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Seasonal variation in habitat preference of the Himalayan monal (*Lophophorus impejanus*) in Langtang National Park, Nepal: Implications for conservation

Birat Raj Rajak[1,2,3], Laxman Khanal[1,*], Asmit Subba[1,2], Amrit Nepali[1], Sandip Kumar Gupta[1], Hem Sagar Baral[4,*], Randall C. Kyes[5]

[1] *Central Department of Zoology*, *Institute of Science and Technology*, *Tribhuvan University*, *Kathmandu* 44618, *Nepal*
[2] *Conservation Himalaya*, *Chandragiri 14*, *Kathmandu* 44619, *Nepal*
[3] *Nepalese Ornithological Union*, *Ganesh Marg*, *Chabahil*, *Kathmandu* 44600, *Nepal*
[4] *Agricultural*, *Environmental and Veterinary Sciences*, *Charles Sturt University*, *Albury-Wodonga* 2640, *Australia*
[5] *Departments of Psychology*, *Global Health*, *and Anthropology*, *Center for Global Field Study*, *and Washington National Primate Research Center*, *University of Washington*, *Seattle*, *WA* 98195, *USA*

ABSTRACT

The Himalayan monal (*Lophophorus impejanus*), Nepal's national bird, is a protected species facing significant conservation challenges. Understanding the distribution and habitat preferences of the Himalayan monal (HM) is crucial for its conservation. This study was conducted in the Langtang National Park (LNP), Nepal using the route census method during both winter (November/December 2022) and summer (June 2023) seasons to examine the seasonal variation in HM's elevational distribution and habitat preference. Further, we assessed their conservation threats by conducting a semi-structured questionnaire survey with the local residents. During the winter period, the HMs preferred grassland habitats, while in the summer, their preference shifted to shrubland and barren area. HM abundance was negatively associated with the Normalized Differential Vegetation Index (NDVI) and the shortest distance from the survey trails in the winter. The HMs actively avoided areas with high anthropogenic pressure. In the summer, they showed a wider elevational range up to 4400 m above sea level (a.s.l.), with a higher sighting frequency between 3600 and 3900 m a.s.l. The questionnaire survey of the local residents revealed that anthropogenic pressure such as poaching and free-ranging livestock grazing are the major threats to the species in the study area. This study provides valuable insight into the complex habitat preferences and critical threats faced by the HMs in LNP and underscores the urgent need for targeted conservation action.

Keywords: Pheasants; National bird; Conservation threats; Seasonal habitats; Elevational distribution

INTRODUCTION

The Himalayan monal (*Lophophorus impejanus*), also known as Impeyan pheasant or Danphe, is a pheasant native to the Himalayan montane ecosystems of Nepal, Afghanistan, Bhutan, China, India, Myanmar, and Pakistan (Bhuju et al., 2007; Johnsgard, 1986; McGowan, 1994; Miller, 2010; Tun, 1970). In Nepal, Himalayan monals (HMs) have been documented across various mountainous protected areas including the national parks of Makalu-Barun, Sagarmatha, Langtang, Shey Phoksundo, Khaptad, Rara, Dhorpatan Hunting Reserve, and the conservation areas of Kanchanjungha, Gaurishankar, Manaslu, Annapurna, and Api-Nampa. Additional records of HMs have been documented extending to Jumla, Humla, Myagdi, and Taplejung districts (Inskipp et al., 2016). The HM is the national bird of Nepal and is legally protected by the National Parks and Wildlife Conservation Act 1973 of Nepal (DNPWC & DFSC, 2018). HMs inhabit high-elevation temperate forests dominated by coniferous and oak trees, often accompanied by open grasslands, typically at elevations between 2400 and 4500 m above sea level (a.s.l.). However, they concentrate within a

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*Corresponding authors, E-mail: laxman.khanal@cdz.tu.edu.np; hbaral@csu.edu.au

narrower elevational range of 2700 to 3700 m a.s.l. (Grimmett et al., 1998, 2016). These areas are often characterized by rocky terrain, with prevalent tree species such as brown oak (*Quercus semecarpifolia*), dwarf spruce (*Picea spinulosa*), and Himalayan fir (*Abies spectabilis*), and an understory of willow (*Salix oritrepha*) and Xizang rose (*Rosa tibetica*), interspersed with steep slopes, cliffs, and alpine meadows (Ma et al., 2011). HMs are also found in cultivated areas, degraded forests, shrubland, herbaceous vegetation, and bare landscapes (Soldatini et al., 2010), with a preference for forest-grassland mosaics and edges (Baral, 2022). To avoid severe winter conditions, they descend to lower elevations during the colder months, reaching as low as 2000 m a.s.l. (Ramesh, 2003). In Nepal, suitable habitats are found between 2500 and 4750 m a.s.l. in barren terrain and open woodlands (Thapa et al., 2013).

HMs are consumed locally in Nepal and face anthropogenic threats primarily from hunting and trapping. These threats are particularly pronounced during winter when the birds descend to lower elevations closer to human settlements (Baral, 2009; Lelliott & Yonzon, 1980). Local hunters, herders, and collectors of medicinal plants have been actively engaging in these hunting activities in the mountainous region of the country for decades, where the species is severely threatened by the trade for its flesh and colorful crest feathers, both of which fetch high prices (Kaul et al., 2004). The HM also is well-established in the mythology of several Himalayan cultures (Delacour, 1977). Due to their aesthetic beauty, their feathers are used in rituals and local celebrations throughout Asia (Inskipp et al., 2016; Kumar et al., 1997; Ramesh, 2003). Unfortunately, due to these activities, as well as human expansion and development leading to habitat degradation, the HM populations have suffered significant declines across most of their natural range (Gupta & McGowan, 2022; McGowan & Gillman, 1997). Anthropogenic pressures such as changes in forest cover, a decrease in grassland areas, overgrazing, burning, hydroelectricity development, and illegal hunting, threaten the species' survival (Ahmad et al., 2019; Inskipp et al., 2016). The interference caused by human activities is detrimental to the pheasant populations in the Himalayan region, leading to declining numbers (Sharief et al., 2022).

