

Impact of Climate Change on Three Indicator Galliformes Species in The Northern Highlands of Pakistan

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Abstract

Global temperatures are predicted to rise from between 1.4 to 5.8°C by 21st century, which could result in a 20 to 30% extinction of species. The negative impacts of climate change on the northern highlands of Pakistan (NHP) could change the species composition. Range shifts and range reduction in the forested landscapes will dramatically affect the distribution of forest dwelling species, including the Galliformes (ground birds). Three Galliformes (e.g., *Lophophorus impejanus*, *Pucrasia macrolopha* and *Tragopan melanocephalus*) are indicator species of the environment and currently distributed in NHP. For this study, we used Maximum Entropy Model (MaxEnt) to simulate the current and future (in 2050 and 2070) distributions of the species using three General Circulation Models (GCMs) and two climate change scenarios, i.e., RCP4.5 (moderate carbon emission scenario) and RCP8.5 (peak carbon emission scenario). Our results indicated that (i) all the three species would be negatively affected by the climate change in 2050 and in 2070. (ii) Under all three climate scenarios, species distribution was predicted to both reduce and shift towards higher altitudes. (iii) Across the provinces in the NHP, the species were predicted to lose over one quarter in 2050 and one-third by 2070 of the current suitable habitat. (iv) The maximum area of climate refugia was projected between the altitudinal range of 2000 m to 4000 m and predicted to shift towards higher altitudes primarily >3000 m in the future. The proposed implications such as establishment and upgradation of the protected areas, ban on hunting, timber mafia and temporary settlements of the local people in the forested landscapes should be under special consideration to mitigate the impact of climate change.

Introduction

Global average temperature has increased by 0.74°C during last few decades, and is projected to further rise by up to 1.4–5.8°C by the end of this century (Schneider and Root, 1998; IPCC, 2001; Reilly et al. 2001; Hotta et al. 2019). Most landscapes and ecosystems were predicted be affected significantly due to changes in species distribution, composition, and productivity (Negi et al. 2012). Changes in temperature and precipitation may cause shifts in habitat and reduction in habitat of many species, and is projected to become the main threat to their survival (Hoffmann et al. 2019). Due to rise in temperature, it is roughly estimated that about 30% of plant and animal species (including a significant number of endemic species), may become extinct by the end of this century (IPCC, 2013; IPCC, 2014). Though species typically adapt to minor environmental fluctuations, however, it could take millennia for species to adapt and adjust their range in response too broad environmental and habitat changes that can result from climate change other changes to the environment (Luniak, 2004; Su et al. 2018). Currently, formulation of effective strategies for the conservation of biodiversity in the context of climate change has become a major concern among governmental and/ non-governmental organizations, scientists, and public (Keith et al. 2008; Moss et al. 2009; Fordham et al. 2020).

Previous studies have been reported that (due to rise in temperature) shifts in species range towards northeastern and northwestern regions of the northern temperate regions (Lehikoinen and Virkkala, 2016). The Himalayan ecosystems are considered as some of the most vulnerable to the impacts of climate change (IPCC,2014). The bird species in the Himalayan biodiversity hotspot are facing a range of threats due to consistent degradation and fragmentation of forested landscapes due to anthropogenic pressure (Tylianakis et al. 2008; Hu et al. 2015). Studies have reported that birds with limited ranges and lower mobility such as ground birds/ Galliformes are likely to be at high risk of extinction due to disturbances in mountainous regions and climate change (Sekercioğlu et al. 2012). The Galliformes, also known as ‘gallinaceous’, is a birds’ group that evolved as terrestrial birds and inhabit in a variety of habitats from deserts to forested landscapes (Coles, 2009). In spite of their attractive plumage and their role as indicators of habitat quality, these birds are among the least studied animals (Bagaria et al., 2021). The IUCN Red List described the worldwide distribution of 290 species of Galliformes (IUCN, 2011) in the families such as Phasianidae (181 species), Cracidae (51), Megapodidae (21), Odontophoridae (31) and Numididae (6) (BirdLife International, 2012). There are 17 species of ground birds (from the family Phasianidae) are currently distributed in Pakistan (McGowan et al., 2012; BirdLife International, 2016). The northern highlands of Pakistan (NHP) are part of the western Himalayan region and are rich in biodiversity, including some rare and endemic Galliformes/ ground bird species (Zahoor et al. 2021a).

The three sympatric Galliformes species, i.e., koklas pheasant (*Pucrasia macrolopha*), monal pheasant (*Lophophorus impejanus*) and western horned tragopan (*Tragopan melanocephalus*) are currently distributed in the forested landscapes of the NHP (Fig. 1, Shah et al. 2013; Awan and Francis, 2014; Ahmad et al. 2019). Though *Pucrasia macrolopha* and *Lophophorus impejanus* are categorized as Least Concern on the IUCN's Red List of Threatened Species and *Tragopan melanocephalus* is considered Vulnerable, yet all three are being indicator species play a very important role in the maintenance of the ecosystem (Chhetri et al. 2021). The habitat regimes of Galliformes are under high anthropogenic pressure in the NHP and people are often involving in hunting and destruction of the breeding grounds of these species (Kabir et al. 2017; Ahmad et al. 2019; Zahoor et al. 2021a; Zahoor et al. 2021b). Now, climate change has become an additional threat to the persistence of such species due to changes in community structure and function of vegetation, which ultimately may lead to declines in their populations in the NHP (Santhakumar et al. 2018; Rai et al. 2020).

Extrapolating the current and future geographical distribution of species under climate change scenarios is one of the best approaches for the formulation of early conservational strategies (Songer et al. 2012; Dai et al. 2021; Zahoor et al. 2021c). Various ecological niche models use bioclimatic and non-climatic variables to explicate current distributions of species and further predict future distributions (Li et al. 2018). The Maximum Entropy Model (MaxEnt) has outstanding predictive power in simulation and evaluation of presence-only data, and create distribution maps and variable response curves by testing the reserved part of the training data (Phillips et al. 2006; Yang et al. 2013; Remya et al. 2015; Zhang et al. 2019).

Though some studies have addressed the GIS and modeling-based analysis of koklas, monal and tragopaon pheasants under climate change, no detailed research has been conducted on these species in the NHP (Singh et al. 2020; Bagaria et al. 2021; Chhetri et al. 2021). In our study, we projected suitable habitat of three Galliformes species under climate change, based on species presence data and used bioclimatic and non-climatic variables to predict the distribution of these species in the NHP. Our objectives were to: (i) project the current and future distribution of three Galliformes species, (ii) identify the potential climate refugia (static suitable habitat under the current and future scenarios) and (iii) propose implications for the management and conservation of these species. Our study provides useful baseline data and scientific information to inform governmental and non-governmental organizations developing early strategies for the conservation and management of these species in the NHP.

