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Potential Distribution of two sympatric pheasant species in Sikkim Himalayas

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Abstract

The Kalij Pheasant *Lophura leucomelanos* and Satyr Tragopan *Tragopan satyra* are sympatric pheasant species distributed across the foothills and temperate forests of the Himalayas, sharing overlapping ecological niches in the region. These species face several conservation challenges like deforestation, habitat fragmentation, and urbanization throughout their range. Although both the species are protected under Wildlife Protection Act of India, their spatial occurrence patterns and habitat requirements remain poorly documented in the eastern Himalayan region. The study presents potential distribution for both the species in the Sikkim Himalayas through Maximum Entropy modeling (MaxEnt) approach. Training datasets comprised 67 occurrence records for Kalij Pheasant and 143 records for Satyr Tragopan from Sikkim Himalayas. Model outputs demonstrated robust predictive accuracy (Kalij Pheasant: AUC = 0.95; Satyr Tragopan: AUC = 0.94), delineating 1241.80 sq. km (17.5%) and 280.29 sq. km (3.95%) as very highly suitable habitats for Kalij Pheasant and Satyr Tragopan, respectively. This is the first baseline distribution study of both sympatric pheasant species in Sikkim Himalayas.

Keywords: Sympatric Pheasants, eastern Himalayas, Conservation, Machine Learning, GIS

INTRODUCTION

The pheasant family *Phasianidae* are highly endemic to Himalayan region with species exhibiting remarkable adaptations to montane forest ecosystems across varying elevation gradients (Norbu *et al.*, 2013). Two of such key species are the Kalij Pheasant *Lophura leucomelanos* and the Satyr Tragopan *Tragopan satyra* which are sympatric in nature as they have overlapping habitats (Khaling et al., 1998; Sathyakumar *et al.* 2010). Despite occupying overlapping geographical ranges throughout the central and eastern Himalayan regions of Bhutan, China, India and Nepal, these two species have evolved distinct ecological niches defined primarily by altitudinal segregation and habitat specialization (AzharJameel *et al.*, 2022b).

The Kalij Pheasant demonstrates a broad elevation range, typically occurring between 381 and 2,700 meters above sea level, with documented records extending from the western Himalayas through to northeastern regions and Southeast Asia (Furqan *et al.*, 2022). Satyr Tragopan inhabits the higher altitude temperate and subalpine forests, predominantly occupying elevations from 2,400 to 4,500 meters during breeding seasons, with seasonal descents to approximately 1,800-2,000 meters in winter (Chhetri *et al.*, 2018; Ali & Ripley, 1987). This altitudinal stratification represents a critical mechanism of niche partitioning, where the Kalij Pheasant favors mixed deciduous and subtropical forest with dense understory vegetation, while the Satyr Tragopan is restricted to moist oak and rhododendron-dominated forests with thick bamboo undergrowth at higher elevations (Chhetri *et al.*, 2021; Grimmett *et al.*, 1998).

Both species serve as bio-indicators of forest ecosystem integrity, responding sensitively to habitat quality and anthropogenic disturbances (Fuller & Garson, 2000). However, in the recent years, these species have faced several anthropogenic threats like poaching, urbanization, overgrazing, etc. (Jolli & Pandit, 2011). The Kalij Pheasant and Satyr Tragopan is classified as Least Concern and Near Threatened respectively IUCN Re list of Threatened Species. Both species confront substantial conservation challenges emerging from habitat loss and degradation, poaching, infrastructure development, and emerging climate change threats that may alter the environmental conditions defining their respective ecological niches (Ramesh *et al.*, 1999).

Environmental changes have long been recognized as key drivers influencing species distributions (Kafash et al. 2021). Therefore, understanding the spatial patterns of species and the factors shaping them is essential for effective conservation and habitat management (Clements & Ozgul 2018). Species distribution modeling (SDM) has become an important approach for studying how species are distributed across landscapes (Elith & Franklin 2016).

These models use species occurrence data combined with environmental predictors to estimate the potential distribution of a species across a landscape (Fahrig 2003). Among the various SDM approaches, MaxEnt has gained prominence due to its spatial precision and strong predictive performance (Anderson & Gonzalez 2011; Duan et al. 2014; Renner & Warton 2013; Warren & Seifert 2010). It has also been widely adopted by research institutions and government agencies for biodiversity mapping and management at regional scales (Elith et al. 2010). Due to lack of comprehensive distribution data of both the sympatric pheasants, the present study aims to predict its potential distribution in Sikkim Himalayas.

