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Diversity of birds recorded at different altitudes in central Nepal Himalayas

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ABSTRACT

Factors determining the spatial distribution of bird species along altitudinal gradients have been important in their ecological and biogeographical research. Here, have used the data on bird species recorded in Manang, central Nepal Himalayas and attempt to determine the drivers of bird species diversity. We also carried out indicator species analysis to observe if any bird species are associated with different altitudinal ranges and land use gradients. We recorded 1331 individuals belonging to 82 species of both resident and itinerant birds. In our study, altitude was the major factor determining species richness and abundance. Position of study localities is main factor determining bird community composition. Diversity of bird species were mainly found in habitats that were far human settlements, having high annual mean temperature and more roughness. Species diversity was high during July-August compared to September-October and in north-facing slopes, and also in shrub and tree covered areas than grassland and places with mostly snow and grassland. Indicator species analysis showed only 21 species were significantly associated with altitudinal gradients, mostly below 3000 m a.s.l. and only eight bird species were associated with two land use gradients (grassland and snow-glacier). In conclusion, position of sampled localities, altitude, aspect, land use types and different climatic factors were important determinants of bird diversity along altitudinal gradients in Manang. To protect bird diversity in Manang, we need to protect habitats that are located mainly in low altitudes for most of the bird species. However, high altitude habitats with snow and glaciers are also important for few bird species. Thus, a large area with heterogenous habitats is important for bird species management and conservation.

1. Introduction

Birds are an important component of nature and are a part of the natural food chain in different ecosystems (Whelan et al., 2008). Understanding the diversity and distributions of species of birds and other organisms is important in terms of understanding adaptability, survival and extinction rates of species and providing knowledge that can be used to protect particular species of birds and other components of biodiversity that are correlated with them (Kremen, 1992). However, there are many challenges to extrapolating diversity patterns based on field studies to large spatial scales (MacArthur, 1984).

The patterns of diversity along altitudinal gradients are similar to those along latitudinal gradients (MacArthur, 1984). There is a decreasing trend in species diversity when moving from low to high altitudes or latitudes (Körner, 2007). The factors associated with these pattern are variations in habitats, temperature, geographical aspect, food availability (Brown, 1984; Sánchez-González and López-Mata, 2005), slope (Basnet et al., 2016), annual precipitation (Currie, 1991), climate (Li et al., 2009) and primary productivity (Lee et al., 2004). When looking at distributions of organism in the world, McCain (2009) categorized their altitudinal patterns into four types: decreasing with altitude, low plateau, low plateau with mid-altitudinal peak and mid-altitudinal peak. Bird species display all four types of patterns. Different studies on birds in Nepal report a monotonous decrease with increasing altitude (Basnet et al., 2016; Katuwal et al., 2016) similar to that reported in the east Himalayas in India (Acharya et al., 2011) and

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central Himalayas in China (Pan et al., 2016). This monotonous decreasing pattern for birds is also reported in other parts of the world, such as Ecuador (Blake and Loiselle, 2000; Paulsch and Müller-Hohenstein, 2008), Andes in Colombia (Kattan et al., 2006; Kattan and Franco, 2004), Mexico (Adolfo and Navarro, 1992) and USA (O'Connell et al., 2000).

In ecology and biogeography, spatial patterns of different species are a major focus of research because such patterns determine diversity and composition of communities (Khatiwada et al., 2019). Spatial patterns also indicate a species tolerance of climate (Fernández and Vrba, 2005) and highlight their evolutionary age (Rohde, 1998). Thus, knowledge of distributions can be used for developing conservation polices (Gavin and Stepp, 2014). Therefore, the Himalayan region with the widest range of altitudes and rich biodiversity has been very attractive for biological studies (Baniya, 2010; Basnet et al., 2016; Rokaya et al., 2012; Shrestha et al., 2020). Although there are studies on bird diversity in various settings in the Himalayan region, including Nepal, a study over a wide range of altitudes would be unique and of interest to ecologist.

Apart from recording the pattern of diversity along altitudinal gradients, finding out different types of bird species that reflect or predict the altitudinal ranges or habitats in which they are found is also crucial for the conservation (Siddig et al., 2016). This can be achieved by using the indicator species analysis as widely used in many studies (Bakker, 2008; Carignan and Villard, 2002; De Cáceres et al., 2010; Siddig et al., 2016). Changes in indicator species can be related to various types of environmental changes (Carignan and Villard, 2002). Thus, the results obtained from the indicator species analysis have been fruitful for management and conservation of different species in various parts of the world, including Himalayan regions (Siddig et al., 2016).

