Habitat suitability assessment for the endangered Nilgiri Laughingthrush: A multiple logistic regression approach

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Application of remote sensing and Geographic Information System (GIS) tools has assumed an increasingly important role in conservation biology and wildlife management by providing means for modelling potential distributions of species and their habitats, unlike the conventional ground surveys. We present here a predictive model of habitat suitability for the Nilgiri Laughingthrush, *Garrulax cachinnans* based on a synergistic use of field surveys and digitally processed satellite imagery combined with features mapped using GIS data layers. Collateral data were created in a GIS framework based on ground surveys comprising layers such as land-use, measures of proximity to likely features of disturbance and a digital terrain model. Multiple binomial logistic regression approach was used for modelling, and the model performance was assessed by the area under the receiver operating characteristics (ROC) curve.

About 320 km^2, 25.12% of the area of the Nilgiris considered for modelling was predicted to be suitable for the Nilgiri Laughingthrush. The area under the ROC curve was found to be 0.984 ± 0.003 (R^2: 0.93 at $P < 0.0001$), implying a highly effective model. The assessed suitable habitat was highly fragmented and comprised of 1352 patches (natural as well as man-made) distributed all over the study area. The smallest suitable patch identified by the model was 400 m^2 and the largest patch 17.65 km^2. Also, ca. 92% of all patches were smaller than 0.5 km^2. We presume that some suitable habitat patches may be unoccupied due to strong fidelity of the species to shola (montane wet temperate forest) patches, low colonization rates, or large inter-fragment distances. Also, larger fragments might serve as source or 'exporters' of surplus individuals to maintain sink populations throughout the rest of the range. We discuss the implication of habitat fragmentation and narrow geographical range and anthropogenic pressure for the conservation of the Nilgiri Laughingthrush.

Keywords: Field surveys, habitat suitability, logistic regression model, Nilgiri Laughingthrush.

UNDERSTANDING the links between animal distribution and habitat plays a pivotal role in designing management for threatened species[1]. While an understanding of habitat preferences is important to improve ecological knowledge about a species, information on the spatial distribution of suitable habitat within their distribution range can help in developing conservation strategies at landscape level[2]. GIS tools have thus assumed an increasingly important role in conservation biology and wildlife management by providing means for quantitative modelling of potential habitat of a species. They also help in monitoring areas of land for their suitability to endangered species, through integration of various habitat variables of both spatial and non-spatial nature[3]. The outputs of such models are usually simple, easily understandable and can be used for the assessment of environmental impacts or prioritization of conservation efforts in a timely and cost-effective manner[4].

The Nilgiri Laughingthrush, *Garrulax cachinnans* is classified as endangered owing to its restricted range and habitat loss[5]. Its global population is principally confined to the Nilgiri Hills, Tamil Nadu, India. Once abundant, its shola habitat witnessed significant loss and fragmentation during the 19th and 20th centuries. Besides, the remnant habitat faces severe biotic pressures from grazing, lopping, clear-felling and encroachment. Beside, no quantitative data exist on its habitat ecology that permit an adequate assessment of these potential threats. There is little information on the patterns of threats and the geographic distribution of potential habitats within its geographical distribution range. Under such circumstances, the long-term status of this curiously restricted-range endemic species is threatened. Remedial measures are being delayed, partly due to lack of good data pertaining to the life histories, population dynamics and suitable habitats of the Nilgiri Laughingthrush.

We used data from field surveys, satellite data (LISS-111), statistical and GIS tools to develop a habitat suit-

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ability model for the Nilgiri Laughingthrush, predicting the extent of suitable habitat, patch size and distribution of suitable habitat fragments. We followed the multiple logistic regression modelling procedure. This procedure has been adopted for wildlife habitat modelling in several studies[2,4,6]. The scope of its applicability can further be understood from its use in predicting insect distribution within fragmented landscapes, to investigate relationships between local extinctions and habitat suitability[7], to investigate the local population distribution and decline[1], and to describe the effects of habitat characteristics on the incidence of particular species[8].

