Received: 16 October 2022 | Revised: 1 February 2023 | Accepted: 3 April 2023

DOI: 10.1002/ecs2.4584

ECOSPHERE
AN ESA OPEN ACCESS JOURNAL

ARTICLE
Climate Ecology

Climate-driven decline in the habitat of the endemic spiny babbler (*Turdoides nipalensis*)

Binaya Adhikari[1,2] | **Suresh C. Subedi**[3] | **Shivish Bhandari**[4,5] | **Kedar Baral**[6,7] | **Sandesh Lamichhane**[8] | **Tek Maraseni**[9]

[1]Institute of Forestry, Tribhuvan University, Pokhara, Nepal
[2]Pokhara Zoological Park and Wildlife Rescue Center, Pokhara, Gandaki, Nepal
[3]Department of Biological Sciences, Arkansas Tech University, Russellville, Arkansas, USA
[4]Department of Biology, Morgan State University, Baltimore, Maryland, USA
[5]Natural Science Society, Kathmandu, Nepal
[6]School of Natural and Computational Science, Massey University, Auckland, New Zealand
[7]Division Forest Office, Kaski, Gandaki, Nepal
[8]School of Forestry and Natural Resource Management, Institute of Forestry, Tribhuvan University, Kathmandu, Nepal
[9]Centre for Sustainable Agricultural Systems (CSAS), University of Southern Queensland, Toowoomba, Queensland, Australia

Correspondence
Binaya Adhikari
Email: bnayadh@gmail.com

Handling Editor: Christopher A. Lepczyk

Abstract

Climate change could amplify the extinction risk of endemic species, and the risk is even greater for species occupying high elevations and mountain ranges. In this study, we assessed the climatically suitable habitat of the only endemic Nepalese bird species, the spiny babbler (*Turdoides nipalensis*), and predicted the extent of the future (2050 and 2070) habitat of this species under two climate change scenarios (SSP2-4.5 and SSP5-8.5). We used georeferenced occurrence points alongside ecologically meaningful climatic and topographic variables to develop an ensemble suitable habitat model using different species distribution modeling algorithms in BIOMOD2. We identified 22,488.83 km^2 (15%) of Nepal's total land area as suitable habitat for this endemic species, where the nonprotected regions incorporated the largest extent of suitable habitat (88%), with a majority of this suitable area within the central Mid-Hill region. Under the SSP2-4.5 scenario, 21.58% and 34.08% of the current suitable habitat range are projected to be lost by 2050 and 2070, respectively. Whereas under the SSP5-8.5 scenario, our projections suggest that 40.45% and 52.18% of habitat will be lost by 2050 and 2070, respectively. Habitat suitability increased with a rise in warmest quarter precipitation (above 1000 mm), coldest quarter precipitation between 50 and 100 mm, and warmest quarter temperature between 20 and 30°C. Given our results, it is crucial to review the conservation policy of nonprotected areas and formulate a spiny babbler-specific conservation action plan with a special focus on protecting their primary habitat in human-dominated landscapes and nonprotected areas.

KEYWORDS
climate change, endemic bird, ensemble modeling, habitat prediction, Nepal

INTRODUCTION

Endemic wildlife, limited to a specific geographic region, faces substantial extinction risks due to global threats such as climate change, land use changes, invasive species, diseases, and other anthropogenic effects (Adhikari, Baral, Bhandari, Szydlowski, et al., 2022; Baral et al., 2022; Dirnböck et al., 2011; Garcia-R & Di

Marco, 2020; Manes et al., 2021; Pouteau et al., 2022). As a result of their adaptation to a particular climatic condition throughout their geographic range, endemic species can often only thrive in a narrow range of environmental conditions (Arajo & Pearson, 2005; Dirnböck et al., 2011; Marshall et al., 2010). Climate plays a significant role in determining how these endemic species are distributed over space and time. The effects of climate change alone might put more than 60% of tropical terrestrial endemic species at risk of extinction, and the risks are 3–10 times higher for endemic species than for other nonendemic native and introduced species (Manes et al., 2021). The risk of climate change is even greater for endemic species in high altitudes and mountain ranges (Dirnböck et al., 2011; Manes et al., 2021). Moreover, the increasing intensity and frequency of climate extremes can make it severely difficult for species with such a narrow distribution range to adapt to the changes (Griffith et al., 2009; Malhi et al., 2022; Subedi et al., 2022).

The spiny babbler (*Turdoides nipalensis*), the only endemic bird species of Nepal, typically inhabits the dense scrub areas or thick secondary growth of the Mid-Hill range within the subtropical zone of Nepal (Inskipp & Baral, 2022). This species is primarily insectivorous and usually feeds on insects such as grasshoppers, caterpillars, and beetles, alongside spiders, snails, and lizards (Ali & Ripley, 1978). The spiny babbler builds nests in low bushes, trees, and rock crevices, and the female usually lays 2–4 eggs (del Hoyo et al., 2017). This species has identical sexes like most birds, and an adult is around 26 cm long and weighs 72 g. A monogamous pair or a polygynous group with one dominant male may make up a group of spiny babblers that ranges in size from two to seven individuals. All of the group members engage in the cooperative rearing of the young, aiding with the chicks' incubation and feeding (Ali & Ripley, 1978).

The spiny babbler is fairly common within its preferred habitat in the Mid-Hills of central Nepal, whereas it is uncommon in the far eastern and far western regions of the country (Inskipp & Baral, 2022). With a short distance of movement along an elevation gradient between 375 and 2135 m, spiny babblers have a similar range of movement during the breeding and nonbreeding periods (Inskipp & Baral, 2022). Despite its endemic status and restricted range (Birdlife International, 2022; Stattersfield et al., 1998), the distributional ecology of this species is largely unknown. Escalating global threats such as climate change could amplify the extinction risk of such endemic and poorly studied species through the repercussions of habitat loss and changes in species distribution patterns across the landscape (Dirnböck et al., 2011; Peters et al., 2015). The Important Bird Areas (IBAs) network, which is vital for the protection of many birds, and other wildlife species, is also projected to become less effective for protecting endemic birds in the future (Coetzee et al., 2009). As a result of climate change, the majority of IBA bird species are predicted to lose climatically suitable space and are expected to shift their ranges in response to changes in precipitation and temperature patterns (Coetzee et al., 2009; Hoffmann et al., 2020; Sierra-Morales et al., 2021), ultimately leading to the loss of IBAs. Therefore, assessment of the current habitat and information on potential changes in the suitable habitat range of endemic birds are vital for their conservation (Coetzee et al., 2009; Hambuckers et al., 2021).

Climate modeling is one of the important tools used by scientists to comprehend historical and potential future environmental changes (Eyring et al., 2016). Shared socioeconomic pathways (SSPs) are projections of anticipated worldwide socioeconomic trends through the year 2100 and are usually applied to create scenarios for greenhouse gas emissions under various climate policies (Riahi et al., 2017; Rogelj et al., 2018). SSPs provide narratives that describe alternative socioeconomic scenarios associated with the national population, urbanization, and gross domestic product. To present a variety of diverse climate change outcomes by the end of the century, SSPs provide a set of scenarios (SSP1, SSP2, SSP3, SSP4, and SSP5) (Hausfather & Peters, 2020). Utilizing global climate models through species distribution modeling (SDM) can predict current and future suitable habitats for species, which is useful for the formulation of conservation strategies (Baral et al., 2023; Bhandari et al., 2022; Bladon et al., 2021; Coetzee et al., 2009; Sierra-Morales et al., 2021). SDMs are also useful tools in ecology that are frequently used for predicting species risk zones and forecasting the effects of past and future climate change on species and communities (Elith & Leathwick, 2009; Guillera-Arroita et al., 2015; Sofaer et al., 2019). Many recent SDM studies have used the "ensemble" SDM methodology, which incorporates predictions from multiple modeling techniques to make better and more accurate predictions (Adhikari, Bhandari, et al., 2022; Ahmad et al., 2020; Araújo & New, 2007; Hao et al., 2019; Meller et al., 2014).

In the context of the extremely limited information about spiny babblers in the world (Inskipp & Baral, 2022), it is crucial to address the gap in knowledge on their distribution range and associated variables. Identifying suitable habitat for this endemic species could be one of the major stepping stones for exploring the ecology of the spiny babbler in the future. As the distribution and range of different bird species are mostly predicted by topographic factors and climatic fluctuations (Chhetri et al., 2021; Davies et al., 2007), it is crucial to evaluate the influence of these variables on distributional