Despite facing several threats, HMs have been classified as Least Concern on the IUCN Red List of Threatened Species considering their wide distribution range (BirdLife International, 2016; DNPWC & DFSC, 2018). They have recently been assessed as Moderately Depleted in the Green Status Assessment of the IUCN because the population is declining across its range (Gupta & McGowan, 2022). It is listed in Appendix I in CITES and has been classified nationally as near threatened in National Red List of Nepal (Inskipp & Baral, 2013; Inskipp et al., 2016). They face conservation threats at a local level but lack a desirable conservation emphasis because of inadequate information on conservation challenges.

Study of the HMs' habitat preferences, distribution patterns, and anthropogenic disturbance is essential to address the prevailing challenges faced by this species and to develop effective long-term conservation strategies in Nepal. Langtang National Park (LNP) in central Nepal is one of the major habitats of HM and knowledge of the seasonal habitat preferences, distribution patterns and threats in the park holds significance for several reasons. Firstly, understanding their habitat preferences, akin to studies conducted on species like blue sheep (*Pseudois nayaur*) (Oli, 1996) and snow leopard (*Panthera uncia*) (Jackson, 1996), enables us to identify critical habitats and key ecological corridors. This knowledge is crucial for informing conservation strategies aimed at preserving the diverse ecosystems and biodiversity of the region. Secondly, studying the distribution patterns of the HM with other species, such as Xizang snowcock (*Tetraogallus tibetanus*) (Jia et al., 2021), provides insights into potential interspecies interactions and ecological dependencies, further enhancing our understanding of the park's ecosystem dynamics. Furthermore, assessing the threats, including anthropogenic disturbances and climate change impacts, as highlighted in studies on avifauna (Katuwal et al., 2016), is essential for implementing targeted conservation measures to mitigate these threats and safeguard the long-term survival of this iconic species in the LNP. Because the central Himalayan region experiences seasonal changes under the influence of South Asian summer monsoon and winter westerlies, considering seasonality in habitat utilization by HMs is important for effective conservation and management strategies in mountain ecosystems. Since upper temperate forests of the Himalaya provides safer shelter and nesting sites, and the overall suitable habitat of HM falls between 2700 m and 3700 m a.s.l. (Grimmet et al., 1998), we hypothesized that HM abundance would be positively associated with areas of dense vegetation and moderate elevation but negatively influenced by proximity to human settlements and areas with high anthropogenic disturbance. Seasonal variations were expected due to changes in resource availability and habitat use. Thus, this study aimed to assess the abundance, seasonal-spatial distribution pattern and habitat preference of HMs in LNP and establish a relationship between their abundance and habitat predictors.

MATERIALS AND METHODS

Study area

LNP is situated in the Himalayan region of central Nepal (N27.96° to N28.38° and E85.21° to E85.88°) and adjoins the Chinese border to the north. The park covers an area of 1 710 km^2 extending across the districts of Rasuwa, Nuwakot and Sindhupalchowk. It has a mosaic landscape along the elevational range between 1000 and 7245 m a.s.l., supporting a highly diverse range of animals including 380 species of birds such as the HM, Satyr tragopan (*Tragopan satyra*), Yellow-rumped honeyguide (*Indicator xanthonotus*), Wood snipe (*Gallinago nemoricola*), etc. (BCN & DNPWC, 2019). A total of 46 species of mammals also have been recorded including the Endangered red panda (*Ailurus fulgens*), snow leopard, Himalayan tahr (*Hemitragus jemlahicus*), Himalayan black bear (*Ursus thibetanus laniger*), Himalayan langur (*Semnopithecus schistaceus*), musk deer (*Moschus chrysogaster*) and Himalayan pika (*Ochotona himalayana*) (DNPWC, 2022). The park is also known for its diverse vegetation, which includes sub-tropical, temperate and alpine forests, shrublands and high-elevation grasslands and over 1000 species of plants including Rhododendron, Oak, Maple and several medicinal plants such as spikenard (*Nardostachys grandiflora*), bitter stick (*Swertia chirayita*), aconite (*Aconitum gammiei*), shatavari (*Asparagus racemosus*), and somlata (*Ephedra gerardiana*).

In Nepal, government regulations permit human settlements

within the protected areas in the mountain regions including the LNP. Tamang and Sherpa communities inhabiting LNP sustain their livelihoods through agriculture, livestock farming, and tourism while preserving natural resources via sustainable farming (LNP, 2018). Renowned for trekking and mountaineering, the park offers accessible peaks and trails, including the Langtang Valley trek and Tamang Heritage Trail, facilitating opportunities for visitors to immerse themselves in the region's natural splendour and local culture.

The study area of focus encompassed an area extending from Ghodatabela (3000 m a.s.l., N28.218°, E85.571°) up to the Kyanjin Ri upper peak (4800 m a.s.l., N28.199°, E85.458°) along the Langtang Valley trekking route, a dirt and stone trail that serves as the primary access trail used by local residents and tourists (Figure 1). This area spans four distinct habitat types including forest, grassland, shrubland and barren area. The trail section between Ghodatabela and Thangsyap (3200 m a.s.l.) is characterized by a lush and diverse forest comprising Rhododendrons, Pine trees, and Sea-buckthorn, among others, interspersed with shrubland and grassland. Beyond Thangsyap, the forested landscape gradually gives way to a predominantly shrubland environment, especially at higher elevations, with grassland becoming more prevalent. Upon reaching elevations above 3900 m a.s.l., the landscape transforms into a barren expanse marked by the presence of rocks and stones.

Visitor numbers in LNP are significantly higher during the winter season than in summer. In winter, there is increased cattle grazing pressure at lower elevations, especially between Ghodatabela and Sindum, as cattle migrate down to escape the harsh winter conditions. In contrast, during the summer, they ascend to higher elevations for grazing, where fresh, lush grasses can be found up to 4500 m a.s.l. near Kyanjin Gompa.

