama*	+	
Red-headed Vulture [CR]	*Sarcogyps calvus*	+	
Black Eagle	*Ictinaetus malaiensis*	+	
Bonelli's Eagle	*Aquila fasciata*	+	
Hen Harrier	*Circus cyaneus*	+	
Indian Roller	*Coracias benghalensis*	+	
Common Kingfisher	*Alcedo atthis*	+	
Pied Kingfisher	*Ceryle rudis*	+	
Great Slaty Woodpecker [VU]	*Mulleripicus pulverulentus*	+	
Indian Pitta	*Pitta brachyura*	+	
Bay-backed Shrike	*Lanius vittatus*	+	
Grey-backed Shrike	*Lanius tephronotus*		+
Spotted Nutcracker	*Nucifraga caryocatactes*	+	
Black-lored Tit	*Parus xanthogenys*	+	
Fire-capped Tit	*Cephalopyrus flammiceps*	+	
Wire-tailed Swallow	*Hirundo smithii*	+	
Oriental Skylark	*Alauda gulgula*	+	
Zitting Cisticola	*Cisticola juncidis*	+	
Tickell's Leaf-warbler	*Phylloscopus affinis*	+	
Yellow-eyed Babbler	*Chrysomma sinense*	+	
Large Grey Babbler	*Turdoides malcolmi*	+	
Red-billed Leiothrix	*Leiothrix lutea*	+	
White-browed Shrike-babbler	*Pteruthius flaviscapis*	+	
Goldcrest	*Regulus regulus*	+	+
Chestnut-bellied Nuthatch	*Sitta castanea*	+	
Bank Myna	*Acridotheres ginginianus*	+	
Asian Pied Starling	*Sturnus contra*	+	
White-collared Blackbird	*Turdus albocinctus*	+	
Grey-winged Blackbird	*Turdus boulboul*	+	
Grandala	*Grandala coelicolor*	+	+
Blue Rock-thrush	*Monticola solitarius*	+	
Slaty-blue Flycatcher	*Ficedula tricolor*	+	+
Rufous-bellied Niltava	*Niltava sundara*	+	
White-throated Dipper	*Cinclus cinclus*	+	+
Crimson Sunbird	*Aethopyga siparaja*	+	
Robin Accentor	*Prunella rubeculoides*		+
Citrine Wagtail	*Motacilla citreola*	+	+

VU - Vulnerable, CR - Critically Endangered, E - Endemic; + Species presence

Brown, J.H. (2001). Mammals on mountainsides: elevational patterns of diversity. *Global Ecology and Biogeography* 10: 101–109.

Carneiro, E., O.H.H. Mielke, M.M. Casagrande & K. Fiedler (2014). Community structure of Skipper butterflies (Lepidoptera, Hesperiidae) along elevational gradients in Brazilian Atlantic forest reflects vegetation type rather than altitude. *PLoS One* 9(10): e108207; https://doi.org/10.1371/journal.pone.0108207

Cavarzere, V. & L.F. Silveira (2012). Bird species diversity in the Atlantic forest of Brazil is not explained by the mid-domain effect. *Zoologia* 29(4): 285–292.

Chao, A., R.L. Chazdon, R.K. Colwell & T.J. Shen (2005). A new statistical approach for assessing similarity of species composition with incidence and abundance data. *Ecology Letters* 8: 148–159.

Chettri, B., S. Bhupathy & B.K. Acharya (2010). Distribution pattern of reptiles along an eastern Himalayan elevation gradient, India. *Acta Oecologica* 36(1): 16–22.

Colwell, R.K. & D.C. Lees (2000). The mid-domain effect: geometric constraints on the geography of species richness. *Trends in Ecology and Evolution* 15(2): 70–76.

Colwell, R.K. & G.C. Hurtt (1994). Non-biological gradients in species richness and a spurious Rapoport effect. *The American Naturalist* 144(4): 570–595.

Colwell, R.K. & J.A. Coddington (1994). Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of*

Royal Society (B) 345: 101–118.

Colwell, R.K. (2016). EstimateS: statistical estimation of species richness and shared species from samples. Version 9.1. Available at http://viceroy.colorado.edu/estimates/

Colwell, R.K., C. Rahbek & N.J. Gotelli (2004). The mid-domain effect and species richness patterns: what have we learned so far? *The American Naturalist* 163(3): 1–23.