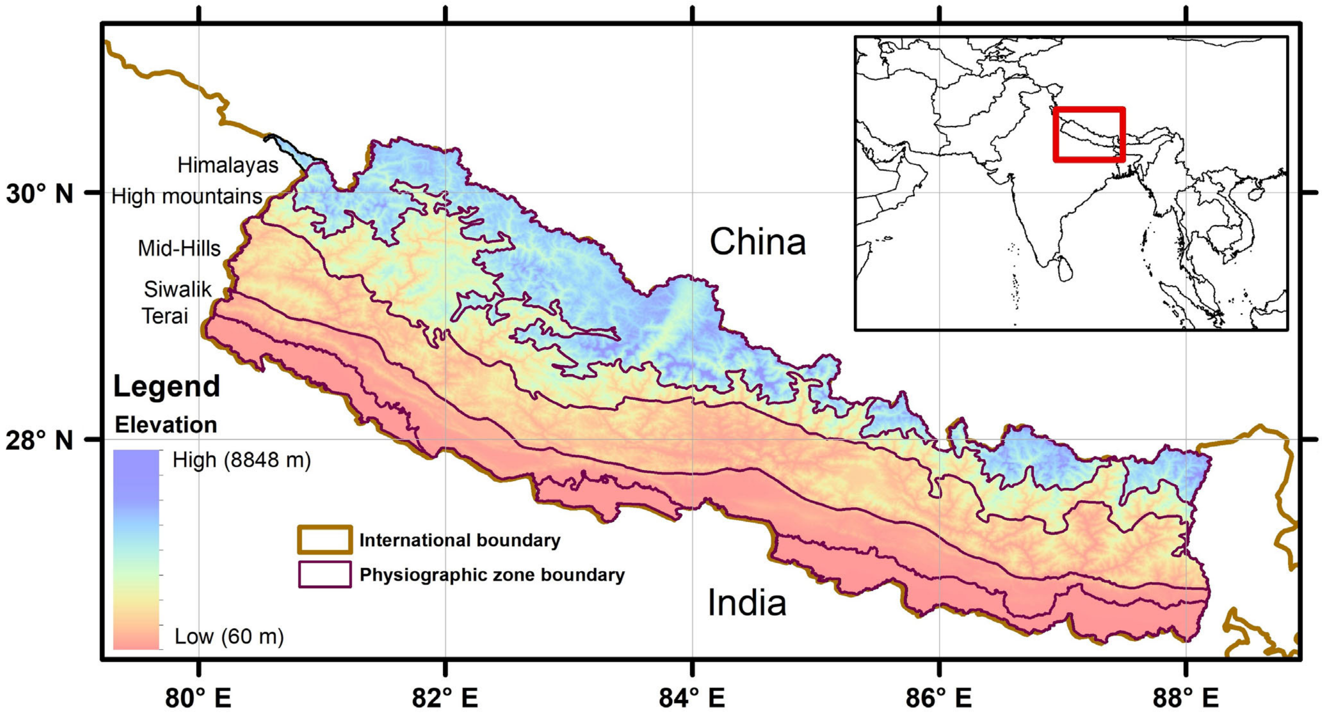

FIGURE 1 Study area map representing five physiographic zones of Nepal (Terai, Siwaliks, Mid-Hills, High Mountains, and Himalayas) and elevation gradient (60 m–8848 m above the mean sea level).

range and identify the extent of range change under future climatic scenarios. The results from such a study could help to formulate a spiny babbler-specific conservation action plan, much like the development of the Pheasant Conservation Action Plan 2019–2023 (DNPWC and DFSC, 2018) in Nepal, which was developed to guide land managers and protected areas (PAs) to implement improved conservation practices following the publication of similar SDM and habitat studies (Chhetri et al., 2018, 2021; Soldatini et al., 2010). Similarly, SDM results generated for endemic montane species have been used for habitat protection and restoration efforts and the creation of PAs all around the world (Aravind & Srinivasan, 2010; Olalla-Tárraga et al., 2016). Therefore, utilizing a reliable method of ensemble SDM by incorporating the effects of topographic and global climatic variables could effectively address the knowledge gap regarding the extent of distribution and support conservation practices. This study has two objectives: (1) to evaluate the current extent of spiny babbler distribution and the variables influencing it; and (2) to ascertain how this endemic species' range would vary under future climate change scenarios. We hypothesized that the distribution of the spiny babbler would be largely concentrated in the central Mid-Hills, and that its range would shrink in the future as a result of climate change.

MATERIALS AND METHODS

Study area

The biodiversity of Nepal (26.36–30.45° N, 80.06–88.2° E) is reflected in its distinct geographic location and significant elevational and climatic variations (Kunwar et al., 2022, 2023; Paudel et al., 2018; Vetaas & Grytnes, 2002) (Figure 1). Although Nepal only covers 0.1% of the Earth's surface, it is home to 3.2% and 1.1% of the known flora and fauna, respectively (Paudel et al., 2016; Uddin et al., 2015). About 118 ecosystems have been identified in Nepal (Lamsal et al., 2017), which support a large number of mammalian as well as bird species (Adhikari, Baral, Bhandari, Kunwar, et al., 2022; Sharma et al., 2021). Nepal harbors nearly 9% (890 species) of the world's known bird species, and among those birds, 9 species are critically endangered, 8 species are endangered, and 21 species are vulnerable, according to the IUCN red list status for globally threatened birds (Birdlife International, 2023).

Nepal consists of 27 important bird and biodiversity areas covering an area of 2,651,592 ha and consisting of 4 endemic bird areas (EBAs) (Birdlife International, 2023). Nepal's PA network, which encompasses about 23.22% of the nation's area, consists of 12 national parks, 1 wildlife reserve, 1 hunting reserve, 6 conservation areas, and 13 buffer zones (DNPWC &

DFSC, 2022). There are five physiographic regions from south to north: the Terai region (<300 m above sea level [asl]) covers over 14% of the nation, the Siwalik Hills (lower hills, 300–1000 m asl) cover over 12% of the nation, the Mid-Hills (1000–3000 m asl) cover over 30% of the nation, the High Mountains (3000–5000 m asl) cover over 20% of the nation, and the Himalayas (>5000 m asl) cover the rest (DNPWC & DFSC, 2022; Uddin et al., 2015). Administratively, Nepal is divided into 77 districts and 7 provinces (Province 1, Madesh, Bagmati, Gandaki, Lumbini, Karnali, and Sudurpashchim).

Data collection and filtering

We extracted spiny babbler records from the Global Biodiversity Information Facility (GBIF, 2022). We used 394 occurrence points from GBIF (391 from eBird and 3 from museum specimens) reported between 1970 and 2022, plus 6 occurrence points from recent field visits by the authors in 2022. One occurrence occurred in the 1970s, 10 in the 1980s, 29 in the 1990s, 12 in the 2000s, 227 in the 2010s, and 115 in the 2020s. Model prediction accuracy is usually inflated by the spatial autocorrelation of sampling effort between training and test data (Veloz, 2009). Thus, spatial filtering was used to minimize sample biases and model over-fitting (Boria et al., 2014; Dimson et al., 2019; Kramer-Schadt et al., 2013). For this, the georeferenced points were spatially filtered using the SpThin package (Aiello-Lammens et al., 2015) in R software (R Core Team, 2020). We retained only one record per grid (1×1 km^2), and a total of 112 occurrence points were retained for further analysis.

Climatic and topographic data

We used 19 bioclimatic and 3 topographic variables (slope, aspect, and elevation) (Appendix S1: Table S1) downloaded from the World Clim database version 2.1 (Fick & Hijmans, 2017) to predict the species' current and future distribution. The gridded historical (near-current) data are the average for the years 1970–2000. We obtained the bioclimatic variables for two future climatic scenarios: SSP2-4.5 and SSP5-8.5 for the years 2050 and 2070, respectively. SSP2-4.5 represents an intermediate greenhouse gas emission in which CO_2 emissions will remain around current levels until 2050, then fall, but will not reach net zero by 2100. However, SSP5-8.5 represents very high GHG emissions, in which CO_2 emissions triple by 2075. We used these two particular scenarios because SSP2-4.5 is regarded as a moderate and highly likely scenario (Hausfather & Peters, 2020), whereas SSP5-8.5 is the most extreme scenario but also the best match to the cumulative emissions from 2005 to 2020 (Schwalm et al., 2020). All the variables were obtained in the form of 30 arcseconds, which nearly equals the resolution of 1 km^2. To reduce multicollinearity among the variables, the variance inflation factors (VIFs) were assessed using the "vif" function in the "car" package (Fox & Weisberg, 2019) in R. All 22 variables (19 bioclimatic, 3 topographic) (Appendix S1: Table S1) were processed using the stepwise elimination process, in which the variables were omitted until only the variables with VIF < 3 remained (Zuur et al., 2010), ultimately retaining eight variables (aspect, slope, bio2, bio3, bio5, bio14, bio18, and bio19) for SDMs.

Species distribution modeling

Combining SDMs created through multiple algorithms has been shown to successfully improve the predictive accuracy of distribution models (Hao et al., 2019; Thuiller et al., 2009). To predict the suitable habitat, we used 10 algorithms in an ensemble approach: generalized additive models (GAMs), generalized linear models (GLMs), generalized boosted regression model (GBM), multiple adaptive regression splines (MARS), random forest (RF), surface range envelop (SRE), classification tree analysis (CTA), flexible discriminant analysis (FDA), artificial neural network (ANN), and maximum entropy (MAXENT). The data were divided into testing (20%) and training (80%) sets. For the training dataset, we produced 10,000 pseudo absence points. Altogether, we ran 90 models using 10 algorithms, 3 pseudo-absence selections, and 3 evaluation runs. The area under curve (AUC) and true skill statistics (TSS) approaches are frequently used to assess the effectiveness of prediction models (Thuiller et al., 2009). Despite being widely used as a model evaluation parameter, AUC is critiqued for having several limitations (Lobo et al., 2008), therefore, we utilized AUC and TSS (range −1 to 1) as model evaluation criteria. The TSS value accounts for both omission and commission errors, and if the TSS value is 1, the model is considered perfect; otherwise, a good model is the one with a TSS value between 0.7 and 0.9. (Allouche et al., 2006; Thuiller et al., 2009). To create an ensemble model using a weighted mean approach, we selected all the models with a TSS value greater than 0.7 as the consensus method based on weighted mean approach increases the accuracy of the model (Marmion et al., 2009). The BIOMOD2 package (Thuiller et al., 2019) for R was used to perform SDM analysis (R Core