Field survey

The study was conducted over a 14-day period (6 hours each day) during the winter season (November/December 2022) and a 12-day period (7 hours each day) during the summer season (June 2023). Consistent sampling effort in the two seasons was ensured by maintaining the same sampling duration (84 hours for each season). Surveys of the abundance and distribution of HMs were conducted using the Route Census method (Ranta et al., 1995). This method was chosen for its suitability in capturing the diverse geographical characteristics of the study area. A total of 25 survey trails, totally 43 km (mean=1720 m, range: 380–15625 m, see Figure 2) were sampled three times during both the winter and summer seasons. On each trail, scanning was done at every 100 m interval, recording the sightings of HMs within a 50 m radius. The highest number of individuals recorded for each point, out of the three replicates, was used for downstream analyses. During the winter survey, the habitat in the study area was characterized by dry and withered shrublands and grasslands, displaying lower Normalized Difference Vegetation Index (NDVI) values. In contrast, the summer

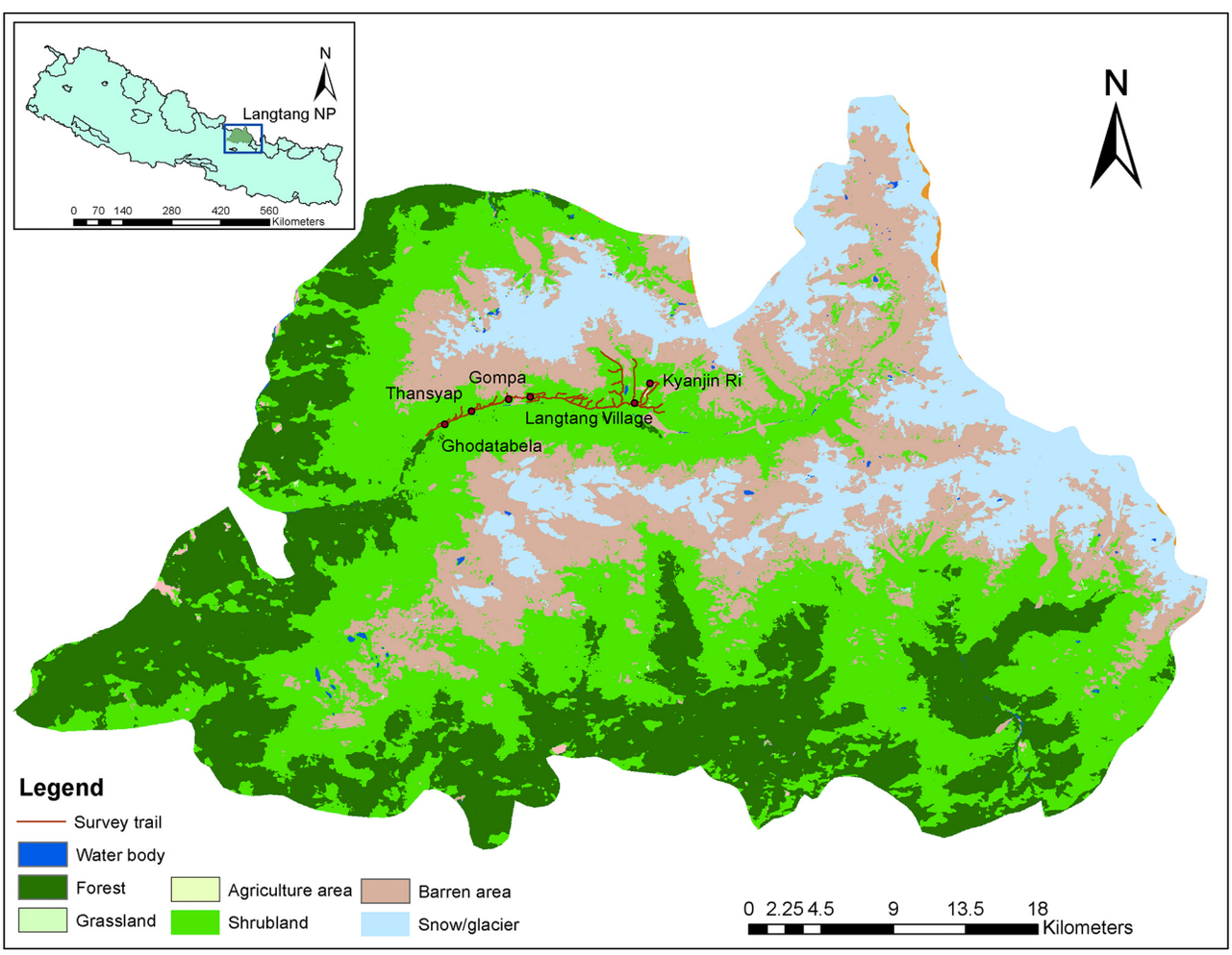

Figure 1 Map of Langtang National Park showing the land use and land cover types and the survey trails

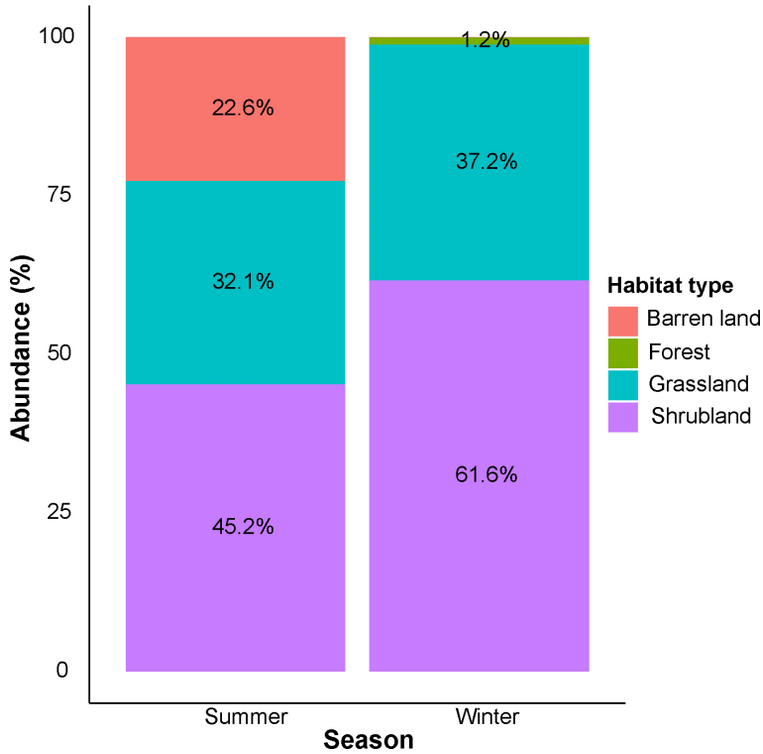

Figure 2 Percentage stacked bar chart representing the seasonal proportion of HM abundance in different habitat types in Langtang National Park