In the present study, our aim is to explore diversity patterns (in terms of species richness, abundance and species composition) and determine the factors associated with diversity patterns of bird species from 1400 to 5400 m above sea level (m a.s.l.) in central Nepal. Specifically, we attempted to answer the following questions: (1) What are the patterns in the diversity and distribution of birds in the Manang region of Nepal? (2) What environmental factors are associated with the altitudinal changes in the diversity of birds? and (3) Which bird species associated with the different altitudinal ranges and land use gradients?

2. Materials and methods

2.1. Study area

Manang region is a part of the *trans*-Himalayan region in north-central Nepal Himalayas. This region has a semi-arid type of climate and phytogeography (28°37′56″ to 28°39′55″ N, 83°59′83″ to 84°07′97″ E). One of the major rivers in Nepal, the Marsyangdi cuts through the valley. Most of the area studied is in the rain shadow of the Annapurna massif, which acts as a climatic barrier and blocks the monsoon clouds. As a result, this area receives less than 1000 mm of precipitation per year (DoHM, 2017), with most falling during the monsoon season (June-September). Hence, the climate in the area is cold-temperate and relatively dry. Snow is common in winter. Soil moisture decreases from east to west in the valley and the south-facing slopes are significantly drier than those facing north. Climate records of the nearest Meteorological station at Chame show that mean annual precipitation is 900 mm (DoHM, 2017). The maximum average temperature in this area over the same period of time was 21.5 °C in June and the minimum average temperature was −3.31 °C in January. The very wide range in altitude and diversity of landscapes in Manang have resulted in a diverse vegetation. The upper part of lower Manang (Gyasumdo) is mostly occupied by *Betula utilis*, *Pinus wallichiana*, *Taxus* species, *Tsuga dumosa*, *Abies spectibilis* and *Picea smithiana*, and the lower part by *Quercus semecarpifolia* and *Rhododendron arboreum*. The upper Manang (Nyeshang valley) is mostly occupied by *Pinus wallichiana*, *Betula utilis* and *Abies spectabilis* forest. The highest altitude (above 4300 m a.s.l.) is occupied by steppe vegetation. The south-facing slope along the Marsyangdi river is occupied by forest comprised of species of pines and juniper. The predominant species are *Berberis, Astragalus, Juniperus, Rosa, Caragana, Ephedra* species along with extensive grasslands (Panthi et al., 2007).

2.2. Data collection

A feasibility survey was carried out in 2014 and an in-depth survey twice in 2015, during July-August and September-October. These two periods were chosen in order to increase the chances of recording resident and late breeding migrant species (Basnet et al., 2016). We collected the data along a very long altitudinal transect ranging from 1400 m a.s.l. to 5400 m a.s.l. In the high altitudes, we collected data in two transects: towards Tilicho late (5100 m a.s.l.) and towards Thorang pass (5400 m a.s.l.). Both transects in high altitudes were not far from each other and were similar in climate and topography. All the localities were far from human settlements (Fig. 1). At each locality, we recorded all the birds observed within a radius of 50 m. A digital rangefinder was used to define the radius. The 19 localities were randomly chosen at different altitudes with the distance between two localities between 200 and 300 m. We did not include data from Yak Kharka (4339 m a.s.l.) in our final analysis because data was only recorded during September-October. In total, there were 36 samples (1 circle × 18 localities × 2 times).

During the recording of the birds the first 15 min were spent adjusting to the location and then we started observing and counting the birds. We used the fixed-point counting method (Basnet et al., 2016; Bibby et al., 2000; Dieni and Jones, 2002; Gregory et al., 2004; Norvell et al., 2003) and data was collected by two individuals using the direct observation technique and vocal recordings (Basnet et al., 2016; Gregory et al., 2004; Kissling et al., 2006; Reynolds et al., 1980). We collected data twice a day during the periods when the birds were active 6:00–9:00 A.M. in the morning and 3:00–5:00P.M. during the afternoon. The birds were observed using Nikon 8 × 42 binoculars and photographed using a Canon 1100D camera. In this study, we did not include very high-flying species such as soaring raptors, swifts and swallows due to the difficulty of identifying these species (Basnet et al., 2016). By reference to published books (BCN and DNPWC, 2011) we also assessed the local status (frequent, common, uncommon, frequent, rare or scarce) of each species of bird observed.