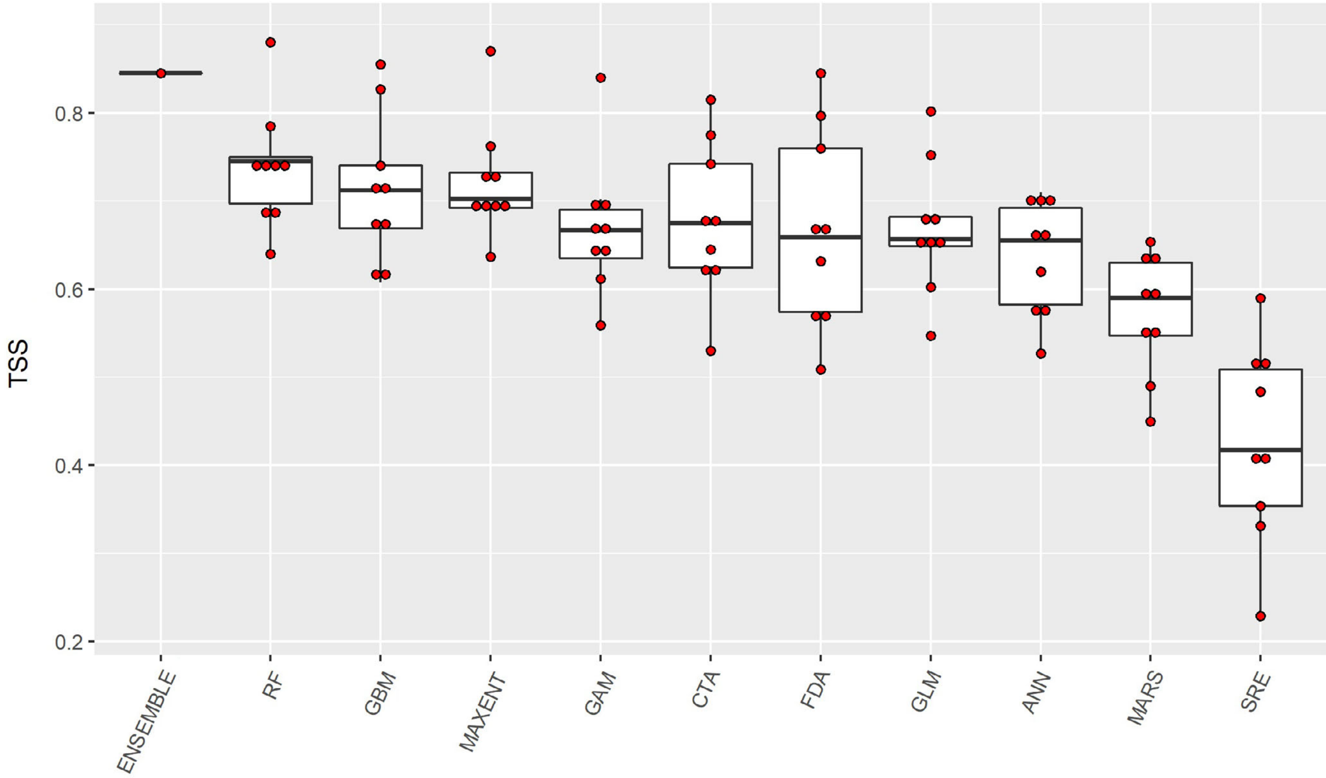

FIGURE 2 Boxplot representing the accuracy of the models used in BIOMOD2. Ensemble method predicted with higher accuracy compared with single-algorithm models: random forest (RF), generalized boosted regression model (GBM), maximum entropy (MAXENT), generalized additive models (GAMs), classification tree analysis (CTA), flexible discriminant analysis (FDA), generalized linear models (GLMs), artificial neural network (ANN), multiple adaptive regression splines (MARS), and surface range envelop (SRE). The upper box limit, midline, and lower box limit represent lower quartile (Q1), the median, and the upper quartile (Q3), respectively. The whiskers represent the extension of the box to the minimum and maximum values that fall within 1.5 times the interquartile range, and any values outside this range are outliers, which are represented by red dots. TSS, true skill statistics.

Team, 2022). To calculate the suitable area according to land use/cover, physiographic zones, and provincial regions, the suitable area obtained from the ensemble model was intersected with the land use/land cover data (Karra et al., 2021) and corresponding shape files.

RESULTS

Present distribution of spiny babbler

Our models for spiny babbler predicted that currently 22,488.83 km^2 (15% of the total area of Nepal) is climatically suitable habitat: 55% forested land, 38% rangelands, 4% built-up (developed) areas, 2% croplands, and 1% bare areas. Among the physiographic regions, the Mid-Hills constituted the largest suitable habitat (73%), followed by the High Mountains (23%). Bagmati province encompassed the largest area (42%) of the total suitable habitat, followed by Gandaki (34%) and Province 1 (15%) (Appendix S1: Table S2). Central Nepal harbored the largest habitat patches compared with western and eastern Nepal, which had very fragmented patches of suitable habitat. Of the total suitable habitat, only 12% (2587.68 km^2) was incorporated within the PA system, Annapurna Conservation Area (36%), Gaurishankar Conservation Area (23%), Langtang Buffer Zone (16%), and Langtang National Park (8%) (Appendix S1: Table S3).

Model accuracy and response curves of important variables

Of the 10 SDM algorithms used to predict the distribution of spiny babbler, three algorithms (GBM, MAXENT, and RF) had a TSS value >0.70, indicating higher model accuracy compared with other models (Figure 2). The ensemble model generated from the best fit models (GBM, MAXENT, and RF) performed the best, with a TSS value of 0.84.

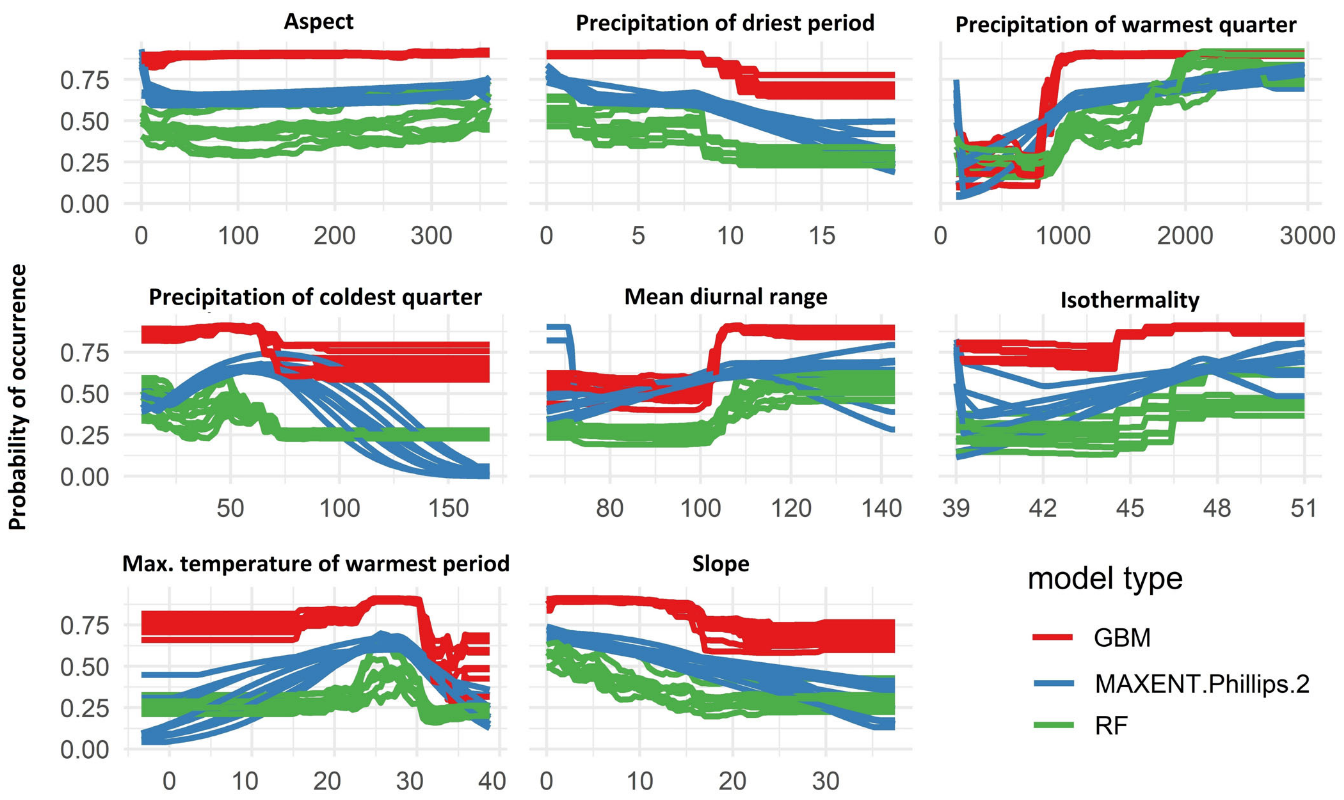

FIGURE 3 Response curve of each variable shown for the three best performing algorithms: generalized boosted regression model (GBM) (red), maximum entropy (MAXENT) (blue), and random forest (RF) (green). The *x*-axis represents the value associated with the specific variables and the *y*-axis represents probability of spiny babbler occurrence. Variables and their corresponding units are as follows: precipitation-related variables (in millimeters), temperature-related variables (in degrees Celsius), isothermality (in percentage), slope (in percentage), and aspect (clockwise in degrees from 0 to 360).

Of the eight variables used in the modeling of the spiny babbler's habitat, bio18 (precipitation of the warmest quarter) contributed the largest (29%), followed by bio5 (max temperature of the warmest period) (19%) and bio19 (precipitation of the coldest quarter) (12%). Habitat suitability increased with increasing precipitation in the warmest quarter (above 1000 mm). Similarly, habitat suitability peaked when the temperature of the warmest quarter was between 20 and 30°C. Similarly, in the coldest quarter, suitability peaked at 50–100 mm of precipitation (Figure 3).