Study area

The Nilgiris is a component of the Western Ghats mountain range in India, which is recognized as one of the hotspots of biological diversity in the world[9]. The region is also one of the 200 globally most important ecoregions, and an Endemic Bird Area with 16 species of restricted-range birds[10]. According to a recent evaluation, the Western Ghats supports one endangered (Nilgiri Laughingthrush), three vulnerable, and seven near-threatened bird species[5]. The study area includes Mukurti National Park (78.46 km^2), and is a part of the Nilgiri Biosphere Reserve. Eight Important Bird Areas (IBAs) were identified recently from the upper Nilgiris[11]. The region faces severe threat from deforestation, developmental activities, conversion to plantations and habitat fragmentation.

The Nilgiris forms the main watershed for two important tributaries (Bhavani and Moyar) of the Cauvery river. It occupies the highest and the westernmost part of Tamil Nadu and lies in Zone-5 (Western Ghats) in the biogeographic classification of India[12]. It is bounded by Kerala on the west, Karnataka on the north, and Coimbatore District on the southeast (Figure 1). The upper Nilgiris plateau rises sharply from the surrounding country and is divided by a range of peaks running in a general north-south direction, the highest being Dodabetta (2634 m), which is also the second highest peak in the Western Ghats, after Anaimudi (2695 m). The area receives both southwest and northeast monsoons. There is considerable local variation in average annual rainfall in the study area, with the western Mukurti National Park and surroundings recording up to 5600 mm rainfall per year.

Figure 1. Location of the Nilgiri Hills in India.

The vegetation of the upper Nilgiris can be broadly classified into southern montane wet forest, grasslands and plantations. Southern montane wet forest type, classified as subgroup 11A/type C1 is popularly known as shola[13]. Presently, most of the forested areas in the Nilgiris are under plantation, with very little shola cover left. Grasslands located at elevation areas[13] fall under subgroup 11A type C1. Once common on the entire upper Nilgiris plateau, the grasslands are presently confined to the Mukurti National Park and few other places. Exotic species, such as wattle (*Acacia* spp.), bluegum (*Eucalyptus* spp.) and pine (*Pinus* spp.), were planted after clear-felling of natural forests and burning of grasslands. Tea (*Camellia sinensis*) plantations are a predominant feature of the landscape of the Nilgiris.

Area considered for modelling

The complete historical range of the Nilgiri Laughingthrush starting at 1200 m elevation on the north, east and south of the Nilgiris has been considered for the modelling. The Mukurti National Park (ranging from 2200 to 2500 m amsl) lies towards the southwest of the modelled area. Geographically the study area lies between longitues 76°26′30.44″ and 77°00′14.35″, latitudes 11°32′35.36″ and 11°11′01.67″, and covers an area of 1277 km^2.

Methods and analyses

Image processing and database creation

Elevation, aspect and slope were derived from the Survey of India (SOI) toposheets at a scale of 1 : 50,000. Toposheets employed were: 58 A/7, A/8, A/10, A/11, A/12, A/14 and A/15. Contours extracted from toposheets were used to generate a Digital Elevation Model (DEM) of the study region with ERDAS Imagine (ver. 8.4) software. Surface analysis of the DEM in ERDAS provided slope and aspect information at each sampled location. Settlement pattern, stream network and road coverage were also extracted from traced SOI toposheets. These layers, after suitable pre-processing, were used as independents in the logistic regression analysis (Table 1).

Indian Remote Sensing Satellite IRS-1D, Linear Imaging Self-Scanning (LISS-III) image of path 99 and row 65 with a ground resolution of 23.5 m acquired on 8 December 2000, was used to digitally segment the area into dif-

Table 1. Independent variables used in the model

Variable	Source	Pre-processing applied
Elevation	Contour map	Inverse distance weighted interpolation
Drainage	Toposheets	Distance function
Settlement	-do-	-do-
All roads	-do-	-do-
Metalled roads	-do-	-do-
Aspect	Elevation map derivative	First derivative of the elevation
Slope	-do-	-do-
Canopy density	Satellite imagery	Visual interpretation
Forest type	-do-	Maximum likelihood classification of scene
Shola edge distance	Forest-type derivative	Distance function

ferent habitat types. The image was radiometrically and geometrically restored using standard procedures. Fieldwork for ground verification of habitat types was undertaken between March and July 2003. The image was classified using maximum likelihood classification algorithm in ERDAS Imagine. Ten broad categories, viz. shola, grasslands, wattle, eucalyptus, pine, settlement, cultivation, scrub, waterbodies and fallow land were identified. The canopy density was analysed visually and the area segmented into four classes of 0–10, 10–40, 40–70 and >70% canopy closures respectively.