Material And Methods

Study area

Our study was carried out in the NHP with an area of 163870 km² that covers total land area of two provinces i.e., Azad Jammu and Kashmir (AJK) and Gilgit Baltistan (GB), while parts of 3 provinces i.e., Federally administered tribal areas (FATA), Khyber Pkhtunkhwa (KPK) and Punjab. There are many protected areas such as national parks, game reserves, and wildlife sanctuaries in the area but their number and size may not sufficient to support the Galliformes populations under the impact of climate change (Fig. 2, Supplementary 1, Zahoor et al. 2021a).

Galliformes are forest dwelling species, however, in Pakistan, the forested landscape area covers only 4.5 million hectares (5.1%), out of which 3.44 million hectares (76%) are primary forests. Maximum primary forests landscape (66%) is in the three provinces of the NHP i.e. 1.51, 0.435 and 0.337 million hectares in KPK, AJK and GB respectively. However, high anthropogenic pressure from the use of natural resources, overgrazing and poor land-use management have steadily decreased forest cover (Nazir et al. 2018; Zahoor et al. 2021a). The forests of NHP fall under the western Himalayan regions that providing habitat to many endemic and endangered species of wild flora and fauna but poor conservational planning, high anthropogenic pressure and climate change could lead to the extirpation of one or more of the Galliformes species in the region (Zahoor et al. 2021a).

Data Collection

A total of 250 presence points were collected for three Galliformes species (*Lophophorus impejanus* = 98, *Pucrasia macrolopha* = 106, *Tragopan melanocephalus* = 46) between 2019–2021 from the NHP. Data collected over the last three

decades (i.e., from 1990 – now) from GBIF (<https://www.gbif.org>), based on human observations only and excluded data based on fossil records and preserved specimens (Table 1). To minimize the autocorrelation, the area was divided into 1 km by 1 km grids and selected (randomly) 1 presence point/ grid using spatial thinning processes (Dai et al. 2019a; Dai et al. 2019b; Zhang et al. 2019; Zahoor et al. 2021c).

Table 1
Occurrence records and source of information of three galliformes species in the northern highlands of Pakistan.

Species	No. of presence points	Total points	Source
<i>Lophophorus impejanus</i>	10	98	Camera traps
	6		Signs i.e. feathers
	31		Previous studies (Abdul, 2004; Shah et al., 2014; Shah, 2015)
	51		GBIF (https://www.gbif.org)
<i>Pucrasia macrolopha</i>	5	106	Camera traps
	7		Signs i.e. feathers
	29		Previous studies (Abdul, 2004; Shah et al., 2014; Shah, 2015)
	65		GBIF (https://www.gbif.org)
<i>Tragopan melanocephalus</i>	6	46	Camera traps
	16		Previous studies (Awan 2014; Awan and Francis, 2014; Awan, 2015; Shabir, 2018)
	24		GBIF (https://www.gbif.org)

Bioclimatic and non-climatic data & climate change scenarios

We downloaded 19 bioclimatic variables data with 1 km resolution for current (average for 1960–1990) and future (2050 and 2070) scenarios from the WorldClim 1.4 database (Hijmans et al. 2005). Based on the physiology of three Galliformes species, we chose climatic variables useful for predicting their distributions (Singh et al. 2020a; Chhetri et al. 2021). To project possible changes in the future, we used the same bioclimatic variables from three widely used general circulation models (GCMs) in Himalayan regions (Dai et al. 2021, Singh et al. 2020b; Zahoor et al. 2021a). We selected BCC-CSM1-1 (Beijing Climate Center Climate System Model), CCSM4 (Community Climate System Model), and HadGEM2-AO (Hadley Global Environment Model 2), to project future species distributions. For each GCM, we selected two emission scenarios (Representative Concentration Pathways: RCP4.5, and RCP8.5; Singh et al. 2020b; Dai et al. 2021; Zahoor et al. 2021) to denote the medium and extreme optimistic and the most pessimistic concentrations of greenhouse gases up to the 21st century (Weyant, 2009).

We downloaded the elevation data (at 1 km resolution) from GTOPO30 (<https://lta.cr.usgs.gov/GMTED2010>; Danielson & Gesch, 2011) and extracted the aspect and slope from it. We collected the data of soil parameters i.e., soil texture represented by percentage of sand, silt and clay, bulk density, soil classes from <https://soilgrids.org/> (Ramesh et al. 1999; Singh et al. 2020a). The global human influence index data (1995 to 2004) at 1 km resolution were downloaded from <http://sedac.ciesin.columbia.edu/>. Moreover, current global land cover data (at 300 m spatial resolution) were obtained from http://due.esrin.esa.int/page_globcover.php.

All the variable layers were resampled to 1 km resolution (30 arc sec) and projected under the coordinate system of WGS_1984_UTM_Zone_43N in ArcGIS 10.2.2 (ESRI Inc.). We used the band collection statistics tool in ArcGIS 10.2 to eliminate highly correlating variables where $|r| > 0.8$ to reduce the multicollinearity of variables (Supplementary 2, Brown et al. 2014; Dai et al. 2019a; Zahoor et al. 2021a, c). (ii) The variables were uploaded into the MaxEnt and after running the model, variables

with contribution rates <1 were excluded. (iii) The most important variables were selected from the first output, and reran the model along with future (2050 and 2070) variables to get the final results (Table 1).

Modeling the habitat suitability

We used Maximum Entropy (MaxEnt) working on “species presence-only data” to model the current and future distribution of three Galliformes species for our study area (Phillips et al. 2006; Li et al. 2017; Thapa et al. 2018; Yu et al. 2019; Dai et al. 2021). The parameters of the MaxEnt model were set as 25% for random test percentage and 1 regularization multiplier. All other setting was left as default values. We ran 15 replicates by performing a cross-validation (Dai et al. 2019a; Dai et al. 2019b; Zahoor et al. 2021a, c). The percent contribution, jackknife test and marginal response curves were used to estimate the importance of variables for the three Galliformes species distribution map (Elith et al. 2011). To distinguish unsuitable and suitable habitats, we selected a threshold value for maximum training sensitivity and specificity (MTSPS) logistic threshold and grids with probability values greater than this threshold were considered as a suitable habitat (Liu et al. 2013; Dai et al. 2019a; Zahoor et al. 2021a, c). AUC has an independent threshold value that validates the accuracy of model outputs. This value ranges from 0 to 1, thus we assessed the model performance based on the following criteria; the value (of AUC) between <0.6 = flop, 0.6 – 0.7 = bad, 0.7 – 0.8 = good, 0.8 – 0.9 = better, and > 0.9 = excellent (Phillips et al. 2006; Antunez et al. 2018; Kamyo & Asanok, 2020; Singh et al. 2020b).