survey revealed dense, green shrublands along with lush grasslands, marked by higher NDVI values. The study area remained free from snow during both survey seasons, as the snow line in LNP typically lies above 5000 m a.s.l. year-round. Snowfall in LNP generally occurs during January and February. The predictor variables were selected based on ecological theory, and their relevance to the species' habitat and behaviour. These include variables such as elevation, slope, aspect, habitat types, human disturbance, distance to nearest water source, human settlement and trekking route, which are known to influence habitat use and resource availability for the HM. Each sighting of HMs involved documentation of the occurrence point using GPS (Garmin 64s), number of individuals sighted, sex, vegetation type, ground cover and elevation. Slope and aspect were extracted using ArcGIS 10.7 from the SRTM-DEM dataset. Distance from the nearest water body, distance from the nearest trekking route and distance from the nearest human settlement were calculated using Google Earth Pro. Landsat 8 imageries of November 2022 (winter) and June 2023 (summer) from the United States Geological Survey (USGS) were used to calculate the NDVI in ArcGIS 10.7. This index provides valuable insights into vegetation density and health, allowing for a comprehensive evaluation of habitat conditions across different seasons.

Questionnaire survey

Despite being legally protected in Nepal, HMs face significant conservation challenges. To better understand the threats to HMs, a questionnaire survey was conducted with the local residents and hospitality personnel in the Langtang Valley. The semi-structured questionnaire included inquiries about HM population trends and major threats to the HMs and their habitat in LNP. The sample size for the survey was determined using Slovin's formula, which is appropriate for calculating sample sizes in small populations:

$$n = \frac{N}{1 + N \times e^2} \quad (1)$$

Where,

"n" is the sample size,

"N" is the total population size (number of households),

"e" is the margin of error, expressed as a decimal.

In this study, the total number of households (N) was 92, and a margin of error (e) of 0.1 was selected to balance precision and resource feasibility.

The sample size obtained was $n \approx 48$. A semi-structured questionnaire survey was conducted involving 50 individuals (Males=32 and Females=18) between 20–50 years of age.

Land cover and land use mapping

The land cover of the study area, for both winter and summer seasons, was assessed by supervised image classification of the Landsat 8 satellite imageries. The image classification was done using the UTM Zone 45N projection system, ensuring accurate spatial representation. Land use and land cover within the study area were categorized into four distinct classes: Forest, grassland, shrubland, and barren area. To establish these categories, a maximum likelihood classification method was adopted. This method required the selection of a minimum of 50 training (pixels) for each land use and land cover type to ensure a robust classification process. The Kappa accuracy method was employed to validate the accuracy of the classification. This statistical measure assesses the reliability and agreement between the observed and the expected classifications. In this case, it indicated a 92% accuracy in the categorization process, thus signifying the robustness of the land cover classification. Subsequently, the raster map, representing the land cover categories, was converted into a polygon format, facilitating a more comprehensive and interpretable representation of the land use and land cover areas. This conversion process allowed for a more detailed estimation of the extent of each land cover

type within the study area, offering valuable insights into the spatial distribution and composition of the landscape.

Data analysis

The habitat selection of HMs was calculated using Ivlev's Electivity Index (Ivlev, 1961; Jacobs, 1974).

$$\text{Ei} = \frac{r - p}{r + p - 2rp} \quad (2)$$

where,

"Ei" is the Ivlev's Electivity Index for the specific habitat type,

"*r*" is the proportion of HM occurrences in a particular habitat type relative to the total number of occurrences,

"*p*" is the proportion of the habitat area occupied by that habitat type relative to the total area of all habitat types.

The interpretation of Ivlev's Electivity Index:

Ei>0 shows the preference for the habitat type,

Ei=0 shows neutral preference for the habitat type,

Ei<0 shows avoidance of the habitat type.

Model combinations were employed to account for potential interactions and collinearity among predictors, providing a robust assessment of their relative importance. A multicollinearity test was conducted among the predictor variables, and those exhibiting high correlation (r>|0.7|) (Dormann et al., 2013) were systematically excluded to avoid multicollinearity in the subsequent analysis of multiple generalized linear models (GLMs). The GLMs were fitted using different combinations of predictor variables, and the best model was selected based on the lowest Akaike Information Criterion (AIC) value. To account for the hierarchical structure of the data, the analysis was extended to generalized linear mixed models (GLMMs) by including random effects. The fixed effects identified in the best GLM were retained in the GLMM, and the models were evaluated using AIC, Bayesian Information Criterion (BIC), and likelihood ratio tests. The fit and validity of the final model was ensured through cross-validation and diagnostics. The subsequent phase involved performing GLMM to identify the habitat preferences of HMs in their natural environment. Here, the number of HMs served as the response variable, while a range of topographic and environmental variables were considered predictor variables. Both GLM and GLMM employed a Poisson distribution, as the data were in a discrete form. Multiple models were formulated using various combinations of predictor variables within the GLMM framework. Model selection was based on criteria such as the model with the lowest AIC value, along with considerations of marginal and conditional R-squared values. The selected model, which effectively identified the habitat preferences of HM in their natural habitat, underwent thorough parameter analysis utilizing the coefplot2 package to gain insights into the model's parameters and its standardized coefficients. Additionally, to evaluate the model's goodness of fit, both marginal and conditional values were obtained using the sjPlot package in R software (R Core Team, 2023). The ggplot package was employed to create box plot graphs for statistically significant variables, such as NDVI, distance from the nearest survey trail, distance from the nearest human settlement, and distance from the nearest water body.