Nilgiri Laughingthrush habitat survey

An intensive survey of the Nilgiri Laughingthrush was conducted from May 2001 to May 2004 across the entire study area. The survey was conducted from 1400 to 2600 m. The surveys were conducted both in the breeding and non-breeding seasons. Breeding-season surveys were conducted primarily for locating nesting sites, while surveys in the non-breeding season were mainly concerned with assessment of the larger presence or absence across the study area. Locations where the Nilgiri Laughingthrush was detected during surveys were considered suitable, while locations where the species was not detected even after intensive checks were considered unsuitable. Only locations that were searched intensively were included to make it unlikely that plots containing Nilgiri Laughingthrush were misclassified as not containing the bird. This was important since the entire mapping exercise rests on a low probability of false negatives.

A total of 871 location data were collected, including 528 locations where the Nilgiri Laughingthrush was present and 343 where it was absent. On each sighting, the geographic location of the site was recorded using a Global Positioning System (GPS). For unbiased comparison, random and geographically stratified points were generated to sample the Upper Nilgiris plateau and to reduce the effects of spatial autocorrelation (i.e. to reduce the probability of using adjacent pixels). The number of random points selected was seen as important and also their prevalence (i.e. the ratio of positive to negative pixels) affects model outcomes[2,14].

Habitat modelling

Ten predictor (independent) variables (Table 1) in the dataset were seen as probable proxies for satellite and GIS-derived data and were used as predictors in the analysis. In view of the observed shola-edge preference by the Nilgiri Laughingthrush, the distance from shola edge was also incorporated as a predictor variable. Individual cases of sightings were considered as Boolean (presence/absence) and binomial multiple logistic regression was used (Logistic regression is employed for estimating event probabilities when the dependent is dichotomous (here the presence or absence of the bird). The independent variables can be both interval and categorical (such as distance from water source and forest type).) The regression coefficients obtained were used for integrating the spatial layers and the result was aggregated using a logit transformation $[P = \{\exp(a + BX...)/1 + (\exp(a + BX...)\}]$ to obtain the probabilistic map of habitat use.

We used a likelihood-ratio reduction constrained backward stepwise variable selection procedure for model selection. It was observed that the significance of categorical variables such as forest type suffered due to low degrees of freedom. Hence, we converted the forest-type variable into an indicator variable specifying whether a point fell in a shola patch.

Results of logistic regression models are often judged as successful if predicted probabilities, i.e. $P > 0.5$ correspond with observed occurrence and values $P < 0.5$ with absence. However, this dichotomy is arbitrary and lacks ecological basis[2]. Contemporary techniques entail the assessment of the model success across the full range of dichotomies using receiver operating characteristics (ROC) plot. A ROC curve plots sensitivity, the proportion of true positives correctly predicted by the model, against specificity, the proportion of predicted true negatives. The ROC curve is therefore a graphical representation of the trade-off between the false negative and false positive rates for every possible probability cut-off. The accuracy of a test, i.e. its ability to correctly classify cases is measured by the area under the ROC curve. A ROC curve was generated in order to see the 'strength of conviction' of probability logistic regression scores that a subject (pixel) falls into one category or another (presence or absence of Nilgiri Laughingthrush in this case). The area under the ROC curve (AUC) varies from 0.5 (for a chance performance) to 1.0 for a perfect fit[2]. We generated the ROC plot using SPSS and calculated the AUC and its standard error using a non-parametric approach. The results are reported here as AUC ± its standard error along with the significance of a test that the area = 0.5, i.e. that the model result does not differ from chance.

Generally two types of errors enter into modelling procedures and geographic prediction efforts; first, the omission and second the commission errors. Certain properties of our sampling method might have biased our results, primarily due to different detectabilities among different habitats during different seasons. Nevertheless, we consider our sample, both in spatial and temporal scales, to be robust enough to be effective in nullifying minor biases. Also some spurious significance is likely, but the results seem reasonable and consistent with theory and field observations.