Future distribution and range change

Spiny babbler's suitable habitat is projected to experience a substantial reduction and shift from the current range. The SSP2-4.5 scenario projected that 12% and 10% of Nepal will be suitable for spiny babblers by 2050 and 2070, respectively. Under SSP5-8.5 scenario, 10% and 7% of Nepal are projected to be suitable for spiny babbler by 2050 and 2070, respectively (Figure 4). Under the SSP2-4.5 scenario, 21.58% and 34.08% of the current suitable habitat range are projected to be lost by 2050 and 2070, respectively, and under the SSP5-8.5 scenario, the loss will be 40.45% by 2050 and 52.18% by 2070 (Figures 5 and 6).

DISCUSSION

Our results shed light on an important component of endemic species conservation by identifying climatically suitable habitat for the spiny babbler and assessing the extent of reduction in the range of this species under future climatic scenarios. The substantial reduction (22%–52%) in the distributional range of this endemic species with future climate change predictions makes this research crucial for exploring conservation strategies and policies in the context of the global effects of climate change. Most importantly, our results showed that most of the current climatically suitable habitat for spiny babblers (>88%) is outside of the PA system and overlaps with areas of high anthropogenic pressure (e.g., urbanization and agriculture), indicating a need to revise conservation policy within non-PAs.

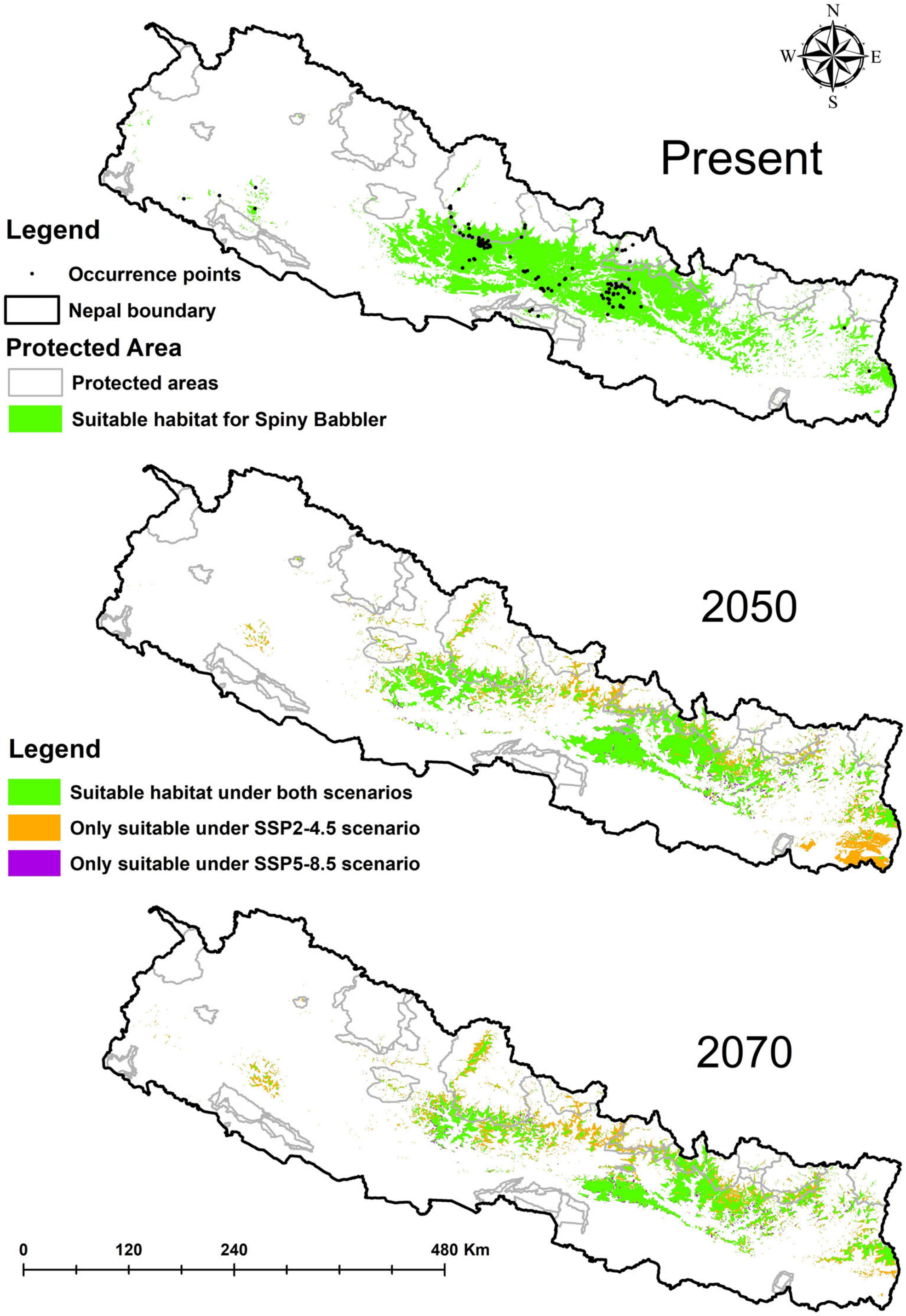

FIGURE 4 Current and future projections (2050 and 2070) of the suitable habitat for spiny babbler under the climatic scenarios of SSP2-4.5 and SSP5-8.5. SSP, shared socioeconomic pathway.

Our findings indicate that the spiny babbler may inhabit only 15% (22,488 km^2) of Nepal's total area, substantially lower than the 88,900 km^2 estimate provided by Birdlife International (2022). This discrepancy was most probably due to an overestimation of the extent of occurrence, as the IUCN and Birdlife International estimations were based on topological methods such as minimum convex polygons, which do not accurately portray environmentally suitable habitat (Burgman & Fox, 2003; Duan et al., 2022). As a result, the extent of suitable habitat identified by SDM is typically smaller than that defined by the IUCN or Birdlife International (Duan et al., 2022). Moreover, the SDM approach is a well-accepted tool for estimating suitable habitat for

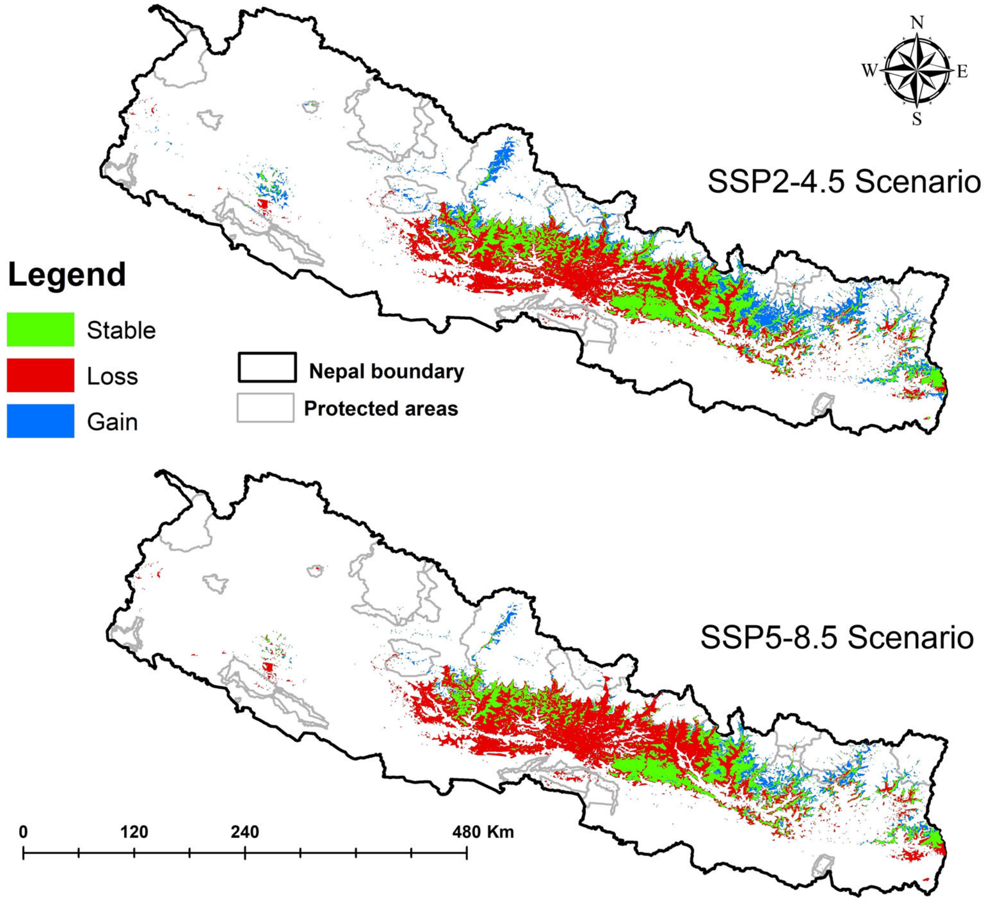

FIGURE 5 Projected change in habitat (from present to 2070) under SSP2-4.5 and SSP5-8.5 scenarios, where green represents stable habitat, red represents loss, and blue represents gain. SSP, shared socioeconomic pathway.