Colwell, R.K., G. Brehm, C.L. Cardelus, A.C. Gilman & J.T. Longino (2008). Global warming, elevational range shifts, and lowland biotic attrition in the wet tropics. *Science* 322: 258–261.

Das, K.S.A. (2008). Bird community structure along the altitudinal gradient in Silent Valley National Park, Western Ghats, India. PhD Thesis. Bharathiar University, Coimbatore.

Franco, A., C.A. Saavedra-Rodriguez & G.H. Kattan (2007). Bird species diversity captured by protected areas in the Andes of Colombia: a gap analysis. *Oryx* 41(1): 57–63.

Gaston, A.J. (1975). Methods for estimating bird populations. *Journal of the Bombay Natural History Society* 72(2): 271–283.

Gaston, A.J., P.J. Garson & S.Pandey (1993). Birds recorded in the Great Himalayan National Park, Himachal Pradesh, India. *Forktail* 9: 45–57.

Gaston, K.J. (2000). Global patterns in biodiversity. *Nature* 405: 220–227.

Google Earth Engine (LANDSAT 7 with 32 days interval). Normalized Differential Vegetation Index (NDVI). Available at https://earthengine.google.com/datasets/

Grimmett, R., C. Inskipp & T. Inskipp (2011). *Pocket Guide to the Birds of the Indian subcontinent*. Oxford University Press, London, 505pp.

Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones & A. Jarvis (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25: 1965–1978.

Hofer, U., L.F. Bersier & D. Borcard (1999). Spatial organization of a herpetofauna on an elevational gradient revealed by null model tests. *Ecology* 80(3): 976–988.

India Meteorological Department (2012). Annual Climate Summary, Pune. http://www.imdpune.gov.in Electronic version accessed 27 January 2014.

Jankowski, J.E., S.K. Robinson & D.J. Levey (2010). Squeezed at the top: interspecific aggression may constrain elevational ranges in tropical birds. *Ecology* 91(7): 1877—1884.

Jayapal, R. & K. Ramesh (2009). Management Plan for Rupi-Bhaba Wildlife Sanctuary, Himachal Pradesh (April 2010–March 2015). Wildlife Institute of India, Dehradun, vii+159pp.

Joshi, K. & D. Bhatt (2015). Avian species distribution along elevation at Doon valley (foothills of western Himalayas), Uttarakhand, and its association with vegetation structure. *Journal of Asia-Pacific Biodiversity* 8(2): 158–167.

Joshi, K.K. & P. Rautela (2014). Avian diversity and species composition along elevation at Doon valley forest of Dehradun District (Garhwal Himalaya) in Uttarakhand State, India. *Asian Journal of Conservation Biology* 3(1): 48–59.

Joshi, K.K., D. Bhatt & A. Thapliyal (2012). Avian diversity and its association with vegetation structure in different elevational zones of Nainital District (western Himalayan) of Uttarakhand. *Journal of Biodiversity and Conservation* 4(11): 364–376.

Kazmierczak, K. (2000). *A Field Guide to the Birds of India, Sri Lanka, Pakistan, Nepal Bhutan, Bangladesh and the Maldives*. Om Book Service, New Delhi, 352pp.

Khan, Z.H., R.H. Raina, M.A. Dar & V.V. Ramamurthy (2011). Diversity and distribution of butterflies from Kashmir Himalayas. *Journal of Insect Science* 24(1): 45–55.

Kulkarni, A.N. & P. Goswami (2012). Avian Fauna of Summer Hill, Shimla-Himachal Pradesh.*The Bioscan* 7(1): 61–64.