Birds were identified in the field or later confirmed by published literature (BCN and DNPWC, 2011; Grimmett et al., 2000; Inskipp, 1989). Data on their distributions, feeding habits and whether migrant, resident, or itinerant were obtained from the same literature. The conservation status (frequent, common, uncommon, frequent, rare or scarce) was obtained from book (BCN and DNPWC, 2011) and online databases (CITES, 2015; IUCN, 2015).

2.3. Bioclimatic data

Altitude at each locality sampled was recorded in the field using Garmin GPS. We used annual mean temperature and annual precipitation that were derived from www.worldclim.org (Hijmans et al., 2005), and land use and cover data derived from global land cover data (https://www.glcn.org; (Latham et al., 2014)). A digital rangefinder was used to establish the distance between the localities and human settlements. We prepared aspect layers using a digital altitude model (DEM) using ArcGIS and clipped all variables to the areas studied. We then extracted the values of each variable associated with the locations where the species occurred. For above-ground net primary productivity, we calculated values from MODIS 14-day data for the years 2013, 2014 and 2015. First maximum NDVI value for each year was calculated and then averaged for the three years (Pan et al., 2016). The variables used in our analyses are given in Appendix 1.

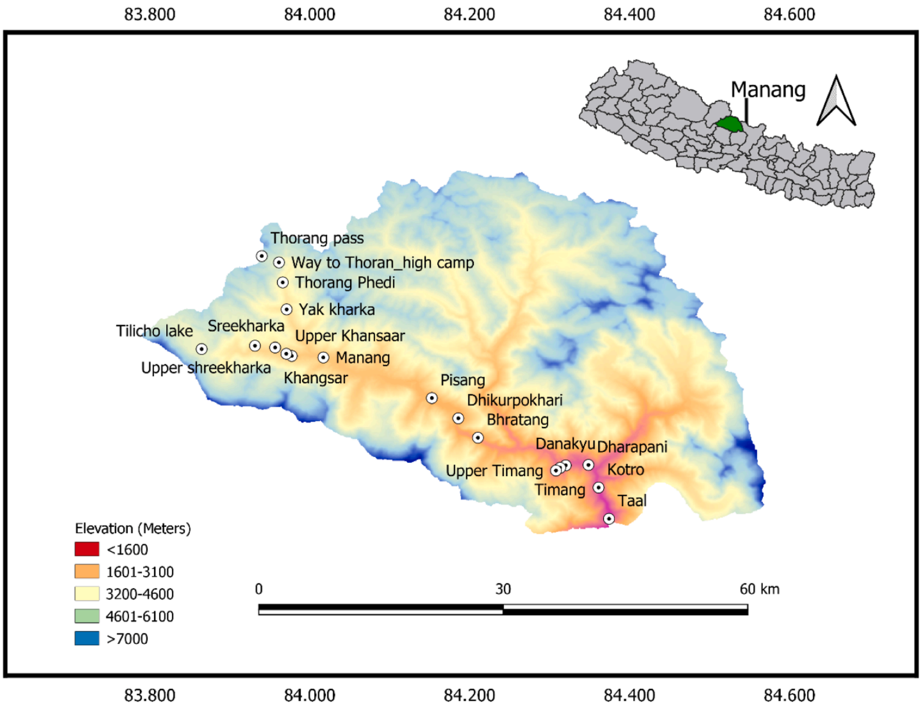

Fig. 1. Map showing the localities studied. In Yak Kharka data was collected only during September-October.

2.4. Data analysis

Three different terms are used to quantify species diversity in this study. They are species richness, species abundance and species composition. Species richness is defined as the number of species of birds at a particular locality (Bhattarai et al., 2004), species abundance is defined as total number of species of birds at particular locality and species composition is pattern of each bird species to found in the community at particular locality/region (Plummer et al., 2019)

We assessed the association of species richness, species abundance and species composition with each location sampled before including them in the final model. First, we calculated Bray Curtis distance between all pairs of points using data on species richness and abundance. We calculated the Euclidean distance between all pairs of points using data on species composition and geographic distance. We used the Mantel test as implemented in the package Vegan in R with 9999 permutations in R 4.0.0 (R Development Core Team, 2020) to calculate the correlation between geographic distance and distance in species richness, abundance and species composition. In the case of significant associations of geographic distance and geographic position of the localities sampled we used a covariate in the subsequent analyses (Basnet et al., 2016).