MATERIALS AND METHODS

Study Area

Sikkim, located in the eastern Himalayas of India (27°00′46″–28°07′48″ N and 88°00′58″–88°55′25″ E), lies within one of the 34 globally recognized biodiversity hotspots (Myers et al. 2000). Covering an area of approximately 7,096 square kilometers, the state extends across an elevation range from about 130 to 5000 meters above sea level. Its varied terrain gives rise to distinct vegetation zones, ranging from subtropical forests to alpine meadows (Tambe et al. 2011), resulting in remarkable species richness and ecological diversity. Sikkim supports numerous Himalayan endemic species and includes 11 Important Bird Areas (IBAs) (Rahmani et al. 2016). The region's protected area network consists of a national park and seven wildlife sanctuaries distributed across the state.

Field Survey and Occurrence Data Collection

Intensive field was conducted across Sikkim from 2020 to 2022 within the known distributional range of Satyr Tragopan and Kalij Pheasant. The survey effort recorded 67 and 143 occurrence points for Satyr Tragopan and Kalij Pheasant respectively, through both direct field observations and camera trap deployments positioned along an altitudinal transect spanning 2100 to 4700 meters above sea level, encompassing vegetation gradients from coniferous forests to high-altitude grasslands. To augment the primary field-derived dataset, supplementary occurrence information was integrated from the eBird Observational Dataset. Data involved applying temporal constraints to EOD records, retaining only those from standardized survey occasions lasting two hours. Spatial filtering was subsequently applied by extracting a single location per 1×1 km^2 cell.

Species Niche Modeling Framework

Developing robust species distribution models requires grounding in species-specific ecological characteristics and behavioral requirements, enabling representation of realized ecological niches. Current best practices emphasize ecological reasoning informed by field knowledge and theoretical foundations rather than purely algorithmic approaches (Peterson et al. 2011, Araujo & Peterson 2012). Such methodologically rigorous frameworks facilitate the design of evidence-based wildlife management interventions.

An initial variable screening phase identified 20 environmental predictors (Table 1) with demonstrated ecological relevance to the selected sympatric pheasants and distribution patterns based on peer-reviewed literature. Bioclimatic and topographic elevation data were sourced from WorldClim (www.worldclim.org/current). Contemporary land cover classifications (Sentinel-2) were retrieved from the Living Atlas (https://livingatlas.arcgis.com/). Infrastructure networks including roads were extracted from OpenStreetMap (OSM) repositories. Proximity metrics were generated using QGIS 3.40.3 distance analysis functionality to quantify spatial relationships to anthropogenic infrastructure, hydrological features, and population centers. Terrain-derived metrics including slope orientation and gradient steepness were computed from SRTM dataset (12.5 m spatial resolution. Vegetation classifications derived from MODIS MCD12Q1.061 Type 2 land cover products (500 m resolution) accessed via Google Earth Engine. Normalized Difference Vegetation Index (NDVI) derivatives were acquired from NASA Earthdata Search (https://www.earthdata.nasa.gov/). Stream pathway mapping utilized terrain processing algorithms within QGIS 3.40.3. All environmental grids were standardized through resampling to uniform 1 × 1 km pixel dimensions with consistent spatial extent. Data transformation to MaxEnt-compatible formats included rasterization to ASCII and coordinate tabulation in comma-separated values (Jarnevich & Young 2015). Multi-collinearity assessment employed Pearson correlation analysis (Mehmud et al. 2021), with a 0.7 threshold applied to filter highly correlated predictors, yielding seven retained variables for model parameterization.

Table. 1 Environmental Variables selected for Kalij Pheasant and Satyr Tragopan

Sl.No.	**Variable Code**	**Environmental Variable Name**	**Data Source**	**Retained for ST**	**Retained for KP**
1	Aspect	Aspect (degrees)	SRTM DEM	✓	✓
2	Bio1	Annual Mean Temperature	WorldClim		
3	Bio12	Annual Precipitation	WorldClim		
4	Bio15	Precipitation Seasonality	WorldClim	✓	✓
5	Bio18	Precipitation of Warmest Quarter	WorldClim		
6	Bio2	Mean Diurnal Range	WorldClim		
7	Bio4	Temperature Seasonality	WorldClim	✓	
8	Bio7	Annual Temperature Range	WorldClim		
9	Dist_Agri	Distance to Agricultural Land	MODIS		✓
10	Dist_For_Edge	Distance to Forest Edge	MODIS		✓
11	Dist_Road	Distance to Road	OpenStreetMap	✓	✓
12	Dist_Settle	Distance to Human Settlement	OpenStreetMap	✓	✓
13	Dist_Water	Distance to Water Body	SRTM	✓	
14	EleV	Elevation	SRTM DEM		
15	EVI	Enhanced Vegetation Index	MODIS		
16	HFP	Human Footprint Index	SEDAC		
17	LULC	Land Cover Classification	MODIS		
18	NDVI	Normalized Difference Vegetation Index	MODIS	✓	✓
19	Pop_Dens	Population Density	LandScan		
20	Slope	Slope	SRTM DEM		

RESULT

In MaxEnt, Area Under Curve (AUC) is an important metric used to evaluate the overall performance of species distribution model (Lissovsky & Dudov 2021). The AUC ranges from 0.5, indicating a model performing no better than chance, to 1.0, which signifies discriminatory ability. Typically, AUC values above 0.75 are regarded as significant (Elith 2000). The final model in the current study achieved an AUC of 0.95 and 0.94 for Kalij Pheasant and Satyr Tragopan respectively, demonstrating strong predictive performance.