Laurance, W.F., D.C. Useche, L.C. Shoo, S.K. Herzog, M. Kessler, F. Escobar, G. Brehm, J.C. Axmacher, I.C. Chen, L.A. Gamez, P. Hietz, K. Fiedler, T. Pyrcz, J. Wolf, C.L. Merkord, C. Cardelus, A.R. Marshall, C. Ah-Peng, G.H. Aplet, M.D.C. Arizmendi, W.J. Baker, J. Barone, C.A. Bruhl, R.W. Bussmann, D. Cicuzza, G. Eilu, M.E. Favila, A. Hemp, C. Hemp, J. Homeier, J. Hurtado, J. Jankowski, G. Kattan, J. Kluge, T. Kromer, D.C. Lees, M. Lehnert, J.T. Longino, J. Lovett, P.H. Martin, B.D. Patterson, R.G. Pearson, K.S.H. Peh, B. Richardson, M. Richardson, M.J. Samways, F. Senbeta, T.B. Smith, T.M.A. Utteridge, J.E. Watkins, R. Wilson, S.E. Williams & C.D. Thomas (2011). Global warming, elevational ranges and the vulnerability of tropical biota. *Biological Conservation* 144: 548–557.

Lee, P.F., T.S. Ding, F.H. Hsu & S. Geng (2004). Breeding bird species richness in Taiwan: distribution on gradients of elevation, primary productivity and urbanization. *Journal of Biogeography* 31: 307–314.

Lessig, H. (2008). Species distribution and richness patterns of bird communities in the high elevation forests of Virginia. MSc Thesis, Virginia Polytechnic institute, Virginia, vii+81pp.

Levanoni, O., N. Levin, G. Pe'er, A. Turbe & S. Kark (2011). Can we predict butterfly diversity along an elevation gradient from space? *Ecography* 34(3): 372–383.

Mattu, V.K. & M.L. Thakur (2006). Bird diversity and status in Summer Hill, Shimla (Himachal Pradesh). *Indian Forester* 132(10): 1271–1281.

McCain, C.M. (2004a). A Monte Carlo simulation program for geometric constraints of species richness. Available at http://spot.colorado.edu/~mccainc/

McCain, C.M. (2004b). The mid-domain effect applied to elevational gradients: species richness of small mammals in Costa Rica. *Journal of Biogeography* 31: 19–31.

McCain, C.M. (2005). Elevational gradients in diversity of small mammals. *Ecology* 86(2): 366–372.

McCain, C.M. (2006). Do elevational range size, abundance and body size patterns mirror those documented for geographic ranges? a case study using Costa Rican rodents. *Evolutionary Ecology Research* 8: 435–454.

McCain, C.M. (2009). Global analysis of bird elevational diversity. *Global Ecology and Biogeography* 18: 346–360.

Md, Nor, S.M. (2001). Elevational diversity patterns of small mammals on Mount Kinabalu, Sabah, Malasia. *Global Ecology and Biogeography* 10: 41–62.

Miller, J.R.B., G.S. Rawat & K. Ramesh (2008). Pheasant population recovery as an indicator of biodiversity conservation in the Great Himalayan National Park, India. Wildlife Institute of India, Dehradun, India, vii+56pp.

Montano-Centellas, F.A. & A.Garitano-Zavala (2015). Andean bird responses to human disturbances along an elevational gradient. *Acta Oecologica* 65(66): 51–60.

Naithani, A. & D. Bhatt (2012). Bird community structure in natural and urbanized habitats along an altitudinal gradient in Pauri District (Garhwal Himalaya) of Uttarakhand State, India. *Biologia* 67(4): 800–808.

Naniwadekar, R. & K. Vasudevan (2007). Patterns in diversity of anurans along an elevational gradient in the Western Ghats, south India. *Journal of Biogeography* 34: 842–853.

Pandit, M.K. & R.E. Grumbine (2012). Potential effects of ongoing and proposed hydropower development on terrestrial biological diversity in the Indian Himalaya. *Conservation Biology* 26(6): 1061–1071.

Patterson, B.D., D.F. Stotz, S. Solari, J.W. Fitzpatrick & V. Pacheco (1998). Contrasting patterns of elevational zonation for birds and mammals in Andes of southern Peru. *Journal of Biogeography* 25(3): 593–607.

Patterson, B.D., V. Pacheco & S. Solari (1996). Distribution pattern of bats along an elevational gradient in the Andes of southeastern Peru. *Journal of Zoology* 240: 637–658.

Rahbek, C. (1995). The elevational gradient of species richness: a uniform pattern? *Ecography* 18(2): 200–205.

Rahbek, C. (1997). The relationship among area, elevation, and regional species richness in neotropical birds. *The American Naturalist* 149(5): 875–902.

Rahbek, C. (2005). The role of spatial scale and the perception of large-scale species-richness patterns. *Ecological Letters* 8: 224–239.