Geographical features of climate refugia

Altitudinal characteristics of climate refugia were studied by overlaying the climate refugia map with the layer of elevation in ArcGis 10.2.2, clipping them and counting the number of grid cells under different altitudinal ranges.

Results

The habitat suitability of three Galliformes species was modeled based on 77 occurrence points and 8 variables for *Lophophorus impejanus*, 94 occurrence points and 8 variables for *Pucrasia macrolopha*, and 40 occurrence points and 9 variables for *Tragopan melanocephalus*.

Maxent Output

For each of the Galliformes species, the maximum contribution was observed by the variable temperature annual range (Bio_7) i.e. for 75.2% for the prediction of model for *Lophophorus impejanus*, 81.4% for *Pucrasia macrolopha* and 76.4% for *Tragopan melanocephalus* of the prediction (Table 2).

Table 2

Percent contribution of bioclimatic and non-bioclimatic variables in the modeling of the three galliform species in the northern highlands of Pakistan.

Code	Variables	Unit	<i>Lophophorus impejanus</i>	<i>Pucrasia macrolopha</i>	<i>Tragopan melanocephalus</i>
Bio_1	Annual Mean Temperature	°C	5.8	3.1	3.6
Bio_2	Mean Diurnal Range	°C			
Bio_3	Temperature Consistency	°C			
Bio_4	Temperature Seasonality	°C	4.3	5.6	5.3
Bio_5	Max Temperature of Warmest Month	°C			
Bio_6	Min Temperature of Coldest Month	°C			
Bio_7	Annual Temperature Range	°C	75.2	81.4	76.4
Bio_8	Mean Temperature of Wettest Quarter	°C			
Bio_9	Mean Temperature of Driest Quarter	°C			
Bio_10	Mean Temperature of Warmest Quarter	°C			
Bio_11	Mean Temperature of Coldest Quarter	°C			
Bio_12	Annual precipitation	mm			
Bio_13	Precipitation of Wettest Month	mm			
Bio_14	Precipitation of Driest Month	mm			
Bio_15	Precipitation Seasonality	mm		5.2	
Bio_16	Precipitation of Wettest Quarter	mm			
Bio_17	Precipitation of Driest Quarter	mm			
Bio_18	Precipitation of Warmest Quarter	mm			
Bio_19	Precipitation of Coldest Quarter	mm	6.4		
Ele	Elevation	m			
Asp	Aspect	m	0.7		1.7
Slop	Slope	M	1.7		2.7
HII	Human Influence Index	M			
LC	Land Cover	M	4.2	1.3	5.7
BD	Bulk Density	M		1.9	1.7
CC	Clay Content	M			
San	Sand	M		0.7	1.8
Sil	Silt	M			
SC	Soil Classes	M	1.6	0.9	1.2

The jackknife test and marginal response curves further indicated the contribution rate of variables (Supplementary 3). The MaxEnt output performance was found excellent under a 15-times cross-validation (Fig. 3, Table 3).

Table 3

The values obtained through MaxEnt output of area under the receiver operating characteristic (ROC) and area under the curve (AUC) for the three galliform species by splitting species presence data into test (25%) and training (75%) with standard deviation (SD).

	<i>Lophophorus impejanus</i>	<i>Pucrasia macrolopha</i>	<i>Tragopan melanocephalus</i>
Training AUC ± SD	0.9368 ± 0.9367	0.9402 ± 0.001	0.9642 ± 0.003
Test AUC ± SD	0.913 ± 0.042	0.920 ± 0.032	0.944 ± 0.045

Projected distributions of three Galliformes species

The presence probability distributions of *Lophophorous impejanus*, *Pucrasia macrolopha* and *Tragopan melanocephalus* under current and future climate scenarios are in Figs. 4 and 5. The Maximum training sensitivity plus specificity logistic threshold (MTSPS) values for *Lophophorous impejanus*, *Pucrasia macrolopha* and *Tragopan melanocephalus* was 0.1389, 0.2018 and 0.1274, respectively. The binary distribution maps of all the three species were also obtained based on these values (Fig. 6).

The current total suitable habitat area of the *Lophophorous impejanus*, *Pucrasia macrolopha* and *Tragopan melanocephalus* was determined as 33228 km², 25438 km² and 17729 km². Under the current and future climate scenarios, the KPK held the largest proportion of potential distribution area, while Punjab held the least potential distribution area for all the Galliformes species (Fig. 6, Table 4). All the species experienced range contractions in 2050 and 2070 under both RCPs. The distribution of *Lophophorous impejanus* was projected to decline by ratios of -28.58% and -38.33% in 2050 while -33.21% and -27.34% in 2070 under RCP4.5 and RCP8.5 respectively (Fig. 6a). The distribution of *Pucrasia macrolopha* decreased by ratios of -14.25% and -38.23% in 2050 and -58.20% and -72.85% in 2070 under RCP4.5 and RCP8.5, respectively (Fig. 6b). Whereas, the distribution of *Tragopan melanocephalus* decreased by ratios of -32.86% and -36.73% in 2050 and -27.97% and -22.36% in 2070 under RCP4.5 and RCP8.5 respectively (Fig. 6c, Table 4). For *Lophophorous impejanus* and *Tragopan melanocephalus* the suitable habitats were predicted to shift towards north in 2050 under RCP8.5 and in 2070 under both RCPs.

Table 4

Potential distribution area of *Lophophorus impejanus*, *Pucrasia macrolopha* and *Tragopan melanocephalus* in the northern highlands of Pakistan.

Species	Province	Current (km ²)		2050				2070			
		Area (km ²)	Area (%)	RCP4.5		RCP8.5		RCP4.5		RCP8.5	
		Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)
<i>Lophophorus impejanus</i>	AJK	5912	17.79	1907	8.04	3025	14.76	2569	11.58	2245	9.30
	FATA	2577	7.76	2257	9.51	1621	7.91	710	3.20	983	4.07
	GB	1121	3.37	630	2.65	396	1.93	1282	5.78	1055	4.37
	KPK	23398	70.42	18926	79.75	15444	75.36	17615	79.38	19859	82.26
	PB	220	0.66	12	0.05	7	0.03	16	0.07	0	0
<i>Pucrasia macrolopha</i>	AJK	5700	22.41	4921	22.56	4600	29.27	2161	20.32	3007	43.54
	FATA	1350	5.31	429	1.97	299	1.90	35	0.33	48	0.70
	GB	568	2.23	480	2.20	184	1.17	238	2.24	302	4.37
	KPK	17512	68.84	15769	72.29	10511	66.89	8200	77.11	3549	51.39
	PB	308	1.21	214	0.98	120	0.76	0	0	0	0
<i>Tragopan melanocephalus</i>	AJK	4645	26.20	1416	11.90	2401	21.40	1915	14.99	1758	12.77
	FATA	491	2.77	767	6.44	326	2.91	202	1.58	252	1.83
	GB	127	0.72	23	0.19	15	0.13	176	1.38	113	0.82
	KPK	12391	69.89	9696	81.46	8474	75.54	10476	82.03	11641	84.58
	PB	75	0.42	1	0.01	2	0.02	2	0.02	0	0