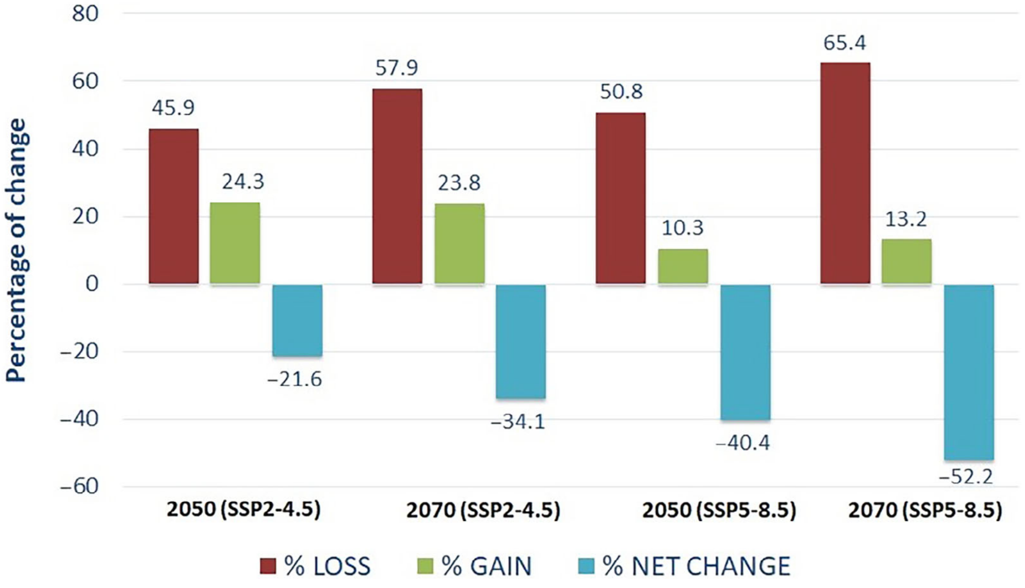

FIGURE 6 Percentage change in suitable habitat range of spiny babbler projected for 2050 and 2070 under the SSP2-4.5 and SSP5-8.5 scenarios. SSP, shared socioeconomic pathway.

many birds and wildlife (Lissovsky et al., 2021; Sofaer et al., 2019). Thus, our estimation in this study is likely more accurate than previous non-SDM-based estimates.

Our study identified that the majority of climatically suitable habitat for the spiny babbler is located in forested land (continuous or closed canopy of trees) and rangelands (moderate to sparse cover of bushes, shrubs, and tufts of grass). However, the spiny babbler's occurrence, abundance, and local distribution are mostly determined by the presence of secondary scrub, preferably dense in structure (Inskipp & Baral, 2022; Proud, 1959; Thakuri, 2020). Inskipp and Baral (2022) have also emphasized a close affinity of spiny babblers toward dense shrublands rather than forests. Therefore, despite the forest areas being climatically suitable, they do not likely support the optimum habitat for the spiny babbler, and the conversion of scrublands to forests in the climatically suitable habitats may disrupt spiny babbler's optimum habitat. Recent trends have depicted increasing forest area in Nepal. Moreover, Nepal's forest area has also changed from 45% during 1964 to 29% in 1994 and again increased to 40% in 2015, largely due to changes in forestry policy (Chapagain & Aase, 2020). Currently, the average annual growth rate of Nepal's forested lands is 0.15% (DFRS, 2015). One of the major reasons for this could be the conversion of scrub into high-canopy forests, owing to community forestry practices in the Mid-Hill regions of Nepal (Gill, 2019). Community forestry practices in Nepal are focused on promoting local participation in forest management and strive for an increase in forest area through participatory reforestation and afforestation (Kanel & Kandel, 2004). The formation of forests through the replacement of scrublands may result in inhospitable habitats for spiny babblers (Inskipp & Baral, 2022). In this context, management of existing scrublands and rangelands for sustainable conservation of the spiny babbler seems essential. Managing scrublands for the conservation of this species requires a multifaceted approach that combines the preservation of existing scrublands, and scrubland restoration through techniques such as silvicultural treatments, planting native scrubs, controlling invasive species, and managing grazing and fire to maintain the open structure of the habitat (Chandler et al., 2009; King et al., 2009). Encouraging sustainable land use practices in and around scrublands can also help to minimize the impact of human activities and help to reduce their dependence on the resources of the scrublands (Thompson, 1988; Young et al., 2005).

The central Mid-Hills region harbors the largest climatically suitable habitat for the spiny babbler. The Central Himalayan EBA, identified by Birdlife International (Birdlife International, 2023), contained the majority of the suitable habitat for the spiny babbler, consistent with the information from other studies (Birdlife International, 2022; Inskipp & Baral, 2022). The Central Himalayan EBA comprises nine IBAs, which include the Annapurna Conservation area, Dharan Forests, Kanchenjungha Conservation Area, Langtang National Park, Mai Valley Forests, Makalu Barun National Park, Phulchoki Mountain Forests, Shivapuri-Nagarjun National Park, and Tamur Valley Watershed (Birdlife International, 2022). Most occurrences of the species have been recorded from west-central to east-central Nepal, with only 6 and 10 records in the last 40 years in the far western and far eastern regions, respectively (Inskipp & Baral, 2022). Although our model predicted that eastern Nepal would have a substantial portion (15%) of total suitable habitat, the low records could be attributed to lower observance coverage in these areas compared with central Nepal. On the other hand, despite the spiny babbler being considered endemic to Nepal, a study has speculated that the range of the species could encompass further west of Nepal, into the northwestern region of India (Inskipp & Inskipp, 1991). However, our model predicted very fragmented patches of climatically suitable habitat in western Nepal, with only a small possibility of suitable habitat extension to the northwestern region of India. In contrast, with the presence of substantial climatically suitable habitat for this species in eastern Nepal, it is highly probable that the range of this species could possibly extend to the northeastern region of India, adjacent to Nepal (potentially between Ilam in Nepal and Darjeeling in India). Therefore, a detailed transboundary survey for verifying the potential occurrence of the spiny babbler between eastern Nepal and northeastern India is crucial for further studies.

Based on our model prediction, a majority (88%) of the current climatically suitable habitat for the spiny babbler is encompassed within the non-PAs. Moreover, some of the suitable habitats in non-PA regions fall within areas of high anthropogenic pressure (e.g., urban areas and agricultural areas). PAs with a strict legal protection have minimal or no human presence, and limited human disturbance in wildlife habitat (Lele et al., 2010). In contrast, non-PAs are inhabited and exploited by the local communities, and their priorities are subsistence needs such as fuel wood, fodder, timber, and other resources. Non-PAs are usually attributed to lower conservation priorities and consequently higher exploitation of resources. Haphazard development and a rapid increase in anthropogenic infrastructure in non-PA regions could escalate the degradation of the spiny babbler's suitable habitat. Even though PAs contribute immensely to the conservation of threatened and endemic species (Brown et al., 2019; Cazalis et al., 2020; Virkkala et al., 1994), the essence of conserving suitable habitats within non-PAs for their sustainable conservation cannot be overlooked (Avigliano et al., 2019; León-Ortega et al., 2017; Norbu et al., 2021; Santos et al., 2008). In this regard, suitable habitat outside of PA should also be accorded equitable conservation priority. For this, incorporating suitable areas within the non-PA system into the PA system could help immensely, because sustainable conservation objectives often require landscape-based conservation planning, which includes both PA and non-PA areas (De Camargo et al., 2018; Radford et al., 2005; Thapa et al., 2021). Awareness, educational outreach, and incentives to conserve the scrubby habitats and protect the connectivity of habitats for this species across the distributional range should be carried out in a landscape-level approach.

In future climate change scenarios, we predicted a 34%–52% decline in the suitable habitat range of the spiny babbler by 2070, which could adversely threaten their survival by dwindling their population. According to the IUCN's range size criterion, a species is vulnerable if the extent of its occurrence is less than 20,000 km^2. Even though the current extent of suitable habitat for the spiny babbler is slightly over the IUCN criterion (22,000 km^2), it is projected to decrease to <15,000 km^2 by 2070 under both climatic change scenarios used in our analysis. With a restricted range in the central Himalayas and a shrinking suitable habitat, this species will likely face a high risk of global extinction in the near future. Several studies have indicated shrinking habitat for endemic birds in future climate scenarios. For example, approximately 36 species of endemic bird species will be exposed to the risk of extinction due to climate change in China (Wu, 2020). Likewise, a study concentrated on eastern Brazilian mountaintops investigated a gradual reduction of suitable habitat for endemic birds, with the mountaintop species experiencing the strongest impact of climate change (Hoffmann et al., 2020).

Precipitation-related variables (bio18 and bio19) and temperature-related variable (bio5) mostly governed the distribution of climatically suitable habitat for the spiny babbler. Habitat suitability increased with rise in warmest quarter precipitation (above 1000 mm), coldest quarter precipitation between 50 and 100 mm, and warmest quarter temperature between 20 and 30°C. High influence of the maximum temperature of the warmest months and precipitation of the driest quarter is consistent with the other studies that have reported factors influencing habitat suitability of endemic birds, such as in Ethiopia (Bladon et al., 2021). Tropical birds are projected to be especially susceptible to rainfall-dependent variables and extreme weather events (Şekercioğlu et al., 2012). The probability of distribution of the spiny babbler was found to be higher in habitats with more than 1000 mm of precipitation in the warmest quarter. For montane birds, the population was found to be positively correlated with rainfall (Walther et al., 2017). Precipitation has long been recognized as a major driver of species richness and distribution (Liang et al., 2020; Yousefi et al., 2017). Temperature-associated impacts on demographics and distribution were also recorded in an Afrotropical understory bird community (Neate-Clegg et al., 2021). These impacts of precipitation and temperature on the distribution of spiny babbler warrant further investigation as the ecology of spiny babbler is largely unknown.