In order to determine which of the environmental variables (altitude, time, annual mean temperature, annual precipitation, distance from a settlement, land use land cover, aspect, roughness and productivity) can be used as predictors of species richness or abundance a generalized linear model (GLM) with Poisson distribution and log link function was used as there was no over-dispersion of data. The analyses were carried out using the lme4 function in lmerTest package in R 4.0.0 (R Development Core Team, 2020). The figures were drawn using STATISTICA (StatSoft Inc, 2015).

Multivariate tests of the species composition of bird communities were carried using a unimodal technique known as Canonical Correspondence Analysis (CCA), as the length of the gradient (5.24) was too long (Lepš and Šmilauer, 2014), using Canoco 5.12 (ter Braak and Šmilauer, 2012). These tests are based on the same logic as univariate analyses. Here, we included longitude, latitude and longitude × latitude as variability explained by these factors was much more than in case of species richness and abundance. We first tested for their significance and if significant were used as a covariate in the subsequent tests. Then we tested the associations with altitude, time, annual mean temperature, annual precipitation, distance from a settlement, land use land cover, aspect, roughness and productivity. Significant predictors were tested using the Monte Carlo permutation test ($n = 499$) using a forward stepwise selection procedure. Finally, only the significant environmental variables were plotted on the graph.

We used the indicator species analysis (Dufrêne and Legendre, 1997) to identify bird species significantly associated with the altitude ranges and land use gradients. The associations of bird species were assessed by using the Indicator Value index (IndVal) function in 'indicspecies' package in R 4.0.0 (R Development Core Team, 2020). The significance (p-value < 0.05) was obtained by a randomization procedure (999 permutations). For altitude gradient, we used seven categories as 1500–2000, 2001–2500, 2501–3000, 3001–3500, 3501–4000, 4001–4500 and 5001–5500. The category 4501–5000 was not present in our dataset. For land use gradient, we used four categories such as tree cover area, shrub cover area, grassland and snow-glacier.

3. Results

3.1. Diversity and conservation status

A total of 82 species of birds, belonging to 24 families, were observed at 18 different localities. A total of 1331 birds were recorded (July–August, 690 and September–October, 641). In terms of families of birds, the largest was Muscicapidae with 16 species, followed by Fringillidae with 11 species, Leiothrichidae and Phylloscopidae with 6 species each and Passeridae with 5 species (Appendix 2).

There were more records of birds categorized as common ($n = 53$) followed by scarce ($n = 11$), frequent ($n = 10$), uncommon ($n = 5$) and rare ($n = 3$). No endemic species were recorded during this survey. Common Hoopoe (*Upupa epops*) was the most commonly recorded in this study and occurred at a very wide range of altitudes from Taal (1600 m a.s.l.) to Khangsar (4200 m a.s.l.). A high number of resident birds ($n =$

61) were recorded, followed by winter visitors (n = 14), itinerant species (n = 5) and summer visitors (n = 2). In terms of diet the highest number were insectivores, followed by omnivores and herbivores (Fig. 2).

3.2. Effect of geographic distance

The Mantel test revealed a significant but a weak correlation between geographic distance and species richness at the locations sampled ($R^2 = 0.059$, $p = 0.001$). There was also a weak significant correlation between the number of species recorded at the localities sampled and their geographic position ($R^2 = 0.017$, $p = 0.0089$). The correlation between species composition recorded at the localities sampled and geographic distance was significant ($R^2 = 0.199$, $p < 0.001$) and relationship was stronger than in previous tests. As the effects of longitude and latitude were weak for species richness and abundance, we only included longitude, latitude and their interactions in species composition of bird species.

3.3. Species richness and abundance

Bird species richness and abundance significantly decreased with increase in altitude and annual precipitation in the Manang region (Fig. 3, Table 1, Appendix 3). Specifically, the highest number of species were recorded at an altitude of 3274 m a.s.l. and the lowest at above 5400 m a.s.l. Contrary to the above patterns, species richness and abundance increased in habitats with high annual mean temperature, far from human settlements and in habitats with more roughness. Only species richness was high during July–August than September. In addition to this, species abundance was high in south-ward facing than in north-ward facing habitats and in shrub and tree covered areas than grassland and places with mostly snow and grassland.