RESULTS

Distribution of Himalayan monal in Langtang Valley

During the winter study period, 86 HMs were sighted across 30 occurrence sites (Figure 2). The majority (51 individuals, from 12 sites) were sighted in shrubland habitats. Additionally, 34 individuals (17 sites) were observed in grasslands, and one individual was recorded in a forest area. During the summer study period, 84 HMs were sighted across 28 occurrence sites. Of the total, 38 HMs were encountered within shrublands (16 sites), 27 individuals (8 sites) in grasslands, and 19 individuals (4 sites) were found in barren areas at higher altitudes.

The distribution of HMs was higher in shrubland compared to grassland and forest area (Figure 2). In the winter, a total of 51 HMs were observed in shrubland, with counts of individuals per sighting ranging between 1 and 6. Additionally, 34 HMs were observed in grasslands where individual counts varied between 1 and 11. In contrast, only a solitary HM was sighted in barren areas. In the summer, a total of 38 individuals were recorded in shrubland, with group sizes ranging from 1 to 6. In contrast, grassland supported 27 individuals, with group sizes varying between 1 and 8, while barren land had the lowest count, with 19 individuals observed in groups of 3 to 7.

There was a contrasting elevational distribution of HMs between the winter and summer study periods (Figure 3A). During the winter period, HM numbers were notably higher within the elevation range of 3100–3300 m a.s.l. This number, however, declined as the elevation increased from 3300–3500 m a.s.l., particularly in the vicinity of the Langtang Village area (Figure 1). From 3500–3800 m a.s.l., a gradual increase in the number of individuals was observed before the count eventually dropped to zero in the barren and rocky terrain beyond 3900 m a.s.l. Conversely, during the summer period, the HM distribution was concentrated at higher elevations, primarily between 3500–3900 m a.s.l., and then again in the elevation range of 4100–4400 m a.s.l. (Figure 3B). The majority of HM sightings within the study area occurred on southwest-facing slopes, suggesting a discernible preference for sun-facing slopes on this aspect, which aligns somewhat with their behavior during the winter period where they also exhibited a marked preference for southwest-facing aspects.

Seasonal habitat preference by Himalayan monals

During the winter period, the HMs exhibited a clear avoidance of forest habitat (Ei: Forest≈−0.57), but preferred grassland habitats (Ei: Grassland≈0.53) and showed a moderate avoidance of shrubland habitats (Ei: Shrubland≈−0.44). Conversely, during the summer period, there was a notable shift in preferences, with the HMs displaying avoidance of grassland habitats (Ei: Grassland≈−0.18) and a strong preference for shrubland habitats (Ei: Shrubland≈0.57). Additionally, there was a preference for barren area habitats (Ei: Barren area≈0.42), indicating a seasonal variation in habitat selection (Figure 4).

Habitat preference determinants of Himalayan monals

During the winter period, the Poisson regression model of GLMM suggested that the NDVI and distance from survey trails (Figure 5) were significant predictor variables determining the distribution of the HM. Other predictor variables did not show a significant effect (Table 1).

In the GLMM model from the winter period, NDVI and distance from the survey trail showed a strong negative correlation with the response variable (frequency of HM) (Table 1). This model best fits the habitat preference model of the HM as it has the lowest AIC value which is 121.8. The