Due to a lack of information, the majority of tropical bird species that are sensitive to climate change are not currently regarded as being at risk of extinction (Şekercioğlu et al., 2012). For example, despite its IUCN red list status as of least concern, the endemic spiny babbler will face the adverse effects of climate change with a shrinking future habitat, potentially leading to extinction. Therefore, it is vital to collect data on the ecology, present distribution, and projected range of these species by incorporating ecologically relevant variables. Our study incorporated important climatic and topographic variables to identify current climatically suitable habitats and predict future distribution, but the incorporation of anthropogenic variables (e.g., land use, human footprints, anthropogenic structures, etc.) could further improve our understanding of the distribution ecology of this endemic species. Due to the unavailability of future scenarios in anthropogenic variables, this study could not incorporate anthropogenic variables to predict future distribution. Therefore, it is recommended to incorporate future land use scenarios and other important anthropogenic variables for future prediction in the distribution of spiny babbler species in further studies.

CONCLUSION AND IMPLICATION ON CONSERVATION

Our findings provide insight into a crucial aspect of endemic species conservation by uncovering the spiny babbler's climatically suitable habitat and determining the extent to which this species' range may shrink under various future climatic scenarios. With 15% of the total area of Nepal as a potential suitable habitat and the central Mid-Hills region as the largest patch of suitable habitat for this endemic species, we projected a significant reduction (up to 52%) in the habitat of the spiny babbler under future climate scenarios by 2070. The potential distribution of the only endemic bird species in Nepal provides important information for developing critical conservation strategies. The presence of a large extent of suitable habitat within the non-PA region suggests that a species-specific action plan incorporating both PAs and non-PAs is crucial for the spiny babbler's sustainable conservation. Management of existing scrublands and restoration of degraded scrublands within a climatically suitable habitat are imperative for the sustainable conservation of the spiny babbler. Similarly, safeguarding the spiny babbler's habitat against climate change may require locally and regionally focused sustainable conservation policies, adaptive management strategies, and educational outreach among the local communities.

AUTHOR CONTRIBUTIONS

Conceptualization: Binaya Adhikari. *Visualization*: Binaya Adhikari, Suresh Chandra Subedi, and Shivish Bhandari. *Investigation*: Binaya Adhikari. *Data curation*: Binaya Adhikari, Shivish Bhandari, and Sandesh Lamichhane. *Methodology*: Binaya Adhikari and Suresh Chandra Subedi. *Formal analysis*: Binaya Adhikari. *Writing—original draft*: Binaya Adhikari. *Writing—review and editing*: Binaya Adhikari, Suresh Chandra Subedi, Shivish Bhandari, Kedar Baral, Sandesh Lamichhane, and Tek Maraseni. *Resources*: Kedar Baral.

ACKNOWLEDGMENTS

We are thankful to the Department of National Parks and Wildlife Conservation, the Department of Forest and Soil Conservation, protected area offices, and division forest offices for their support throughout the study.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data (Adhikari, 2023) are available from Dryad: https://doi.org/10.5061/dryad.jwstqjqfp.

ORCID

Binaya Adhikari https://orcid.org/0000-0002-1777-5879
Suresh C. Subedi https://orcid.org/0000-0001-8689-0689
Sandesh Lamichhane https://orcid.org/0000-0003-0119-855X

REFERENCES

Adhikari, B. 2023. "Climate-Driven Decline in the Habitat of the Endemic Spiny Babbler (*Turdoides nipalensis*)." Dryad. Dataset. https://doi.org/10.5061/dryad.jwstqjqfp.

Adhikari, B., K. Baral, S. Bhandari, R. M. Kunwar, and S. C. Subedi. 2022. "Prevalence of Mortality in Mammals: A Retrospective Study from Wildlife Rescue Center of Nepal." *Conservation Science and Practice* 4(10): e12799.

Adhikari, B., K. Baral, S. Bhandari, M. Szydlowski, R. M. Kunwar, S. Panthi, B. Neupane, and R. K. Koirala. 2022. "Potential Risk Zone for Anthropogenic Mortality of Carnivores in Gandaki Province, Nepal." *Ecology and Evolution* 12(1): e8491.

Adhikari, B., S. Bhandari, K. Baral, S. Lamichhane, and S. C. Subedi. 2022. "Raptors at Risk: Attributes of Mortality within an Anthropogenic Landscape in the Mid-Hills Region of Nepal." *Global Ecology and Conservation* 38: e02258.

Ahmad, S., L. Yang, T. U. Khan, K. Wanghe, M. Li, and X. Luan. 2020. "Using an Ensemble Modelling Approach to Predict the Potential Distribution of Himalayan Gray Goral (*Naemorhedus goral bedfordi*) in Pakistan." *Global Ecology and Conservation* 21: e00845.

Aiello-Lammens, M. E., R. A. Boria, A. Radosavljevic, B. Vilela, and R. P. Anderson. 2015. "spThin: An R Package for Spatial Thinning of Species Occurrence Records for Use in Ecological Niche Models." *Ecography* 38(5): 541–5.

Ali, S., and S. D. Ripley. 1978. *Handbook of the Birds of India and Pakistan*. Oxford: Oxford University Press.

Allouche, O., A. Tsoar, and R. Kadmon. 2006. "Assessing the Accuracy of Species Distribution Models: Prevalence, Kappa and the True Skill Statistic (TSS)." *Journal of Applied Ecology* 43(6): 1223–32.

Araújo, M. B., and M. New. 2007. "Ensemble Forecasting of Species Distributions." *Trends in Ecology & Evolution* 22(1): 42–7.

Aravind, N. A., and U. Srinivasan. 2010. "Modelling Bird Species Distribution in the Western Ghats, India." *Journal of Biogeography* 37(11): 2089–104.

Avigliano, E., J. J. Rosso, D. Lijtmaer, P. Ondarza, L. Piacentini, M. Izquierdo, et al. 2019. "Biodiversity and Threats in Non-Protected Areas: A Multidisciplinary and Multi-Taxa Approach Focused on the Atlantic Forest." *Heliyon* 5(8): e02292.

Baral, K., B. Adhikari, S. Bhandari, R. M. Kunwar, H. P. Sharma, A. Aryal, and W. Ji. 2023. "Impact of Climate Change on Distribution of Common Leopard (*Panthera pardus*) and Its Implication on Conservation and Conflict in Nepal." *Heliyon* 9: e12807.

Baral, K., S. Bhandari, B. Adhikari, R. M. Kunwar, H. P. Sharma, A. Aryal, and W. Ji. 2022. "Anthropogenic Mortality of Large Mammals and Trends of Conflict over Two Decades in Nepal." *Ecology and Evolution* 12(10): e9381.

Bhandari, S., B. Adhikari, K. Baral, S. Panthi, R. M. Kunwar, T. Thapamagar, M. Psaralexi, D. R. Bhusal, and D. Youlatos. 2022. "Climate Change Threatens Striped Hyena (*Hyaena hyaena*) Distribution in Nepal." *Mammal Research* 67(4): 433–43.

BirdLife International. 2022. "Species Factsheet: *Acanthoptila nipalensis*." http://www.birdlife.org.

BirdLife International. 2023. "Country Profile: Nepal." http://datazone.birdlife.org/country/nepal.

Bladon, A. J., P. F. Donald, N. J. Collar, J. Denge, G. Dadacha, M. Wondafrash, and R. E. Green. 2021. "Climatic Change and Extinction Risk of Two Globally Threatened Ethiopian Endemic Bird Species." *PLoS One* 16(5): e0249633.

Boria, R. A., L. E. Olson, S. M. Goodman, and R. P. Anderson. 2014. "Spatial Filtering to Reduce Sampling Bias Can Improve the Performance of Ecological Niche Models." *Ecological Modelling* 275: 73–7.

Brown, J. A., J. L. Lockwood, J. D. Avery, J. Curtis Burkhalter, K. Aagaard, and K. H. Fenn. 2019. "Evaluating the Long-Term Effectiveness of Terrestrial Protected Areas: A 40-Year Look at Forest Bird Diversity." *Biodiversity and Conservation* 28(4): 811–26.

Burgman, M. A., and J. C. Fox. 2003. "Bias in Species Range Estimates from Minimum Convex Polygons: Implications for Conservation and Options for Improved Planning." *Animal Conservation* 6(1): 19–28.

Cazalis, V., K. Princé, J. B. Mihoub, J. Kelly, S. H. Butchart, and A. S. Rodrigues. 2020. "Effectiveness of Protected Areas in Conserving Tropical Forest Birds." *Nature Communications* 11(1): 1–8.

Chandler, R. B., D. I. King, and C. C. Chandler. 2009. "Effects of Management Regime on the Abundance and Nest Survival of Shrubland Birds in Wildlife Openings in Northern New England, USA." *Forest Ecology and Management* 258(7): 1669–76.

Chapagain, P. S., and T. H. Aase. 2020. "Changing Forest Coverage and Understanding of Deforestation in Nepal Himalayas." *Geographical Journal of Nepal* 13: 1–28.

Chhetri, B., H. K. Badola, and S. Barat. 2018. "Predicting Climate-Driven Habitat Shifting of the Near Threatened Satyr Tragopan (*Tragopan satyra*; Galliformes) in the Himalayas." *Avian Biology Research* 11(4): 221–30.

Chhetri, B., H. K. Badola, and S. Barat. 2021. "Modelling Climate Change Impacts on Distribution of Himalayan Pheasants." *Ecological Indicators* 123: 107368.