3.4. Species composition

Species composition varied significantly in different sampled localities (longitude × latitude). Species composition at different altitudes also differed significantly (Fig. 4, Table 2, Appendix 4). The bird species that were found at high altitudes were *Phylloscopus trochiloides, Phoenicurus ochruros, Pyrrhocorax pyrrhocorax, Columba leuconota* and *Phylloscopus affinis* whereas species that were found at low altitudes were *Lanius schach*, *Ficedula westermanni*, *Heterophasia capistrata*, *Phylloscopus pulcher* and *Passer montanus*.

In addition to position of sampling sites and altitude, the species composition of bird communities was significantly associated with five more environmental factors (mean annual temperature, annual precipitation, roughness, distance from the settlements and aspect) (Fig. 4, Table 2). *Pyrrhocorax pyrrhocorax*, *Motacilla alba*, *Motacilla cinerea*, *Passer domesticus* and *Corvus macrorhynchos* were found in habitats with high mean annual temperature, annual precipitation and roughness. Most of the species were found to be away from human settlement and in the south aspect.

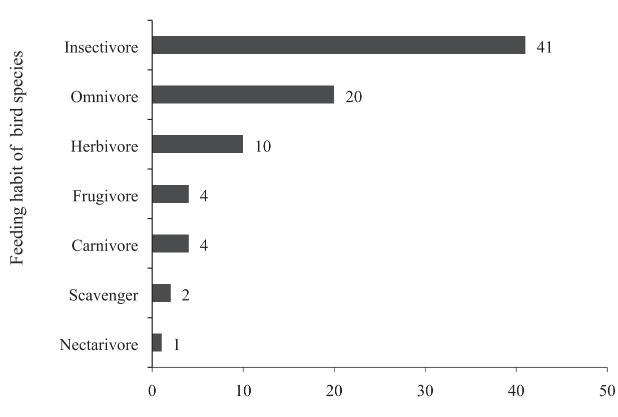

Fig. 2. Bar diagrams showing the number of species of birds with particular feeding habits in Manang in central Nepal.

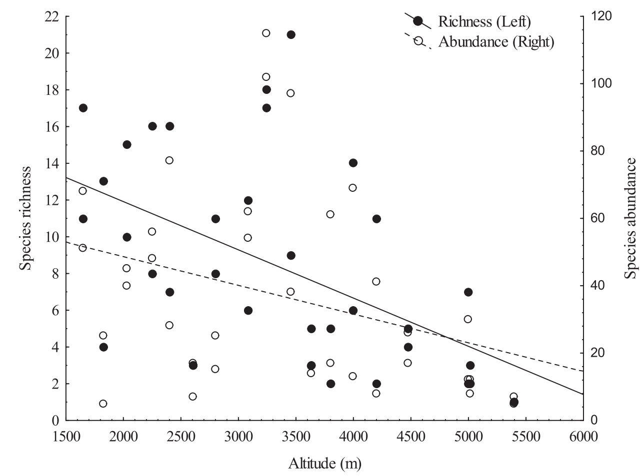

Fig. 3. Plot showing the relationship between bird species richness, abundance and altitude (m) in Manang in central Nepal.

Table 1
Results of the generalized linear model (GLM) of the factors associated with bird species richness and abundance in Manang, central Nepal. 'NT' means not tested. Significant values are marked in bold.

		Species richness		Species abundance	
	Df	p-value	R^2	p-value	R^2
Longitude	1	NT	NT	NT	NT
Latitude	1	NT	NT	NT	NT
Longitude × Latitude	1	NT	NT	NT	NT
Altitude	1	**<0.001**	0.276	**<0.001**	0.115
Time	1	**0.020**	0.039	0.179	–
Annual mean temperature	1	**0.020**	0.039	**<0.001**	0.112
Annual precipitation	1	**0.001**	0.080	**<0.001**	0.198
Distance from settlement (log)	1	**0.024**	0.036	**<0.001**	0.031
Land use land cover	3	0.528	–	**<0.001**	0.033
Aspect	1	0.522	–	**0.002**	0.012
Roughness	1	**<0.001**	0.102	**<0.001**	0.121
Productivity	1	0.100	–	**<0.001**	0.018

3.5. Indicator species analysis

Out of total, only 21 species showed significant associations with different altitudinal categories (Table 3). 14 species were associated with one altitude group, 4 species with two altitude groups, 1 species with 3 altitude groups and 2 species four altitude groups (Table 3, Appendix 5). 16 bird species that were characteristic to different altitudinal ranges were resident, four species (*Carduelis carduelis*, *Grandala coelicolor*, *Phylloscopus humei* and *Phylloscopus pulcher*) were winter visitor and only one bird (*Motacilla alba*) was itinerant species.