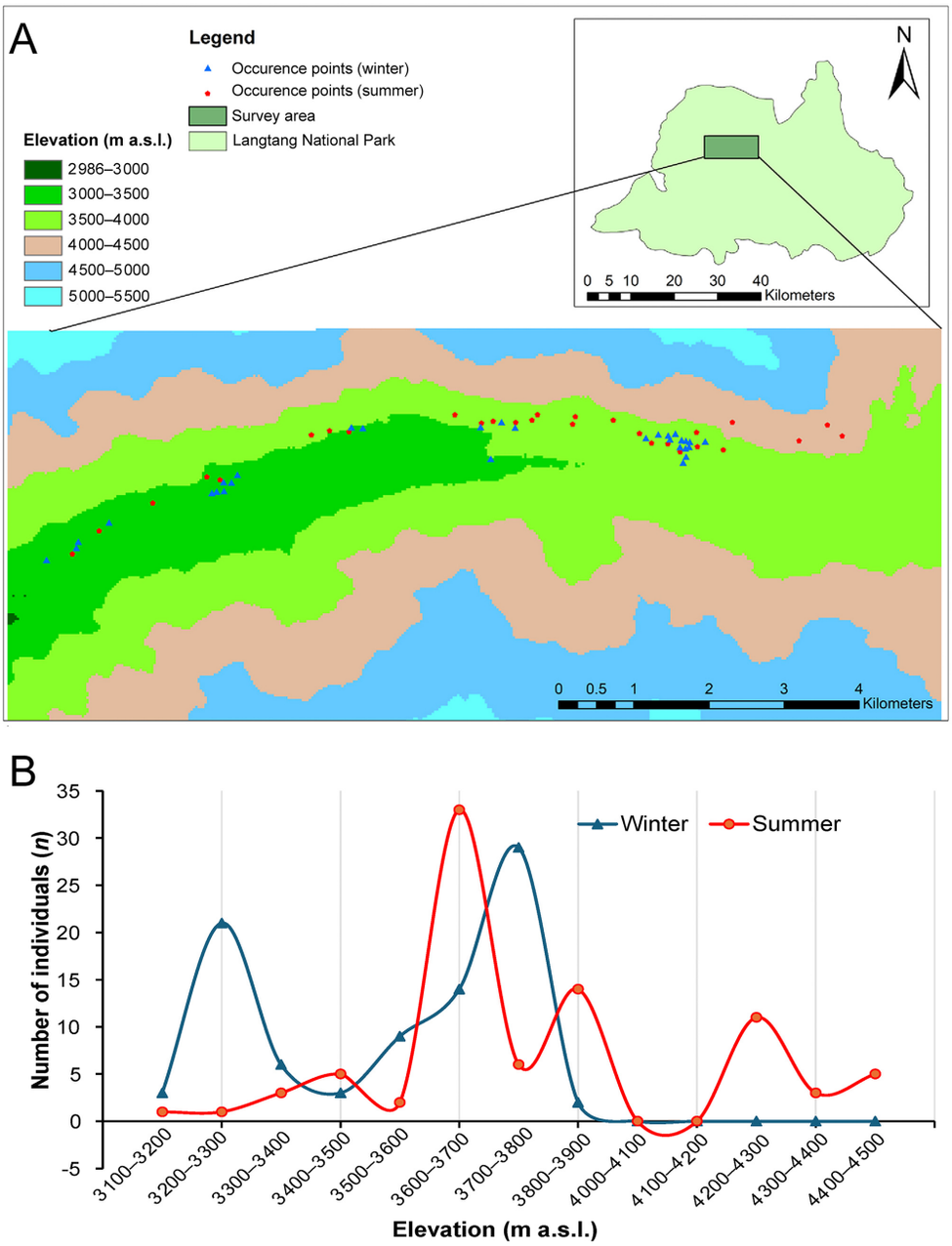

Figure 3 Seasonal distributions of Himalayan monals along the elevational gradient in the Langtang Valley

A: Seasonal occurrence points; B: Number of individuals observed at different elevational ranges.

marginal and conditional R-squared values indicate that the model explains a significant amount of the variation in the data.

The GLMM from the summer period indicated that the distance from the village had a statistically significant effect on the response variable, with a positive relationship. The results suggest that the NDVI, distance from water, and distance from the survey trail do not have statistically significant effects on the response variable. However, the distance from the village is marginally significant and has an impact on the response variable.

Conservation threats

The majority of local residents surveyed in Langtang Valley (80%, *n*=40) believe that the HM population in LNP is declining. They view poaching as the primary threat to HMs, followed by livestock grazing and other human-related factors. Among the 50 respondents, 90% (*n*=45) identified poaching as the principal threat to HMs in LNP (Figure 6).

DISCUSSION

Having adequate information on the distribution and habitat preferences of a species is vital for effective conservation and management strategies. Despite its standing as Nepal's national bird, the Himalayan monal remains one of the least studied species in Nepal, with limited data derived primarily from short-term surveys and status reports. There is a significant data gap in Nepal regarding the distribution and understanding of the habitat preferences of the HM. To our knowledge, the present study represents the first detailed study of the HM in Nepal and provides valuable insights into its seasonal distribution patterns in LNP, Nepal. The HM sightings were documented from Ghodatabela to Kyanjin, encompassing elevations ranging from 2 800 m to 4 800 m a.s.l. with a broader elevational range in summer compared to

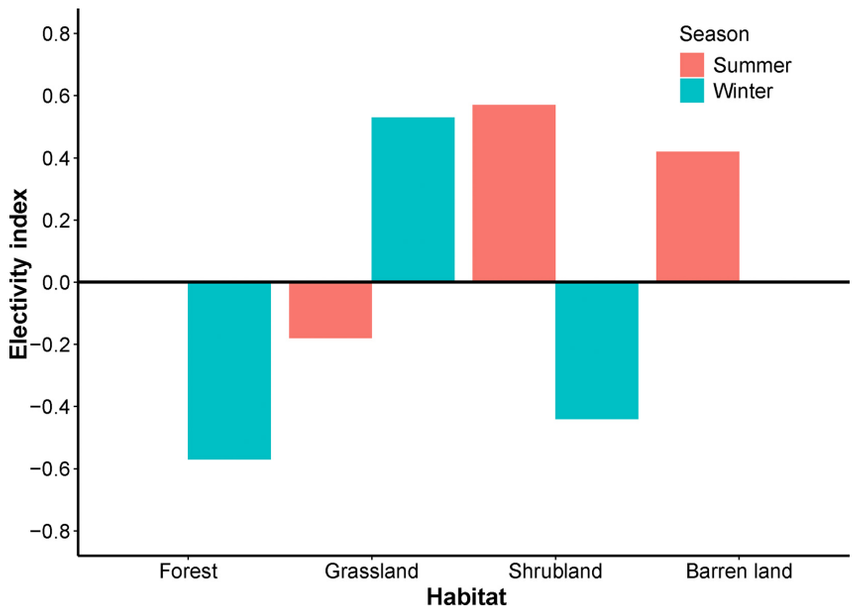

Figure 4 Ivlev's electivity index for the seasonal habitat preference of Himalayan monals