Coetzee, B. W., M. P. Robertson, B. F. Erasmus, B. J. Van Rensburg, and W. Thuiller. 2009. "Ensemble Models Predict Important Bird Areas in Southern Africa Will Become Less Effective for Conserving Endemic Birds under Climate Change." *Global Ecology and Biogeography* 18(6): 701–10.

Davies, R. G., C. D. L. Orme, D. Storch, V. A. Olson, G. H. Thomas, S. G. Ross, T.-S. Ding, et al. 2007. "Topography, Energy and the Global Distribution of Bird Species Richness." *Proceedings of the Royal Society B: Biological Sciences* 274(1614): 1189–97.

De Camargo, R. X., V. Boucher-Lalonde, and D. J. Currie. 2018. "At the Landscape Level, Birds Respond Strongly to Habitat Amount but Weakly to Fragmentation." *Diversity and Distributions* 24(5): 629–39.

del Hoyo, J., A. Elliott, and D. A. Christie, eds. 2017. *Handbook of the Birds of the World Alive*. Barcelona: Lynx Edicions.

DFRS. 2015. *State of Nepal's Forests. Forest Resource Assessment (FRA) Nepal*. Kathmandu: Department of Forest Research and Survey (DFRS).

Dimson, M., S. C. Lynch, and T. W. Gillespie. 2019. "Using Biased Sampling Data to Model the Distribution of Invasive Shot-Hole Borers in California." *Biological Invasions* 21(8): 2693–712.

Dirnböck, T., F. Essl, and W. Rabitsch. 2011. "Disproportional Risk for Habitat Loss of High-Altitude Endemic Species under Climate Change." *Global Change Biology* 17(2): 990–6.

DNPWC and DFSC. 2018. *Pheasant Conservation Action Plan for Nepal (2019–2023)*. Kathmandu: Department of National Parks and Wildlife Conservation and Department of Forests and Soil Conservation.

DNPWC and DFSC. 2022. *Status of Tigers and Prey in Nepal 2022*. Kathmandu: Department of National Parks and Wildlife Conservation and Department of Forests and Soil Conservation. Ministry of Forests and Environment.

Duan, H., X. Yu, S. Xia, and Y. Liu. 2022. "Comparison of IUCN and Species Distribution Modeling-Estimated Ranges of Shorebirds in Coastal Mainland China." *Global Ecology and Conservation* 38: e02236.

Elith, J., and J. R. Leathwick. 2009. "Species Distribution Models: Ecological Explanation and Prediction across Space and Time." *Annual Review of Ecology, Evolution and Systematics* 40(1): 677–97.

Eyring, V., S. Bony, G. A. Meehl, C. A. Senior, B. Stevens, R. J. Stouffer, and K. E. Taylor. 2016. "Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) Experimental Design and Organization." *Geoscientific Model Development* 9(5): 1937–58.

Fick, S. E., and R. J. Hijmans. 2017. "WorldClim 2: New 1-km Spatial Resolution Climate Surfaces for Global Land Areas." *International Journal of Climatology* 37(12): 4302–15.

Fox, J., and S. Weisberg. 2019. *An R Companion to Applied Regression*, 3rd ed. Thousand Oaks, CA: Sage. https://socialsciences.mcmaster.ca/jfox/Books/Companion/.

Garcia-R, J. C., and M. Di Marco. 2020. "Drivers and Trends in the Extinction Risk of New Zealand's Endemic Birds." *Biological Conservation* 249: 108730.

GBIF.org. 2022. "GBIF Occurrence Download." https://doi.org/10.15468/dl.m4b9qp.

Gill, P. 2019. "In Nepal Out-Migration Is Helping to Fuel a Forest Resurgence." Yale Environment 360. https://e360.yale.edu/features/in-nepal-out-migration-is-helping-fuel-a-forest-resurgence.

Griffith, B., J. M. Scott, R. Adamcik, D. Ashe, B. Czech, R. Fischman, P. Gonzalez, J. Lawler, A. D. McGuire, and A. Pidgorna. 2009. "Climate Change Adaptation for the US National Wildlife Refuge System." *Environmental Management* 44(6): 1043–52.

Guillera-Arroita, G., J. J. Lahoz-Monfort, J. Elith, A. Gordon, H. Kujala, P. E. Lentini, M. A. McCarthy, R. Tingley, and B. A. Wintle. 2015. "Is My Species Distribution Model Fit for Purpose? Matching Data and Models to Applications." *Global Ecology and Biogeography* 24(3): 276–92.

Hambuckers, A., S. de Harenne, E. Rocha Ledezma, L. Zúñiga Zeballos, and L. François. 2021. "Predicting the Future Distribution of *Ara rubrogenys*, an Endemic Endangered Bird Species of the Andes, Taking into Account Trophic Interactions." *Diversity* 13(2): 94.

Hao, T., J. Elith, G. Guillera-Arroita, and J. J. Lahoz-Monfort. 2019. "A Review of Evidence about Use and Performance of Species Distribution Modelling Ensembles like BIOMOD." *Diversity and Distributions* 25(5): 839–52.

Hausfather, Z., and G. P. Peters. 2020. "Emissions–The 'Business as Usual'story Is Misleading." *Nature* 577(7792): 618–20.

Hoffmann, D., M. F. de Vasconcelos, and G. W. Fernandes. 2020. "The Fate of Endemic Birds of Eastern Brazilian Mountaintops in the Face of Climate Change." *Perspectives in Ecology and Conservation* 18(4): 257–66.

Inskipp, C., and H. S. Baral. 2022. "Spiny Babbler (*Turdoides nipalensis*), Version 2.0." In *Birds of the World*, edited by S. M. Billerman. Ithaca, NY: Cornell Lab of Ornithology. https://doi.org/10.2173/bow.spibab1.02.

Inskipp, C., and T. P. Inskipp. 1991. *A Guide to the Birds of Nepal*, 2nd ed. London: Christopher Helm.

Kanel, K. R., and B. R. Kandel. 2004. "Community Forestry in Nepal: Achievements and Challenges." *Journal of Forest and Livelihood* 4(1): 55–63.

Karra, K., C. Kontgis, Z. Statman-Weil, J. Mazzariello, M. Mathis, and S. Brumby. 2021. "Global Land Use/Land Cover with Sentinel-2 and Deep Learning." IGARSS 2021–2021 IEEE International Geoscience and Remote Sensing Symposium.

King, D. I., R. B. Chandler, S. Schlossberg, and C. C. Chandler. 2009. "Habitat Use and Nest Success of Scrub-Shrub Birds in Wildlife and Silvicultural Openings in Western Massachusetts, USA." *Forest Ecology and Management* 257(2): 421–6.

Kramer-Schadt, S., J. Niedballa, J. D. Pilgrim, B. Schröder, J. Lindenborn, V. Reinfelder, M. Stillfried, et al. 2013. "The Importance of Correcting for Sampling Bias in MaxEnt Species Distribution Models." *Diversity and Distributions* 19(11): 1366–79.

Kunwar, R. M., B. Baral, S. Luintel, Y. Uprety, R. C. Poudel, B. Adhikari, et al. 2022. "Ethnomedicinal Landscape: Distribution of Used Medicinal Plant Species in Nepal." *Journal of Ethnobiology and Ethnomedicine* 18(1): 34.

Kunwar, R. M., K. B. Thapa-Magar, S. C. Subedi, D. H. Kutal, B. Baral, N. R. Joshi, B. Adhikari, et al. 2023. "Distribution of Important Medicinal Plant Species in Nepal under Past, Present, and Future Climatic Conditions." *Ecological Indicators* 146: 109879.

Lele, S., P. Wilshusen, D. Brockington, R. Seidler, and K. Bawa. 2010. "Beyond Exclusion: Alternative Approaches to Biodiversity Conservation in the Developing Tropics." *Current Opinion in Environmental Sustainability* 2(1–2): 94–100.

León-Ortega, M., J. E. Martínez, E. Pérez, J. A. Lacalle, and J. F. Calvo. 2017. "The Contribution of Non-Protected Areas to the Conservation of Eurasian Eagle-Owls in Mediterranean Ecosystems." *Ecosphere* 8(9): e01952.

Liang, C., J. Liu, B. Pan, N. Wang, J. Yang, G. Yang, and G. Feng. 2020. "Precipitation Is the Dominant Driver for Bird Species Richness, Phylogenetic and Functional Structure in University Campuses in Northern China." *Avian Research* 11(1): 1–8.

Lissovsky, A. A., S. V. Dudov, and E. V. Obolenskaya. 2021. "Species-Distribution Modeling: Advantages and Limitations of Its Application. 1. General Approaches." *Biology Bulletin Reviews* 11(3): 254–64.

Lobo, J. M., A. Jiménez-Valverde, and R. Real. 2008. "AUC: A Misleading Measure of the Performance of Predictive Distribution Models." *Global Ecology and Biogeography* 17(2): 145–51.

Malhi, Y., T. Lander, E. le Roux, N. Stevens, M. Macias-Fauria, L. Wedding, C. Girardin, et al. 2022. "The Role of Large Wild Animals in Climate Change Mitigation and Adaptation." *Current Biology* 32(4): R181–96.

Manes, S., M. J. Costello, H. Beckett, A. Debnath, E. Devenish-Nelson, K. A. Grey, R. Jenkins, et al. 2021. "Endemism Increases Species' Climate Change Risk in Areas of Global Biodiversity Importance." *Biological Conservation* 257: 109070.

Marmion, M., M. Parviainen, M. Luoto, R. K. Heikkinen, and W. Thuiller. 2009. "Evaluation of Consensus Methods in Predictive Species Distribution Modelling." *Diversity and Distributions* 15(1): 59–69.