Projected climate refugia with altitudinal range

The sum total area of climate refugia for *Lophophorus impejanus* was projected to be 23167 km² and 20418 km² (under RCP4.5 and RCP8.5 respectively) in 2050, and 21119 km² and 21948 km² (under RCP4.5 and RCP8.5 respectively) in 2070. For *Pucrasia macrolopha*, the total area of climate refugia was projected as 19972 km² and 15046 km² (under RCP4.5 and RCP8.5, respectively) in 2050, and 10098 km² and 6453 km² (under RCP4.5 and RCP8.5 respectively) in 2070. For *Tragopan melanocephalus*, the total area of climate refugia was projected as 10787 km² and 11010 km² (under RCP4.5 and RCP8.5 respectively) in 2050, and 11255 km² and 10545 km² (under RCP4.5 and RCP8.5 respectively) in 2070. The climate refugia for all Galliformes species was primarily projected in the KPK, followed by AJK under all RCPs in 2050 and 2070 (Fig. 7).

Under climate change, the distribution areas of climate refugia for two Galliformes species are predicted to shift towards higher altitudinal areas, with the shift of *Lophophorus impejanus* being higher than *Tragopan melanocephalus* (Figs. 7, 8). Currently, the altitudinal distribution of all three Galliformes species was projected between 2000 m to 4000 m. The projected rate of shifting was observed above 3000 m for *Lophophorus impejanus* and *Tragopan melanocephalus* under both RCPs in 2050 and 2070, and the rate was even higher under RCP8.5. In contrast, a consistent decline in the altitudinal range of climate refugia for *Pucrasia macrolopha* was observed in the future (2050 and 2070) under both RCPs (Fig. 8).

Suitable habitats and climate refugia under the protected areas

Some protected areas of central region (from east to west) of NHP overlap suitable habitats and climate refugia of three Galliformes species under the current and future scenarios (in 2050 and 2070 under both RCPs). Out of the total 93 protected areas about 37 protected areas, National Parks, Game Reserves (i.e., Government Game Reserves and Community Game Reserves and wildlife sanctuaries fall within current and future suitable habitats (Fig. 4 – 7, Supplementary 1).

Discussion

Predicting the future habitat suitability of species through SDMs is pivotal to understanding the ecological needs of a particular species and their biological and ethological responses to climate change (Aitken et al. 2008; Alexander et al. 2018). This is the first detailed study that highlighted the impact of climate change on the habitat suitability of three Galliformes species in the NHP under the current and future scenarios (2050 and 2070). While modeling the habitat suitability of the Galliformes species, we found excellent performance and high accuracy of our model based on AUC value of 0.913, 0.920 and 0.944 for *Lophophorus impejanus*, *Pucrasia macrolopha* and *Tragopan melanocephalus*, respectively (Table 3). The projection of current suitable habitat of all the species lined up precisely with the collected presence points used in this study (Fig. 4).

Impact of Climate change on habitat suitability of Galliformes species

Our results predict that *Lophophorus impejanus*, *Pucrasia macrolopha* and *Tragopan melanocephalus* will all be negatively impacted by the climate change due to habitat loss and shifts in habitat regimes towards higher altitudes in 2050 and 2070 under RCP4.5 and RCP8.5. The shifts in the distribution of species towards high altitudes and latitudes is one of the most common types of change in suitable habitat suitability expected as a result of climate change (Kharouba and Wolkovich, 2020; Penteriani et al. 2019; Dai et al. 2021; Zahoor et al. 2021c). Previous studies have predicted that changes in climate promote alterations in habitat distribution patterns to higher latitudes and lower altitudes (Lenoir and Svenning, 2015). Our findings are consistent with the recent studies suggesting that habitat of Galliformes species are likely to decline and shift towards higher altitudinal ranges in the future (Singh et al. 2020a; Chhetri et al. 2021). However, the change rates of distribution areas varied under different RCP scenarios, likely due to the fluctuation in CO₂ emissions in 2050 and 2070 (Abbasi et al. 2020; Behera and Dash, 2017). Our model projected no shift towards higher altitudes for *Pucrasia macrolopha*, and could be more alarming for the species existence. Among all three species, our model predicted the maximum suitable habitat area for *Lophophorus impejanus* and minimum suitable habitat area for *Tragopan melanocephalus*. But all three species are predicted to experience the huge loss in suitable habitat from the southern regions mainly from the AJK and KPK.

The altitudinal range of climate refugia

Our study projects that the altitudinal range of climate refugia between 2000 to 4000 m would provide ideal habitat to these species, which is consistent with the elevation ranges of these species in Pakistan reported in other studies (Fig. 7, 8). For instance, *Lophophorus impejanus* is mainly distributed in the range of 2600 m – 4000 m (Ahmad et al. 2019), *Pucrasia macrolopha* is distributed in the range of 2000m – 3700 m (Shah et al. 2013) while *Tragopan melanocephalus* is distributed in the range of 2400 m – 3600 m (Awan and Francis, 2014). Forested landscapes at these elevations provide food and shelter to these ground birds for concealment and rest, and to escape danger. Shifts in the tree line and a reduction of the suitable habitat area in the future could limit natural resources such as food, water and shelter, which could increase the pressure from interspecific and intraspecific competitions, and could lead to local extirpations. Current distribution of *Tragopan melanocephalus* indicates that the range of the species is extended from the eastern parts of the AJK to the western part of the KPK. However, previous studies indicated the presence of this species only in the AJK as Abdul (2014) and Shah (2014) conducted some basic studies for this species in the KPK but found no records. However, we collected the presence data for this species (from KPK) via GBIF (<https://www.gbif.org>) based on human observations from the year 1990 to 2000. Therefore, an extensive field survey in the KPK is needed to monitor this species, and if the species is not found then plans are needed to restore the species. As the KPK is currently and even in the future is providing maximum suitable habitat to this species. For this prevention of anthropogenic activities such as deforestation, regulations related to the species breeding sites, and restrictions against damaging their eggs and hunting in particular must be under consideration.