Likewise, only eight bird species showed significant associations with land use gradients (Appendix 3). Six bird species (*Anthus hodgsoni*, *Aquila chrysaetos*, *Carpodacus pulcherrimus*, *Carpodacus rodochroa*, *Carpodacus rubicilla* and *Corvus macrorhynchos*) were associated with grassland whereas only two bird species (*Pyrrhocorax graculus* and *Prunella collaris*) were associated with high altitude habitat that are mostly covered with snow and glacier throughout the year (Appendix 5). In this category, all bird species were resident birds except *Aquila chrysaetos* and *Carpodacus pulcherrimus* that were winter visitors

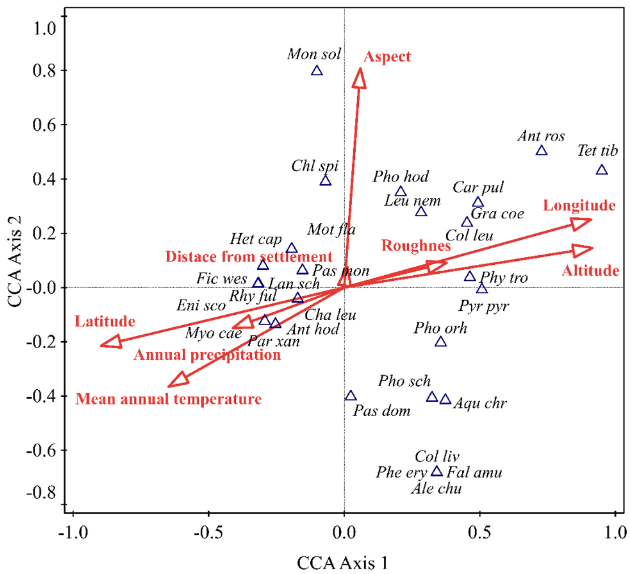

Fig. 4. Association between different environmental factors and species composition of birds in Manang, central Nepal. The 1st canonical axis explained 14.94% and the 2nd 9.01% of the total variation in the data set. Abbreviations and their full forms: *Ale chu - Alectoris chukar; Ant hod - Anthus hodgsoni; Ant ros - Anthus roseatus; Aqu chr - Aquila chrysaetos; Aqu chr - Aquila chrysaetos; Car pul - Carpodacus pulcherrimus; Cha leu - Chaimarrornis leucocephalus; Chl spi - Chloris spinoides; Col leu - Columba leuconota; Col liv - Columba livia; Eni sco - Enicurus scouleri; Fal amu - Falco amurensis; Fic wes - Ficedula westermanni; Gra coe - Grandala coelicolor; Het cap - Heterophasia capistrata; Lan sch - Lanius schach; Leu nem - Leucosticte nemoricola; Mon sol - Monticola solitarius; Mot fla - Motacilla flava; Myc cae - Myophonus caeruleus; Par xan - Parus xanthogenys; Pas dom - Passer domesticus; Pas mon - Passer montanus; Phe ery - Phoenicurus erythrogastrus; Pho hod - Phoenicurus hodgsoni; Pho orh - Phoenicurus ochruros; Pho sch - Phoenicurus schisticeps; Phyt tro - Phylloscopus trochiloides; Pyr pyr - Pyrrhocorax pyrrhocorax; Rhy ful - Rhyacornis fuliginosa; Str ori - Streptopelia orientalis* and *Upu epo - Upupa epops*.

Table 2
Results of Canonical Correspondence Analysis (CCA) of the association between different environmental variables and the species composition of birds in Manang, central Nepal. Significant values are marked in bold.

	Species composition	
	p-value	% explained by canonical axis
Longitude	**0.002**	0.524
Latitude	**0.002**	0.575
Longitude × Latitude	**0.002**	0.813
Altitude	**0.004**	0.217
Time	0.984	–
Annual mean temperature	**0.01**	0.193
Annual precipitation	**0.002**	0.222
Distance from settlement (log)	**0.004**	0.195
Land use land cover	0.08	–
Aspect	**0.002**	0.233
Roughness	**0.02**	0.173
Productivity	0.114	–