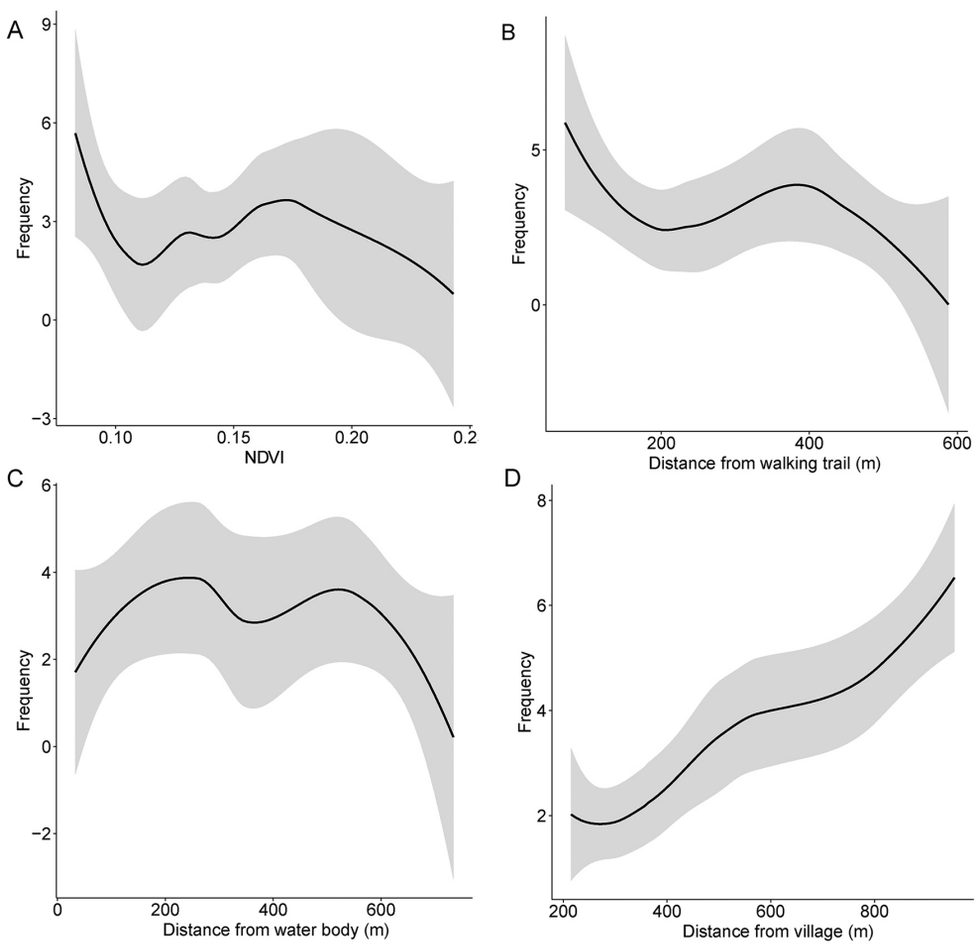

Figure 5 Variation in Himalayan monal observation frequency with NDVI (A), distance from survey trail (B), distance from water in winter season (C), and distance from village in summer (D)

a narrower range at lower elevations in winter. HMs are known to thrive within an elevational range of 2500 to 4750 m a.s.l. (Inskipp et al., 2016) and are concentrated to a more limited elevational range in disturbed areas (Rai et al., 2020; Sharief et al., 2022). They migrate to lower elevations during the winter which is attributed to ecological factors such as topography, slope, aspect, temperature and vegetation types in the Himalayan region (Ma et al., 2011; Ramesh, 2003; Srinivasan et al., 2018). In the Langtang Valley, habitat preference of HMs varied based on the slope of the landscape at different elevational ranges. The higher number of HM individuals found in the elevational ranges between 3100 to

Table 1 Coefficients of response variable (abundance of Himalayan monals) with predictor variables that best fit the GLMM for the winter and summer study periods

	Winter				Summer			
	Estimates	SE	*Z* value	*Pr*(>|z|)	Estimates	SE	*Z* value	*Pr*(>|z|)
(Intercept)	0.9063	0.1313	6.902	<0.001	0.9880	0.1204	8.207	<0.0001
Slope	-0.0715	0.1354	-0.528	0.5972	-	-	-	-
Aspect	-0.0741	0.2258	-0.328	0.7428	-	-	-	-
NDVI	-0.6674	0.2634	-2.534	0.0113	-0.2145	0.1593	-1.347	0.178
Distance to water	0.5012	0.2585	1.939	0.0525	-0.1717	0.1090	-1.576	0.115
Distance to survey trail	-1.0434	0.2636	-3.958	<0.001	0.0657	0.1785	0.368	0.713
Distance to village	-	-	-	-	0.3242	0.1744	1.859	0.05

Habitat use winter: (R^2m-0.459, R^2c-0.459); summer: (R^2m-0.437, R^2c-NA).

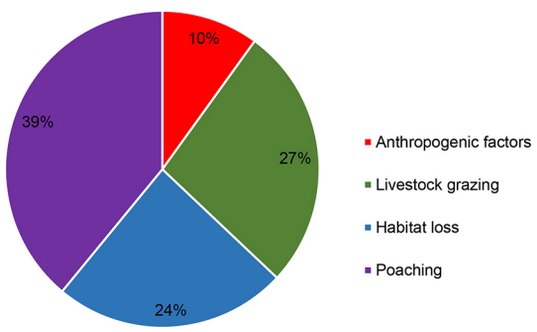

Figure 6 The perceived threats to Himalayan monals in the Langtang Valley based on the questionnaire survey

3300 m a.s.l. and 3500 to 3800 m a.s.l. in LNP can be attributed to the availability of suitable habitats characterized by moderate slope and shrubland. The Langtang Village area (~3500 m a.s.l.) had a lower abundance of HMs which could be due to the presence of the human settlement, livestock grazing, and other anthropogenic factors. Such disturbances have a significant impact on the sensitive HMs (Jolli & Pandit, 2011), causing them to avoid areas of human-induced disruptions (Bhattacharya et al., 2009; Ramesh, 2003). These findings shed light on the dynamic habitat preferences of HMs across changing seasons and human disturbance, offering valuable insights for ecological understanding and conservation.

HM's habitat preferences varied among the major habitat types during the study seasons. In the winter season, HMs showed a higher abundance in grassland areas and a markedly lower abundance in the forest. Conversely, during the summer season, a higher preference for shrubland and a lower preference for barren area was observed. Proximity to forests, forest-grassland mosaics, and forest-grassland edges played pivotal roles in reflecting the species' habitat preference. Furthermore, the HMs are known to forage in open grasslands (Soldatini et al., 2010) and seek shelter in forests (DNPWC & DFSC, 2018), making both habitat types crucial for their survival. These factors may explain the species' affinity for grassland and woodland mosaics. However, it's worth noting that our findings diverge from a study conducted in Sagarmatha National Park where the HMs were reported to prefer cultivated areas while showing considerable neglect for forest and shrublands (Soldatini et al., 2010). Thorny shrubs in the habitat may offer HM a degree of protection against various threats, including humans, livestock grazing and feral dogs which might have accounted for the higher preference of shrubland in LNP during the breeding season. In some instances, the HMs were observed in alpine and sub-alpine areas characterized by steep grassy slopes and open rocky terrain which might assist in evading predators and disturbances, aligning with observations by Lelliott (1981). The Ivlev's electivity index values also signified a clear avoidance of forest habitats and a preference for grassland habitats in winter. Conversely, in the summer season, HMs displayed avoidance of grassland habitats and a strong preference for shrubland. These findings underscore the adaptive nature of HMs' habitat preferences in response to seasonal changes in environmental conditions within LNP. Understanding these dynamics is crucial for effective conservation management strategies tailored to the specific habitat requirements of the HM throughout the year in this protected area.