Projected current and suitable habitats under protected areas

Our model projected that most of the suitable habitat outside of the protected areas for all species. Out of a total 93 protected areas, only about 40% (n=37) protected areas (under current and future scenarios) overlapped suitable habitat, and most of them fell in the suitable habitat area of species *Lophophorous impejanus*. Additionally, the sizes of these protected areas are very small and insufficient for conservation purposes. Thus, establishment of new protected areas and improvement and increasing status of existing protected areas are much needed for the conservation of biodiversity, including Galliformes species in the NHP.

Under the impact of climate change, the distribution of these three indicator species in the NHP region will greatly change in the future. Vulnerability of current suitable habitat could be as high as one-quarter in 2050 and one-third in 2070 (Fig. 6, Table 4). All the provinces will face a similar decline in suitable habitat, however, Punjab will be seriously threatened as the province is currently has only a few, small patches of suitable habitat for these species, and no demarcated protected areas. In addition, forested landscapes of both protected and non-protected areas of the NHP are under high anthropogenic pressure as people stay as temporary residents (from early spring to early autumn) and carry out activities such as deforestation, hunting, agricultural practices and collection of medicinal plants (Kabir et al. 2017; Zahoor, et al. 2021a). Thus, the area may have a more profound negative impact due to climate change and ultimately lead to the local extirpation of the species.

Conservation Implications

In order to mitigate the risk of species extinction in NHP, some conservation measures should be taken by governmental and non-governmental bodies. Our main recommendations are: (i) Some avian reserves in the region be established on the suitable habitat areas for Galliformes species, and that meet international standards for protected areas. (ii) Hunting and human interference, particularly timber mafia, agricultural practices, and settlements of local people (during summer) in the forested landscapes must be banned. (iii) The size of current protected areas in the projected suitable habitats of the species should be increased to reach the potential of serving as a “stepping stone” for conservation of these species in the future. (iv) Provincial border areas that currently provide a great proportion of habitat suitable for Galliformes species should be protected to promote habitat connectivity and facilitate the dispersal of individuals across the provinces. To achieve this, provincial governments from provinces with the maximum suitable habitat, i.e., KPK and AJK, could work together to establish new protected areas that cross borders and promote biodiversity conservation. (v) Adding projected range shifts into biodiversity management planning is a practical approach to help mitigate the impacts of climate change on forested landscapes and thus, on the animals that dependent on them for survival.

Study limitations

There are some limitations to our study, for example, the human influence index data and land cover data were available only for the current scenario, so we had to use the same layers for modeling future distributions. Non-climatic variables e.g., biotic interaction, dispersal mode, invasive species, and outbreaks of diseases, were also avoided during the study which could interrupt the distribution of the species and could potentially be a major shortcoming of this study. Though uncertainties and assumptions are existing in the study, these models could play a significant role to formulate the conservation strategies to mitigate the impact of climate change in the future on such endangered Galliformes species (Ackerly et al. 2010; Wiens et al. 2010).

Conclusion

Our model projected suitable habitat under current and future (in 2050 and 2070) scenarios and climate refugia for three Galliformes species *Lophophorus impejanus*, *Pucrasia maculophya* and *Tragopan melanocephalus* in the NHP. The model projected the spatial variation of suitable habitats for all the three Galliformes species currently and in the future. We found habitat reduction and shift of suitable habitat towards higher elevations, with more area in 2070 and under RCP8.5. Conservation implications such as establishment and increased status and improvement of the protected areas (particularly at the provincial borders) with the proper management system are required for the conservation of these three indicator species in the NHP.

Declarations

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Author contributions

Paper concept: B.Z.; Primary authorship: B.Z.; Additional review and editing: X.L. and M.S.; All authors have read and agreed to publish the final version.

Declaration of interests

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.

Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethical approval

Not applicable.

Consent to participate

Not applicable.

Consent to publish

All the authors have declared their consent to publish the manuscript.

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Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request

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Figures

Species

Male

Female

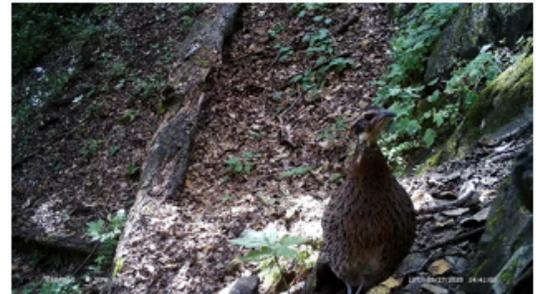
Monal Pheasant

(Lophophorus impejanus)



Koklas pheasant

(Pucrasia macrolopha)



**Western horned
tragopaon**

(Tragopan melanocephalus)



Figure 1

Three galliform species captured by two different type of camera traps in Machiara National Park, Azad Jammu and Kashmir (AJ&K), Pakistan. All photos were taken by Babar Zahoor, Tsinghua University