Permutation importance and percentage contribution are the two main output values in MaxEnt that evaluates variables. While percentage contribution can offer insight into the model-building process, permutation importance evaluates the variables in the final model, making it a more significant indicator for assessing variable effectiveness (Songer et al. 2012). In the current study, the environmental variables that showed highest permutation importance for Kalij Pheasant in the model were Precipitation Seasonality, Distance to Agricultural Land and Distance to Human Settlement (Table 2). Similarly, the environmental variables that showed highest permutation importance for Satyr Tragopan in the model were Aspect, Distance to Road, NDVI and Precipitation Seasonality (Table 3).

The spatial distribution of Satyr Tragopan habitat suitability in Sikkim showed Very Highly Suitable habitat occupies 280.29 sq. km (3.95%) of the state's total area. Similarly, Highly Suitable habitat covered 928.16 sq. km (13.08%), while Moderately Suitable habitat extended across 1,131.10 sq. km (15.94%) (Figure 1 a).

Table 2. Permutation Importance of Environmental Variables for Kalij Pheasant

Environmental Variable	Permutation Importance
Aspect	28.45
Precipitation Seasonality	24.38
Temperature Seasonality	1.57
Distance to Agricultural Land	0.43
Distance to Forest Edge	3.94
Distance to Road	18.58
NDVI	22.67

Table 3. Permutation Importance of Environmental Variables for Satyr Tragopan

Environmental Variable	Permutation Importance
Aspect	28.34
Precipitation Seasonality	24.17
Temperature Seasonality	3.82
Distance to Road	18.43
Distance to Human Settlement	1.94
Distance to Waterbody	0.74
NDVI	22.56

The model suggested 1596.60 sq km (22.5%) as Very Highly Suitable habitat and 1241.80 sq km (17.5%) as highly suitable for Kalij Pheasant in Sikkim Himalayas, indicating the most optimal environments for the species in terms of vegetation, elevation, and cover (Figure 1 b).