4. Discussion

Patterns in the diversity and distributions of birds are widely studied (Adolfo and Navarro, 1992; Basnet et al., 2016; Herzog et al., 2005; Kattan et al., 2006; Kattan and Franco, 2004; Katuwal et al., 2016). Although there are number of such studies for the Himalayan region (Basnet et al., 2016; Katuwal et al., 2016; Paudel and Šipoš, 2014), few of them include field data recorded at a wide range of altitudes (Basnet et al., 2016; Katuwal et al., 2016). In order to explain the variability in species diversity and species composition of birds, we carried out a field research at a remarkably wide range of altitudes (4000 m long) between 1400 and 5400 m a.s.l. in Manang, Nepal. Most of the birds recorded in this study belonged to the families Muscicapidae, Fringillidae, Leiothrichidae and Phylloscopidae, which is similar to that expected for Muscicapidae and Fringillidae, which are largest families of birds in Nepal (BCN and DNPWC, 2011). However, it differs from the results of studies in different parts of Nepal (Adhikari et al., 2019; Basnet et al., 2016; Katuwal et al., 2016). This discrepancy results from the variation in habitat diversity and climate in different parts Nepal (Khatiwada et al., 2019; Vetaas et al., 2019).

Table 3
Bird species, altitudinal categories and significant p-value for indicator species analysis.

Bird species	Altitude categories	p-value
Carduelis carduelis	3001–3500	0.014
Chaimarrornis leucocephalus	1500–2000, 2001–2500, 2501–3000, 3001–3500	0.014
Delichon dasypus	2001–2500	0.017
Delichon nipalensis	2001–2500	0.011
Emberiza cia	3001–3500	0.022
Enicurus scouleri	1500–2000	0.004
Grandala coelicolor	4001–4500	0.008
Heterophasia capistrata	2001–2500	0.001
Motacilla alba	1500–2000, 3001–3500	0.04
Motacilla cinerea	1500–2000, 3001–3500	0.027
Motacilla flava	2001–2500, 3001–3500	0.037
Myophonus caeruleus	1500–2000, 2001–2500, 2501–3000, 3001–3500	0.037
Nucifraga caryocatactes	2501–3000, 3001–3500	0.015
Passer montanus	1500–2000	0.003
Pericrocotus speciosus	2001–2500	0.018
Phoenicurus ochruros	3501–4000	0.001
Phylloscopus humei	3001–3500	0.004
Phylloscopus pulcher	1500–2000	0.032
Pycnonotus flaviventris	1500–2000	0.032
Pycnonotus leucogenys	1500–2000	0.011
Pyrrhocorax graculus	3001–3500, 3001–3500, 4001–4500	0.002

The prevalence of a high number of summer visitors and only a few winter visitors and itinerant species in Manang is because of the harsh environment at the highest altitudes in the Himalayas, which are covered with snow throughout almost the whole year and not suitable for birds. Even at the lower altitudes, birds move to other places for feeding and breeding during winter and in spring and summer these birds again migrate to higher altitudes as the environment there becomes more suitable for them.

Most of the species recorded were insectivores, followed by omnivores and herbivores. This result is similar to that reported in previous studies (Basnet et al., 2016; Katuwal et al., 2016) and in the bird fauna of Nepal (Baral and Inskipp, 2005; BCN and DNPWC, 2012). This might reflect the abundance of insects in the cloud forest zone at around 2000–2500 m a.s.l. and decrease in insect availability with increase in altitude (Katuwal et al., 2016). Prevalence of insectivorous birds is also recorded at rural sites and is associated with the high insect richness and abundance in these areas (Basnet et al., 2016; Katuwal et al., 2016).

The correlations between species composition of birds in Manang with geographic distances indicate that suitable habitats are mostly auto correlated meaning that there are similar bird communities in places that are close to one another. This is similar to birds that are recorded in a study at low altitudes in central Nepal (Basnet et al., 2016) and butterflies recorded in the Manang region (Shrestha et al., 2020). The effects of latitude and longitude, which remained significant even when included as covariates in tests. However, position in space is not so important for species richness and abundance as variability birds is estimate by them was very low (around 5%). These two variables thus cannot be fully used as a proxy for climate at large spatial scales.