Marshall, D. J., C. D. McQuaid, and G. A. Williams. 2010. "Non-Climatic Thermal Adaptation: Implications for Species' Responses to Climate Warming." *Biology Letters* 6(5): 669–73.

Meller, L., M. Cabeza, S. Pironon, M. Barbet-Massin, L. Maiorano, D. Georges, and W. Thuiller. 2014. "Ensemble Distribution Models in Conservation Prioritization: From Consensus Predictions to Consensus Reserve Networks." *Diversity and Distributions* 20(3): 309–21.

Neate-Clegg, M. H., T. R. Stanley, Ç. H. Şekercioğlu, and W. D. Newmark. 2021. "Temperature-Associated Decreases in Demographic Rates of Afrotropical Bird Species over 30 Years." *Global Change Biology* 27(10): 2254–68.

Norbu, L., P. Thinley, T. Wangchuck, U. Dechen, L. Dorji, T. Choephel, and P. Dorji. 2021. "On the High Bird Diversity in the Non-Protected Regions of Trashiyangtse District in Bhutan." *Journal of Threatened Taxa* 13(9): 19274–92.

Olalla-Tárraga, M. A., D. Oro, E. Gómez-Díaz, M. P. Delgado, and J. A. Donázar. 2016. "Identification of Priority Areas for the Conservation of the Andean Condor: A Multi-Scale Approach." *Biological Conservation* 200: 365–74.

Paudel, P. K., J. Sipos, and J. F. Brodie. 2018. "Threatened Species Richness along a Himalayan Elevational Gradient: Quantifying the Influences of Human Population Density, Range Size, and Geometric Constraints." *BMC Ecology* 18(1): 1–8.

Paudel, B., Y. L. Zhang, S. C. Li, L. S. Liu, X. Wu, and N. R. Khanal. 2016. "Review of Studies on Land Use and Land Cover Change in Nepal." *Journal of Mountain Science* 13(4): 643–60.

Peters, H., B. C. O'Leary, J. P. Hawkins, and C. M. Roberts. 2015. "Identifying Species at Extinction Risk Using Global Models of Anthropogenic Impact." *Global Change Biology* 21(2): 618–28.

Pouteau, R., C. Brunel, W. Dawson, F. Essl, H. Kreft, B. Lenzner, C. Meyer, et al. 2022. "Environmental and Socioeconomic Correlates of Extinction Risk in Endemic Species." *Diversity and Distributions* 28(1): 53–64.

Proud, D. 1959. "Notes on the Spiny Babbler, *Acanthoptila nipalensis* (Hodgson), in the Nepal Valley." *Journal of the Bombay Natural History Society* 56: 330–2.

R Core Team. 2020. *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.

Radford, J. Q., A. F. Bennett, and G. J. Cheers. 2005. "Landscape-Level Thresholds of Habitat Cover for Woodland-Dependent Birds." *Biological Conservation* 124(3): 317–37.

Riahi, K., D. P. Van Vuuren, E. Kriegler, J. Edmonds, B. C. O'neill, S. Fujimori, N. Bauer, et al. 2017. "The Shared Socioeconomic Pathways and Their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview." *Global Environmental Change* 42: 153–68.

Rogelj, J., A. Popp, K. V. Calvin, G. Luderer, J. Emmerling, D. Gernaat, S. Fujimori, et al. 2018. "Scenarios towards Limiting Global Mean Temperature Increase below 1.5°C." *Nature Climate Change* 8(4): 325–32.

Santos, K. C., J. Pino, F. Rodà, M. Guirado, and J. Ribas. 2008. "Beyond the Reserves: The Role of Non-Protected Rural Areas for Avifauna Conservation in the Area of Barcelona (NE of Spain)." *Landscape and Urban Planning* 84(2): 140–51.

Schwalm, C. R., S. Glendon, and P. B. Duffy. 2020. “RCP8.5 Tracks Cumulative CO_2 Emissions.” *Proceedings of the National Academy of Sciences of the United States of America* 117(33): 19656–7.

Şekercioğlu, Ç. H., R. B. Primack, and J. Wormworth. 2012. “The Effects of Climate Change on Tropical Birds.” *Biological Conservation* 148(1): 1–18.

Sharma, H. P., B. Adhikari, S. Bhandari, K. Baral, and R. M. Kunwar. 2021. “Crab-Eating Mongoose *Herpestes urva*: Occurrence and Its Activity in Mid-Hills of Nepal.” *Journal of Institute of Science and Technology* 26(2): 53–60.

Sierra-Morales, P., O. Rojas-Soto, C. A. Ríos-Muñoz, L. M. Ochoa-Ochoa, P. Flores-Rodríguez, and R. C. Almazán-Núñez. 2021. “Climate Change Projections Suggest Severe Decreases in the Geographic Ranges of Bird Species Restricted to Mexican Humid Mountain Forests.” *Global Ecology and Conservation* 30: e01794.

Sofaer, H. R., C. S. Jarnevich, I. S. Pearse, R. L. Smyth, S. Auer, G. L. Cook, T. C. Edwards, et al. 2019. “Development and Delivery of Species Distribution Models to Inform Decision-Making.” *BioScience* 69(7): 544–57.

Soldatini, C., Y. V. Albores-Barajas, and B. Pellizzi. 2010. “Habitat Preferences of High-Altitude Galliformes in Sagarmatha National Park, Nepal.” *Italian Journal of Zoology* 77(3): 347–53.

Stattersfield, A. J., M. J. Crosby, A. J. Long, and D. C. Wege. 1998. *Endemic Bird Areas of the World: Priorities for Biodiversity Conservation*. BirdLife Conservation Series 7. Cambridge: BirdLife International.

Subedi, S. C., S. C. Walls, W. J. Barichivich, R. Boyles, M. S. Ross, J. A. Hogan, and J. A. Tupy. 2022. “Future Changes in Habitat Availability for Two Specialist Snake Species in the Imperiled Rocklands of South Florida, USA.” *Conservation Science and Practice* 4(10): e12802.

Thakuri, R. 2020. “Population, Status, Distribution and Threats Assessment of Spiny Babbler (*Turdoides nipalensis*) in Lwang-Ghalel Area of Annapurna Conservation Area.” PhD diss., Tribhuvan University, Institute of Forestry.

Thapa, A., P. K. Pradhan, B. D. Joshi, T. Mukherjee, M. Thakur, K. Chandra, and L. K. Sharma. 2021. “Non-Protected Areas Demanding Equitable Conservation Strategies as of Protected Areas in the Central Himalayan Region.” *PLoS One* 16(8): e0255082. https://doi.org/10.1371/journal.pone.0255082.

Thompson, I. 1988. “A Proposed Scrubland Management Regime.” *Banko Janakari* 2(1): 5–8.

Thuiller, W., B. Lafourcade, R. Engler, and M. B. Araújo. 2009. “BIOMOD—A Platform for Ensemble Forecasting of Species Distributions.” *Ecography* 32(3): 369–73.

Uddin, K., H. L. Shrestha, M. S. R. Murthy, B. Bajracharya, B. Shrestha, H. Gilani, S. Pradhan, and B. Dangol. 2015. “Development of 2010 National Land Cover Database for the Nepal.” *Journal of Environmental Management* 148: 82–90.

Veloz, S. D. 2009. “Spatially Autocorrelated Sampling Falsely Inflates Measures of Accuracy for Presence-Only Niche Models.” *Journal of Biogeography* 36(12): 2290–9.

Vetaas, O. R., and J. A. Grytnes. 2002. “Distribution of Vascular Plant Species Richness and Endemic Richness along the Himalayan Elevation Gradient in Nepal.” *Global Ecology and Biogeography* 11(4): 291–301.

Virkkala, R., A. Rajasärkkä, R. A. Väisänen, M. Vickholm, and E. Virolainen. 1994. “The Significance of Protected Areas for the Land Birds of Southern Finland.” *Conservation Biology* 8(2): 532–44.

Walther, B. A., J. R. J. Chen, H. S. Lin, and Y. H. Sun. 2017. “The Effects of Rainfall, Temperature, and Wind on a Community of Montane Birds in Shei-Pa National Park, Taiwan.” *Zoological Studies* 56: e23.

Wu, J. 2020. “The Changes in Suitable Habitats for 114 Endemic Bird Species in China during Climate Warming Will Depend on the Probability.” *Theoretical and Applied Climatology* 141(3): 1075–91.

Young, J., A. Watt, P. Nowicki, D. Alard, J. Clitherow, K. Henle, R. Johnson, et al. 2005. “Towards Sustainable Land Use: Identifying and Managing the Conflicts between Human Activities and Biodiversity Conservation in Europe.” *Biodiversity and Conservation* 14: 1641–61.

Yousefi, M., M. Ahmadi, E. Nourani, A. Rezaei, A. Kafash, A. Khani, M. E. Sehhatisabet, M. A. Adibi, F. Goudarzi, and M. Kaboli. 2017. “Habitat Suitability and Impacts of Climate Change on the Distribution of Wintering Population of Asian Houbara Bustard *Chlamydotis macqueenii* in Iran.” *Bird Conservation International* 27(2): 294–304.

Zuur, A. F., E. N. Ieno, and C. S. Elphick. 2010. “A Protocol for Data Exploration to Avoid Common Statistical Problems.” *Methods in Ecology and Evolution* 1(1): 3–14.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Adhikari, Binaya, Suresh C. Subedi, Shivish Bhandari, Kedar Baral, Sandesh Lamichhane, and Tek Maraseni. 2023. “Climate-Driven Decline in the Habitat of the Endemic Spiny Babbler (*Turdoides Nipalensis*).” *Ecosphere* 14(6): e4584. https://doi.org/10.1002/ecs2.4584