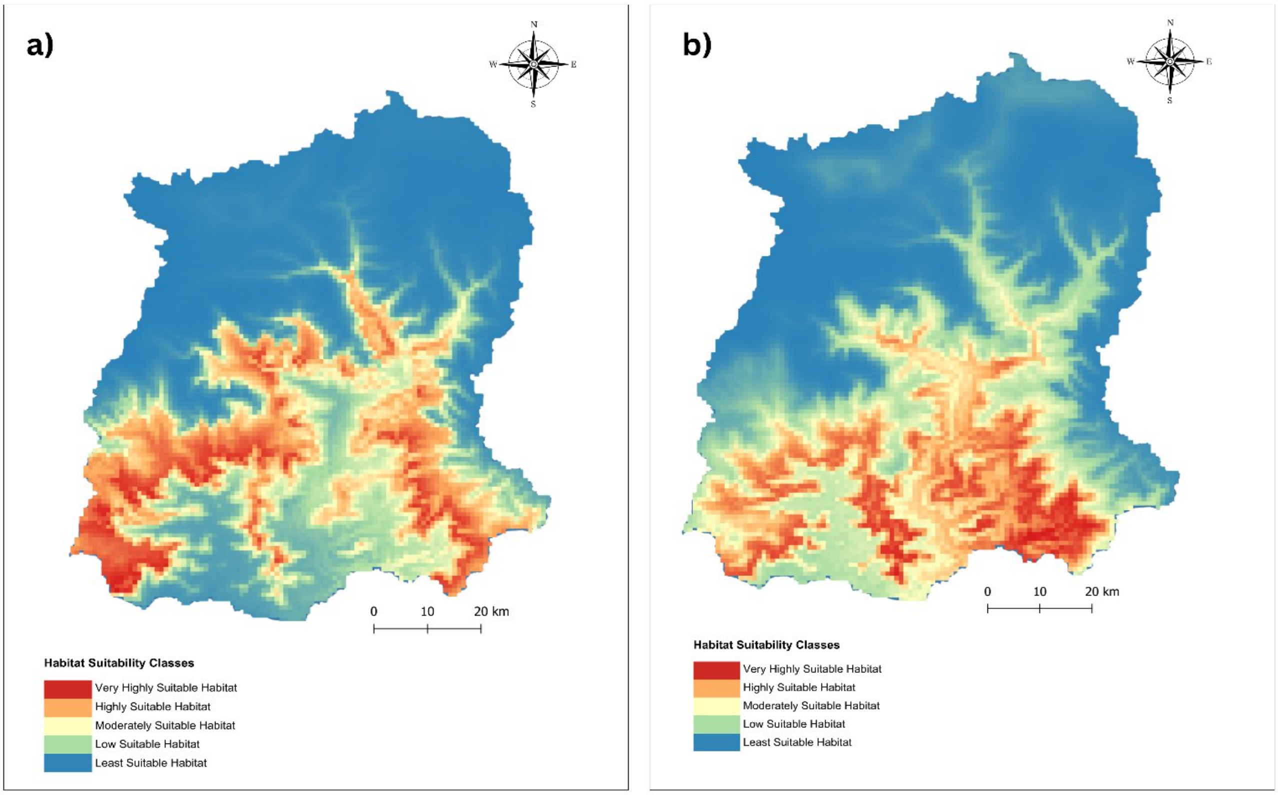

Figure 1 a) Potential Distribution of Satyr Tragopan in Sikkim Himalayas. b) Potential Distribution of Kalij Pheasant in Sikkim Himalayas.

DISCUSSION

The present study provides the first spatially explicit distribution model for two sympatric Himalayan pheasants - Kalij Pheasant and Satyr Tragopan in Sikkim Himalayas, offering insights into their habitat preferences and conservation priorities. Both models demonstrated high predictive performance (AUC > 0.94), indicating that the environmental variables selected effectively captured the ecological relationships governing the species' distributions.

Environmental predictors identified as determinants of Kalij Pheasant occurrence, including precipitation seasonality, proximity to agriculture, and distance from settlements, suggest its tolerance of moderately disturbed landscapes with dense undergrowth and mosaic vegetation patterns. Comparable habitat association has been reported from Nepal and Western Himalayas, where Kalij Pheasants exhibited affinity for secondary forests and ecotones adjoining human-modified areas (Jolli & Pandit, 2011). Such adaptability may facilitate local persistence under mild anthropogenic influence but also exposes the species to risks of hunting and habitat degradation in unprotected zones.

Conversely, Satyr Tragopan distribution was primarily explained by elevation, NDVI, slope aspect, and distance from road networks, underscoring its dependence on intact temperate broadleaf and subalpine forests at higher altitudes. Similar conclusions were drawn by Chhetri et al. (2021) in the Eastern Himalayas, where Satyr Tragopan abundance closely correlated with dense rhododendron and coniferous canopy cover, and avoidance of disturbed areas. The species' strong response to NDVI and topographic variables indicates sensitivity to vegetation productivity and micro-climatic stability, consistent with its ecological specialization as a forest-interior breeder.

Although both species share overlapping geographic ranges across Sikkim, the study's outputs highlight clear altitudinal and habitat segregation. Kalij Pheasant occupies lower montane zones (up to 2700 m), while Satyr Tragopan prefers higher elevations exceeding 3000 m. This vertical niche separation aligns with classical accounts of Himalayan pheasant ecology (Ali & Ripley, 1987; Ramesh et al., 1999) and supports the hypothesis that altitudinal stratification reduces direct interspecific competition. Such partitioning likely reflects evolutionary adaptations to distinct vegetation assemblages and foraging strategies, as well as differential behavioral responses to climatic gradients.

A critical outcome of this work is the observation that the majority of highly suitable habitats for both species lie outside the existing protected area network. For long-term population viability, it is essential to strengthen conservation measures in high suitability regions beyond designated sanctuaries, including habitat restoration, grazing regulation, and community-based surveillance against poaching. The strong anthropogenic variable influence (e.g., settlement and road distance) implies that expanding infrastructure could increasingly fragment suitable habitat corridors, which in turn may restrict dispersal and gene flow. Integrating these model outputs into land-use planning frameworks could therefore help mitigate future conflict between development and biodiversity conservation.

By quantifying the current distribution and ecologically significant predictors of Kalij Pheasant and Satyr Tragopan, this research establishes a baseline for habitat prioritization and monitoring in the Sikkim Himalayas. The integration of fine-resolution environmental layers and field-verified occurrence data enhances the reliability of the outputs for regional conservation planning. Expanding this approach to include future climate scenarios, seasonal movement data, and finer-scale vegetation metrics could offer a more holistic understanding of how these flagship sympatric pheasant species respond to rapidly changing mountain ecosystems.

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