In Manang, species richness and abundance increased up to 3200 m a.s.l. and then declined all the way up to 5400 m a.s.l. Our results are not consistent with the mid-domain effect as mid-altitude is around 2700 m a.s.l., but consistent with the more frequently reported unimodal hump-shaped relationship between species richness and altitude (Colwell et al., 2008; McCain and Grytnes, 2010), reported for birds in Nepal (Basnet et al., 2016; Katuwal et al., 2016; Paudel and Šipoš, 2014) and amphibians in east Nepal (Khatiwada et al., 2019). This pattern is also similar to that reported in studies in other parts of the world, e.g. Ecuador (Blake and Loiselle, 2000; Paulsch and Müller-Hohenstein, 2008), Andes in Colombia (Kattan et al., 2006; Kattan and Franco, 2004), Mexico (Adolfo and Navarro, 1992) and USA (O'Connell et al., 2000). Compared to our findings, a previous study on bird species distribution in Nepal showed the maximum predicted and observed bird richness occurred approximately at 2800–2900 m a.s.l. (Paudel and Šipoš, 2014). A study on birds in six valleys in central Nepal report peaks at between 2600 and 3000 m a.s.l. (Katuwal et al., 2016). The differences might be due to the spatial differences in the habitats, topography and climate in Nepal (Basnet et al., 2016; Khatiwada et al., 2019; Vetaas et al., 2019).

The decrease in bird diversity (in terms of species richness and abundance) with altitude is closely associated with the decrease in temperature and vegetation, which is a source of food and nesting sites, with increase in altitude (Basnet et al., 2016; Herzog et al., 2005; Kattan et al., 2006; Katuwal et al., 2016). In addition to altitude, other environmental factors determined the patterns of species richness, abundance and the species composition for birds in the Manang region. This kind of scenario is similar to previous studies in Nepal (Katuwal et al., 2016; Khatiwada et al., 2019; Paudel and Šipoš, 2014) and also in global scale (Quintero and Jetz, 2018). The higher bird species were recorded in July-August than in September-October in Mannag is due to season change that occurs from late summer to autumn. With the onset of cold conditions in autumn (September-October) birds move down to lower altitudes or to warmer regions (Katuwal et al., 2016). Although a few species of birds are found in or near human settlements, most of the species are found far from settlements in localities where there is more shrub and tree species. This shows that forested areas are suitable for bird species (Pino et al., 2000; Schindler et al., 2013).

The high bird diversity recorded in places with low precipitation is because there is less food and poorer habitats for breeding in high rain fall areas (Illán et al., 2010). Distribution pattern of birds in Manang partly support the idea that there is a high diversity at low and intermediate altitudes, which may be due to presence of more water and energy at those altitudes, according to "water-energy dynamics" (O'Brien, 2006; Vetaas et al., 2019), but not the rule of "climatic variability'' or "the seasonal variability hypothesis'' (Stevens 1992) that argue for the existence of high species diversity at low and high altitudes. As bird community composition is partially correlated with productivity, we can conclude that community composition is more diverse in the more productive habitats in Manang partially support the "productivity hypothesis" (Gillman et al., 2015; Mittelbach et al., 2001; Šímová et al., 2013).

Indicator species analysis showed that most of the bird species are characteristic to three altitudinal ranges (1500–2000, 2001–2500, 2501–300 m). Only one species (*Pyrrhocorax graculus*) was found in high altitude from 3000 to 4500 m a.s.l. This shows that low elevations are more important for bird species and special considerations is needed for bird conservation. Land use categories did not show many indicator bird species as six species were restricted to grassland and only two species were restricted to high altitude habitat that are mostly covered with snow and glaciers. This might be due to the fact that most of the birds are moving around in search of food and also for breeding and not much restricted to particular land use type (Basnet et al., 2016; Grimmett et al., 2000; Katuwal et al., 2016). However, it is important to protect heterogenous habitats for effective bird conservation.

5. Conclusions

The present study indicated that Manang is an important place for birds with the high diversity and main determinants of diversity were altitude, habitat types and climatic factors such as temperature and precipitation. Indicator species analysis showed that altitudinal range (mostly below 3000 m a.s.l.) was important for bird species. Grassland and high-altitude habitat with snow–glaciers are also important for few bird species. These results provide us information that could be used for designing effective management and conservation plans for maintaining the bird diversity in Manang, central Nepal Himalayas. The effective conservation can only be achieved by protecting diverse habitats inside a large area.

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Author contributions

M.B.R. conceived the idea; A.G., M.B.R., U.B.S. collected field data; M.B.R. and B.T. analyzed data and wrote the original draft; M.K, K.B., P. K. contributed significantly to the ideas presented, reviewed and edited the draft. All authors contributed critically to the final manuscript and approved its publication.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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