Rahmani, A.R. & M. Zafar-ul-Islam (eds.) (2004). *Important Bird Areas* *in India: Priority Sites for Conservation*. Indian Bird Conservation Network, Mumbai. Bombay Natural History Society, 1133pp.

Ralph, C.J., G.R. Geupel, P. Pyle, T.E. Martin & D.F. DeSante (1993). *Handbook of Field Methods for Monitoring Landbirds*. USDA, Forest Service, Pacific Southwest Research Station, Albany, CA. General Technical Report, PSW-GTR-144, 41pp.

Raman, T.R. (2003). Assessment of census techniques for interspecific comparisons of tropical rainforest bird densities: a field evaluation in the Western Ghats, India. *Ibis* 145: 9–21.

Raman, T.R.S., N.V. Joshi & R. Sukumar (2005). Tropical rainforest bird community structure in relation to altitude, tree species composition and null models in the Western Ghats, India. *Journal of the Bombay Natural History Society* 102(2): 145–157.

Raza, R.H. (2006). Diversity and rarity in avifaunal assemblages in the western Himalaya: a study of patterns and mechanisms. PhD Thesis. Forest Research Institute, Dehradun, xv+171pp.

Rickart, E.A. (2001). Elevational diversity gradients, biogeography and the structure of montane mammal communities in the intermountain region of North America. *Global Ecology and Biogeography* 10(1): 77–100.

Rosenzweig, M.L. (1992). Species diversity gradients: we know more and less than we thought. *Journal of Mammalogy* 73(4): 715–730.

Sanders, N.J. & C. Rahbek (2012). The patterns and causes of elevational diversity gradients. *Ecography* 35: 1–3.

Sanders, N.J. (2002). Elevational gradients in ant species richness: area, geometry, and Rapoport's rule. *Ecography* 25(1): 25–32.

Sanders, N.J., J. Moss & D. Wagner (2003). Patterns of ant species richness along elevational gradients in an arid ecosystem. *Global Ecology & Biogeography* 12: 93–102.

Sharma, I. & A. Kumar (2012). Fauna of protected areas of Himachal Pradesh: 1–14. Published by Zoological Survey of India, Kolkata, 144pp.

Sokal, R.R. & F.J. Rohlf (1995). *Biometry the Principles and Practice of Statistics in Biological Research - 3rd Edition*. W.H. Freeman & Company, New York, 871pp

Srinivas, G. (2011). Distribution pattern of amphibians in Megamalai landscape, Western Ghats, Tamil Nadu. PhD Thesis. Bharathiar University, Coimbatore, India, 144pp.

Stevens, G.C. (1992). The elevational gradient in altitudinal range: an extension of Rapoport's latitudinal rule to altitude. *The American Naturalist* 140(6): 893–911.

Terborgh, J. (1971). Distribution on environmental gradients: theory and a preliminary interpretation of distributional patterns in the avifauna of the Cordillera Vilcabamba, Peru. *Ecology* 52(1): 23–40.

Terborgh, J. (1977). Bird species diversity on an Andean elevational gradient. *Ecology* 58(5): 1007–1019.

Thakur, M.L., V.K. Mattu & R.M. Sharma (eds.) (2006). Bird diversity and status in Tara Devi, Shimla, Himachal Pradesh, pp. 95–113. In: *Biodiversity and Environment*. A.P.H. Publications, New Delhi.

Wiens, J.J. & M.J. Donoghue (2004). Historical biogeography, ecology and species richness. *Trends in Ecology and Evolution* 19(12): 639–644.

WORLDCLIM database. Climatic data. Available at http://www.worldclim.org

Wu, Y., R.K. Colwell, C. Rahbek, C. Zhang, Q. Quan, C. Wang & F. Lei (2013). Explaining the species richness of birds along a subtropical elevational gradient in the Hengduan mountains. *Journal of Biogeography* 40: 2310–2323.

Yu, X.D., L. Lu, T.H. Luo & H.Z. Zhou (2013). Elevational gradient in species richness pattern of Epigaeic Beetles and underlying mechanisms at east slope of Balang Mountain in southwestern China. *Plos One* 8(7): e69177; https://doi.org/10.1371/journal.pone.0069177

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