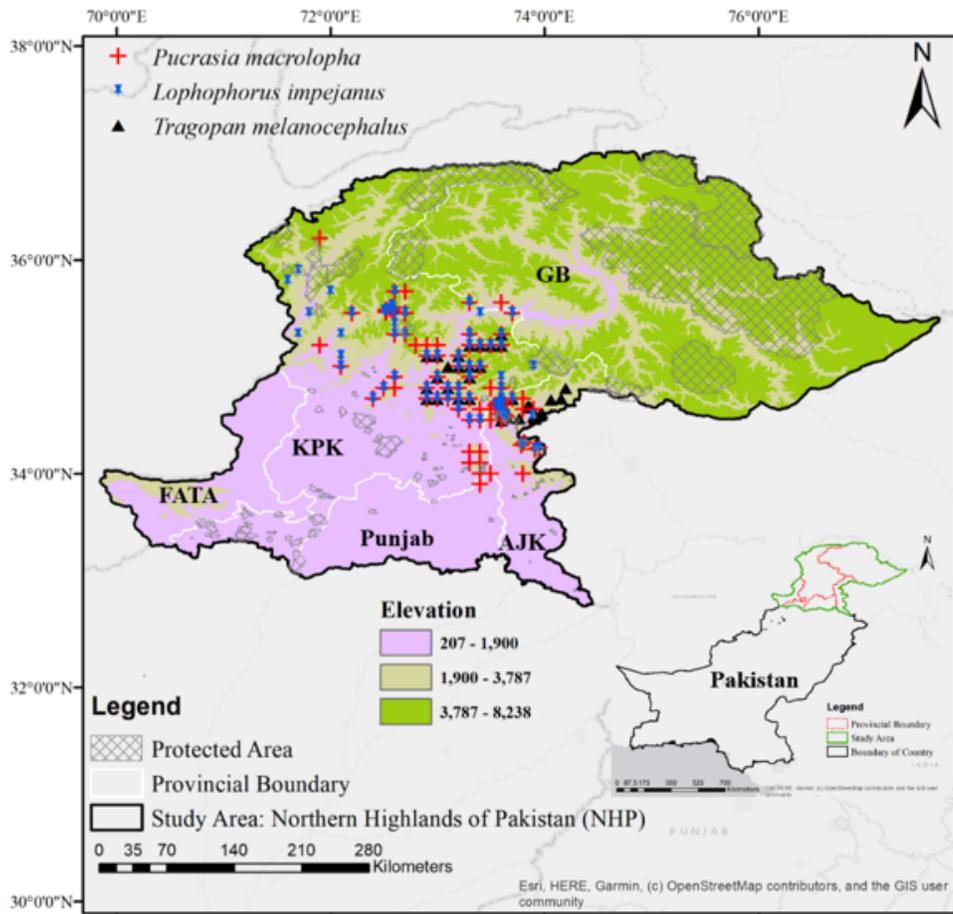


Figure 2

Study area: Northern highlands of Pakistan

AJK: Azad Jammu Kashmir; FATA: Federally administered tribal areas; GB: Gilgit Baltistan; KPK: Khyber Pakhtunkhwa

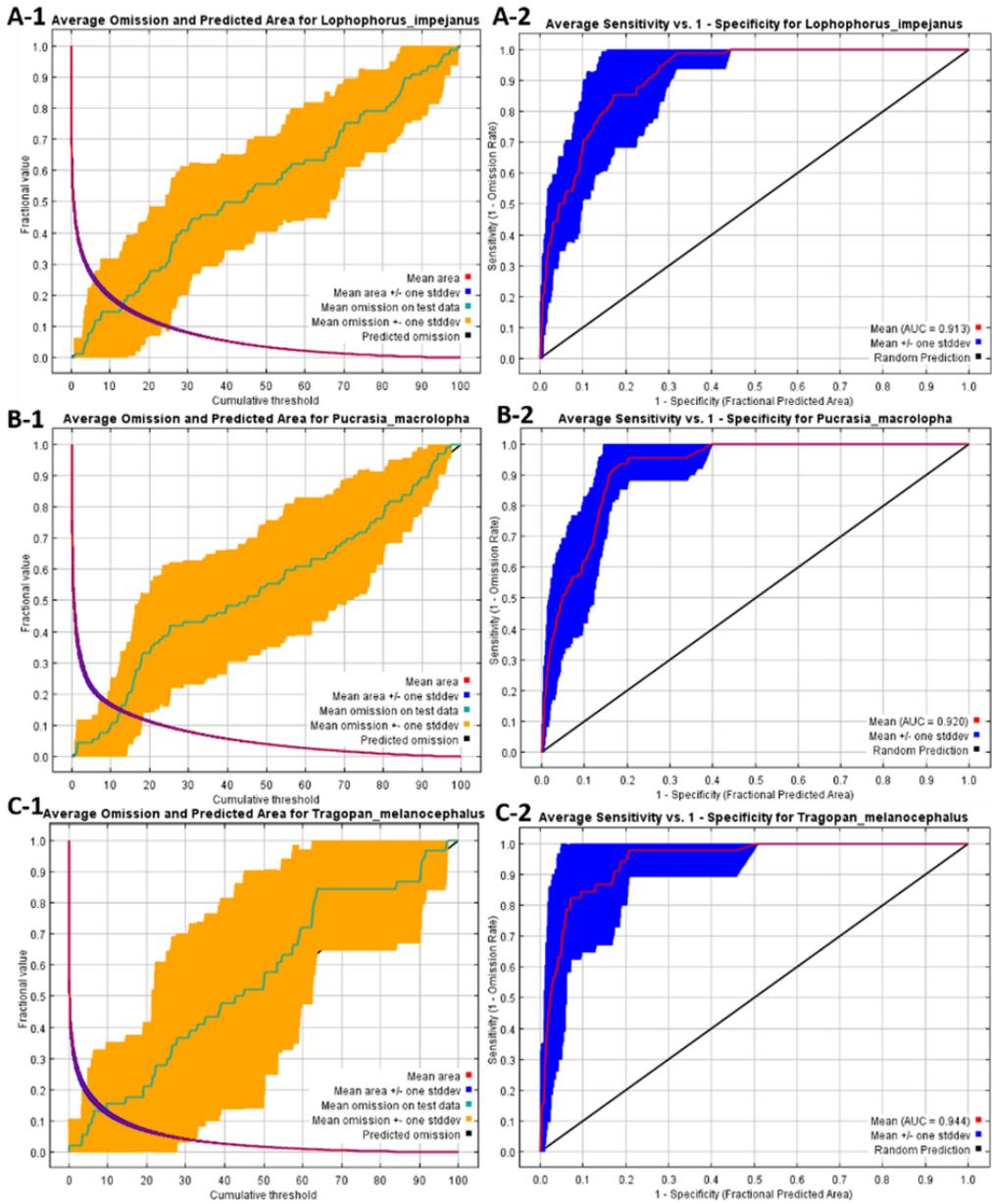


Figure 3

A1, B1 and C1 are the receiver operating characteristic (ROC) curve and average test AUC accuracy analysis for the prediction of habitat suitability for *Lophophorous impejanus*, *Pucrasia maculophya* and *Tragopan melanocephalus* respectively. A2, B2 and C2 are investigating the test omission rate and predicted area, where values are showing the training gain only with variables for *Lophophorous impejanus*, *Pucrasia maculophya* and *Tragopan melanocephalus* respectively