The findings of our study offer a compelling comparative perspective on the habitat preferences and environmental influences on the HM during winter and summer seasons. During the winter season, the NDVI and the distance from survey trails showed statistically significant relationships with HM presence. A strong negative association was observed between the HM abundance and NDVI suggesting the HM's tendency to favour drier habitats for feeding, and an avoidance of habitat overlap with other notable herbivores like Himalayan tahrs, Himalayan langurs, and wild boar, which tend to thrive in areas with lush vegetation. Similarly, we found that the HM abundance was negatively associated with the distance from the trekking route, especially in the area between Thangsyap and Gompa. This was likely because of a gradual decrease in suitable HM habitat characterized by rocky, steep slopes with increasing distance from the trails (Ilyas, 2022). In contrast, the summer season data revealed a different set of factors influencing the HM's habitat preferences. Here, the distance from human settlements emerged as a statistically significant variable in our GLMM analysis. The HM displayed a preference for locations farther from human settlements during the summer season indicating an avoidance of anthropogenic disturbances. While elevation did not show a significant statistical relationship in the GLMM, correlation tests and plots indicated an association between HM abundance and elevation at seasonal timeframes. During the summer season, the HM's distribution pattern extended to higher elevations, specifically between 3 900 to 4 400 m a.s.l., in contrast to their winter preferences. During the summer season, we observed groups of HMs raising their chicks in rugged, barren landscapes in rocky areas away from free-roaming livestock and feral dogs which might serve as a protective strategy for nesting and rearing. These findings underscore the species' adaptability and the complex interplay between environmental variables that shape their distribution

patterns across seasons.

Illegal hunting and poaching of HMs for food and the feather trade has increased the risk of decline in their population, especially in the winter season when they migrate to lower elevations. Similarly, livestock grazing and anthropogenic pressures such as fodder collection, herding, mountain trekking, etc. present additional threats to the HMs thus forcing them to hide and seek shelter in dense shrublands. Langtang Valley is one of Nepal's major trekking routes for tourists. Trekkers seem to be unaware of the HM habitat and often make loud noise while trekking thus producing unnecessary disturbance. Garson et al. (1995) and Ahmad et al. (2019) found that anthropogenic pressure and hunting of HMs for the food trade are major threats, in addition to over-exploitation of the HM habitat for fodder, medicinal plants and mushroom collection. Destruction of HM nests in the breeding season and habitat destruction forces them to seek safer habitat far from the settlement area and trekking routes (Shansaz et al., 2021). Bhattacharya et al. (2009) suggested a lower abundance of HMs during the summer season when there is a higher presence of humans near their habitats, due to increased livestock grazing accompanied by herders and feral dogs. Chhetri et al. (2021) analysed impacts of climate change on Himalayan pheasants and predicted that the core zone habitat of Himalayan pheasants would shift towards a higher elevation and latitude gradient due to the intensification of greenhouse gases. This shifting of suitable habitat, in turn, could be a serious threat to their existence.

The current study faced several challenges, including the rugged mountain terrain and harsh winter weather, which hindered accessibility. Dense shrubs reduced detectability, while thorny vegetation in the summer restricted movement along trails. Additionally, livestock grazing within the HM habitats altered their natural behaviour, complicating observations. These factors collectively posed limitations to data collection, necessitating caution in interpreting results.

The results of this study have significant conservation implications. The negative association between HM abundance with NDVI and human presence suggests that human disturbances and vegetation health impact their distribution, highlighting the need for stricter regulation of human activities and habitat protection, especially in the region between Thangsyap and Gompa. The preference for sunny slopes, particularly those facing to the southwest, for foraging in both seasons emphasizes the need to protect these specific microhabitats. Seasonal elevation shifts between 3 100 m to 4 500 m underscores the importance of conserving a range of elevations to accommodate their habitat needs throughout the year. Addressing threats identified in the questionnaire, such as poaching and livestock grazing, through enhanced law enforcement and community engagement within the national park is crucial. Additionally, mitigating habitat loss and anthropogenic pressures by implementing sustainable land-use practices and promoting awareness programs can further support HM conservation.

CONCLUSIONS

This comprehensive study demonstrated significant seasonal shifts in the HM's elevational distribution patterns. HMs preferred forest-grassland interfaces at lower elevation during the winter season and displayed a wider elevational range during the summer. During the winter season, the HM preferred grasslands on sunny slopes in proximity to the survey trails. This preference however shifted to shrubland and barren area, during the summer season, thus avoiding anthropogenic disturbance. This behavioural distinction underscores the HM's ability to adapt to seasonal environmental changes and its keen responsiveness to human presence. While shedding light on the species' ecological preferences, our study also unveiled significant threats to the HM population in the study area. Anthropogenic pressure, livestock grazing, feral dogs and habitat destruction have emerged as significant challenges. Among these, poaching poses the most pressing threat, followed closely by the impacts of livestock grazing, feral dogs and overall anthropogenic pressure. These threats not only disrupt the HM's habitat but also jeopardize their nesting sites, further compromising their survival. These results emphasize the urgent need for conservation efforts and a careful strategy to protect the HM's habitat and population in Langtang National Park.

SCIENTIFIC FIELD SURVEY PERMISSION INFORMATION

Required permission for the research was obtained from the Department of National Parks and Wildlife Conservation, Government of Nepal Kathmandu (Permission No. 079/80-ECO-828) and the Langtang National Park, Rasuwa (Permission No. 079/80-214).

DATA AVAILABILITY

The data used in this paper has been submitted to the Science Data Bank (https://www.scidb.cn/) and has been assigned the DOI: https://doi.org/10.57760/sciencedb.zrdc.00021

COMPETING INTEREST

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

B.R.R.: Conceptualization, Data curation, Formal analysis, Observation, Methodology, Writing – original draft, Writing – review & editing. L.K.: Conceptualization, Writing – original draft, Writing – review & editing, Supervision, Project administration. A.S.: Methodology, Data analysis, Writing – review & editing. A.N.: Methodology, Writing – review & editing. S.K.G.: Methodology, Writing – review & editing. H.S.B.: Conceptualization, Writing – review & editing, Funding acquisition, Supervision. R.C. K.: Methodology, Writing – review & editing. All authors read and approved the final version of the manuscript.

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