(a) *Lophophorus impejanus*

(b) *Pucrasia macrolopha*

(c) *Tragopan melanocephalus*

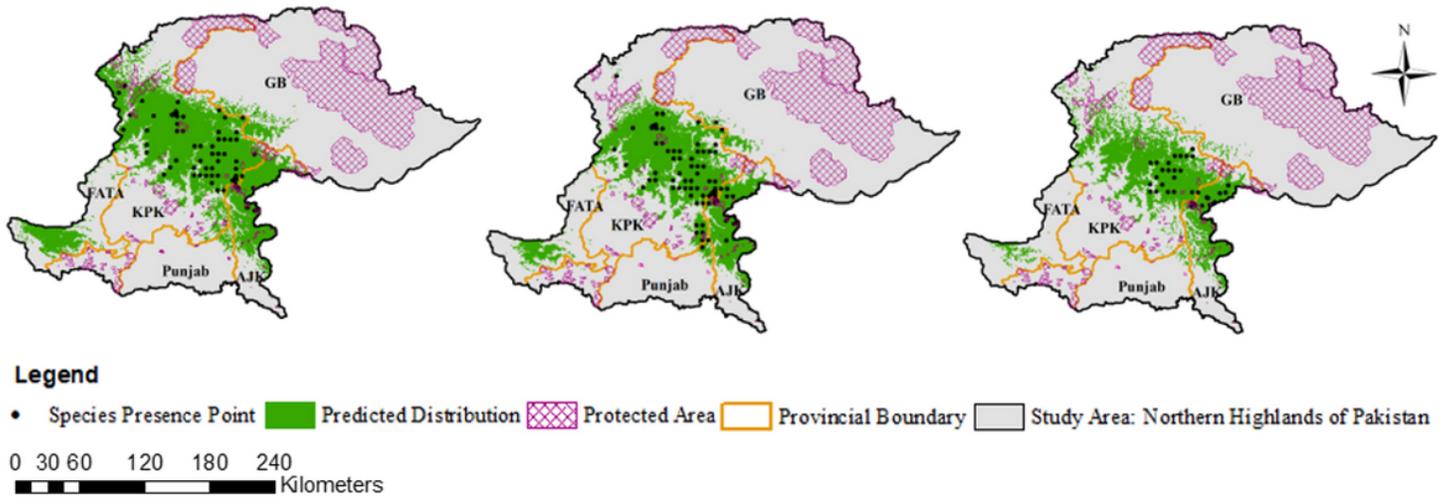


Figure 4

Current distribution probabilities of three galliform species (a) *Lophophorus impejanus*, (b) *Pucrasia macrolopha* and (c) *Tragopan melanocephalus* in the northern highlands of Pakistan

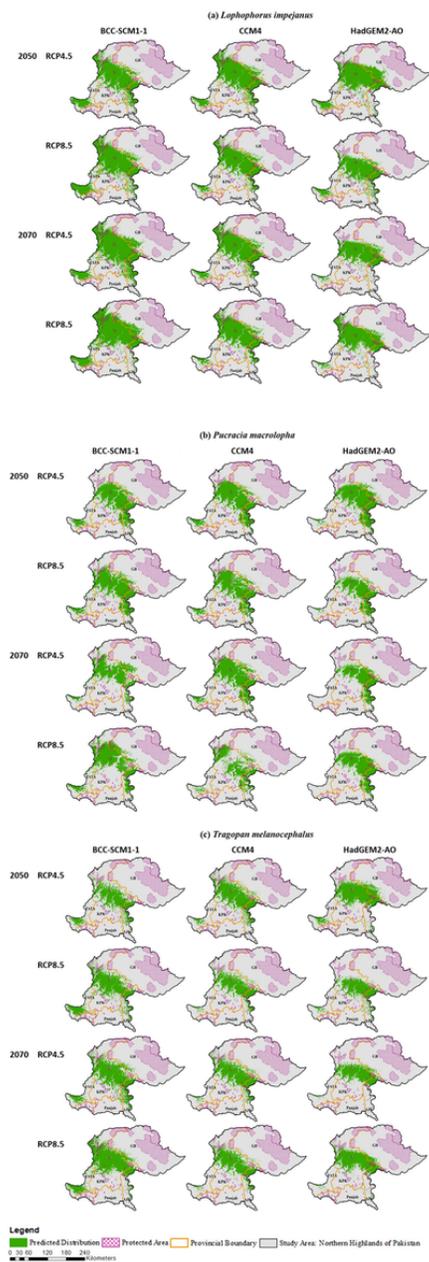


Figure 5

Distribution probabilities of three galliform species (a) *Lophophorus impejanus*, (b) *Pucrasia macrolopha* and (c) *Tragopan melanocephalus* under future scenarios (in 2050 and 2070) under RCP 4.5, and RCP 8.5 in the northern highlands of Pakistan

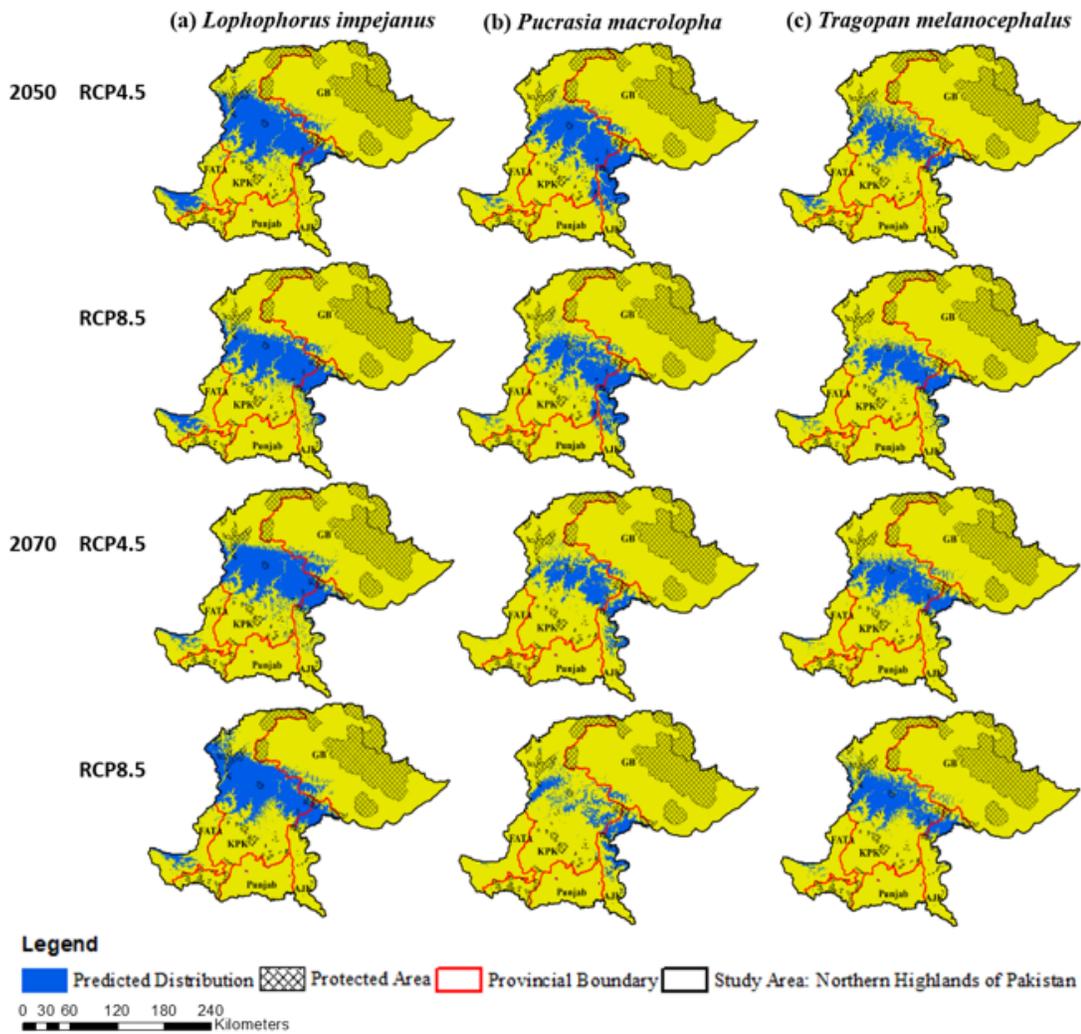


Figure 6

Binary distribution maps of three galliform species (a) *Lophophorus impejanus*, (b) *Pucrasia macrolopha* and (c) *Tragopan melanocephalus* under the future scenario (in 2050 and 2070) of RCP 4.5 and RCP 8.5 in the northern highlands of Pakistan. Future habitat suitability are the intersection area of the three GCMs (BCC-CSM1-1, CCSM4 and HadGEM2-AO)

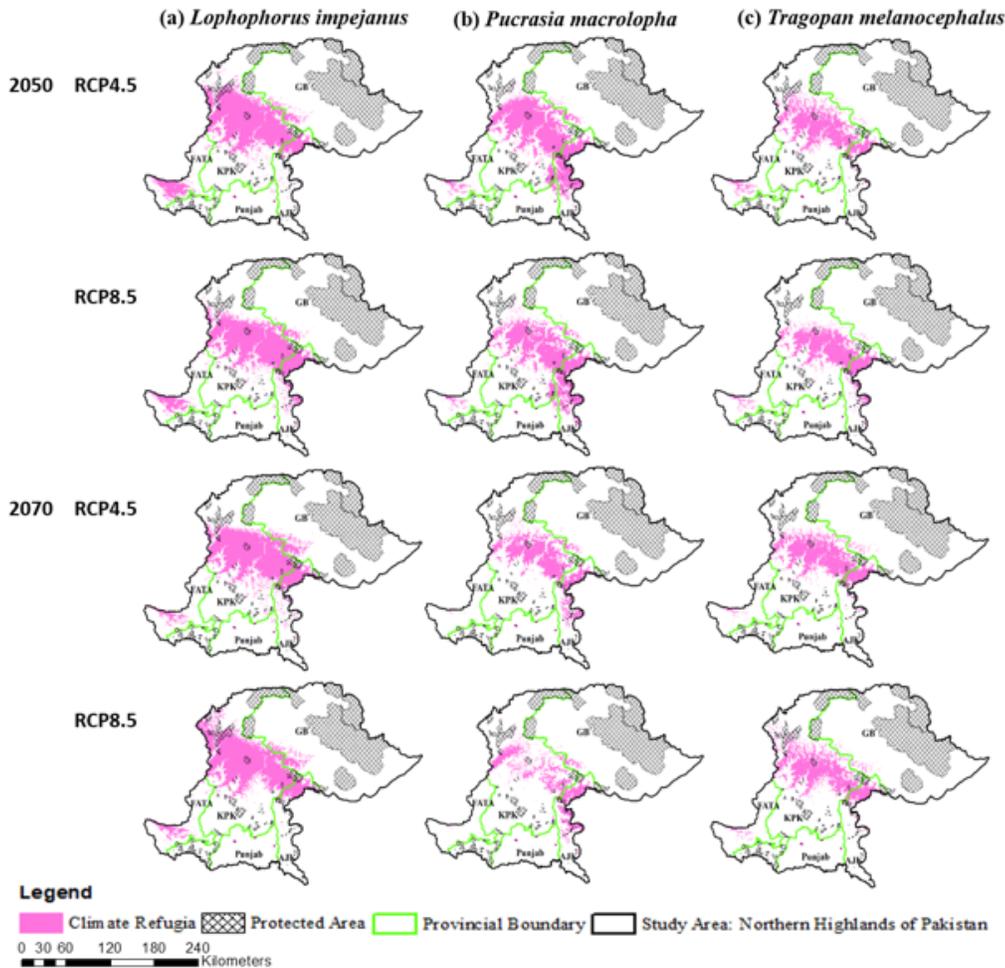


Figure 7

Climate refugia of three galliform species (a) *Lophophorus impejanus*, (b) *Pucrasia macrolopha* and (c) *Tragopan melanocephalus* in the northern highlands of Pakistan. Climate refugia refers the areas of currently suitable distribution and predicted to be suitable distribution (intersected from three GCMs) in 2050 and 2070 under RCP4.5 and RCP8.5

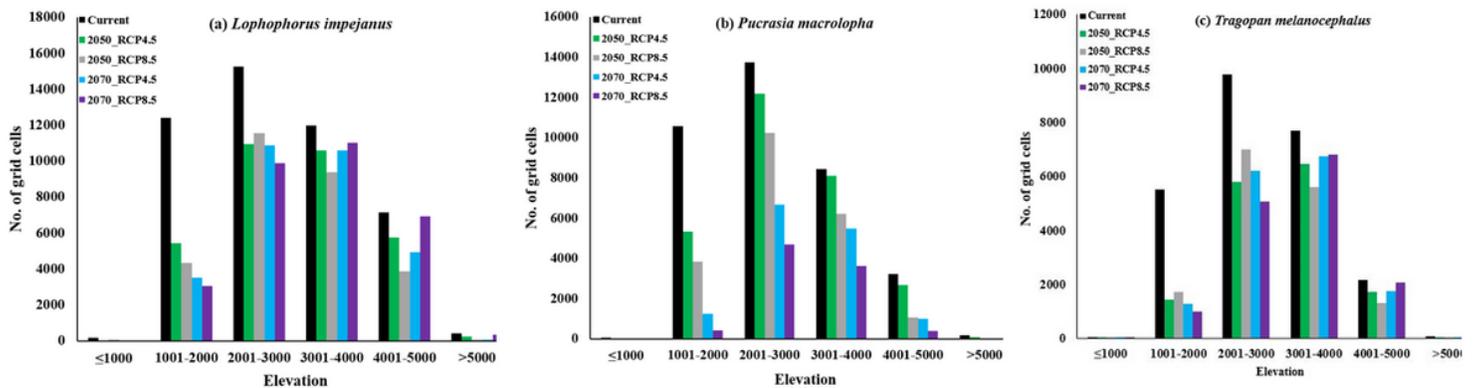


Figure 8

Altitudinal distribution range of (a) *Lophophorus impejanus*, (b) *Pucrasia macrolopha* and (c) *Tragopan melanocephalus* under current and future scenarios (2050 and 2070) for RCP 4.5 and RCP 8.5 in the northern highlands of Pakistan

Supplementary Files

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