Results

Habitat suitability

The land-cover map derived from satellite imagery suggests that the study area is highly fragmented into a lattice of settlements, tea plantations, cultivations, water reservoirs, grasslands and other landscape features that do not form usable habitat for the Nilgiri Laughingthrush. The logistic regression model results indicate ca. 320 km^2 of the study area as suitable habitat for the Nilgiri Laughingthrush. The model predictions are given in Figure 2. However, the predicted suitable area is highly fragmented and comprises of 1352 such fragments distributed across the study area. Most of the suitable patches are concentrated towards the west and southwest of the Nilgiris near the Mukurti National Park, not surprisingly, an area with minimal human disturbance. Coefficients of the final model are given in Table 2.

The final model:

$$Y \sim \text{constant} + B1^*(\text{aspect}^{\#}) + B2^*(\text{canopy density}^{\#}) + B3^*(\text{distance to shola}) + B4^*(\text{distance to drainage}) + B5^*(\text{distance to settlements}) + B6^*(\text{shola patch}^{\$}),$$

$$P \sim \text{logit}(Y) = \log(1/(1 + \exp(-Y))).$$

$^{\#}$Categorical variables; $^{\$}$Indicador (dummy) variable.

The AUC statistics was 0.984 ± 0.003, signifying a highly significant model fit with both commission and omission errors contained at a very high level.

Size of suitable habitat fragments

A size-class distribution of different suitable habitat patches is presented in Figure 3. The smallest suitable patch for the Nilgiri Laughingthrush was 400 m^2 and the largest was 17.64 km^2. Of the total 1352 patches found suitable in this model, the majority (~93%) were equal to or smaller than 0.5 km^2 (Table 3).

Discussion

Starting with the premise that the Nilgiri Laughingthrush habitat suitability may be related to vegetation, topography and human influences, digital datasets that could characterize these features were selected. The analysis carried out subsequently successfully predicted the occurrence of the Nilgiri Laughingthrush at the landscape scale in the Nilgiris, with most of the variables used found to be significant predictors. The assessed strength of the model also indicated high classification accuracies. It is important to note that, though the Nilgiri Laughingthrush is thought to be shola-dependent, it also utilizes wattle plantations and mixed habitat (dominated by native shrubs) in the vicinity of the shola. However, the pattern of use differs over time of the day as well as season. The overall suitable habitat for the Nilgiri Laughingthrush in the model output captures such locations too.

Although around 25.12% of the study area was found to be potentially suitable for the Nilgiri Laughingthrush, the potentially suitable habitat for nesting would be less than the overall suitable area, as nesting is primarily seen along shola edges. Plantations having no shola within 300 m

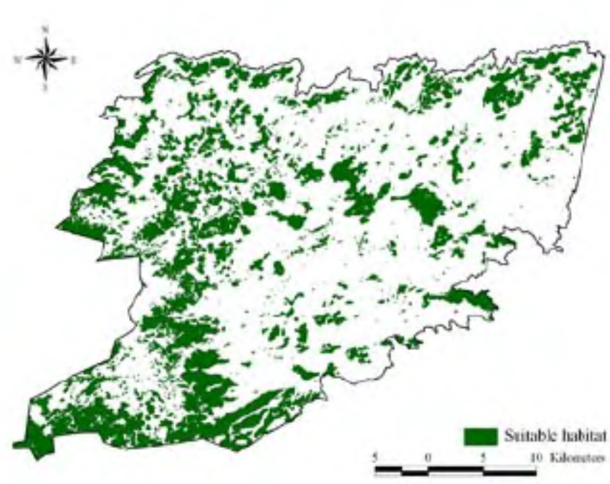

Figure 2. Habitat suitability map for the Nilgiri Laughingthrush.

Table 2. Summary results of the logistic regression analysis carried on GIS data layers

Predictor	*B*	SE (*B*)	Wald	D*f*	*P*	Exp(*B*)
Aspect of slope			16.592	8	0.035	
N	–1.8206	0.801	5.165	1	0.023	0.162
NE	–0.9542	0.796	1.437	1	0.231	0.385
E	0.2856	0.789	0.131	1	0.717	1.331
SE	–1.8708	1.150	2.648	1	0.104	0.154
S	–1.1530	1.069	1.164	1	0.281	0.316
SW	–1.3266	1.087	1.489	1	0.222	0.265
W	–2.1472	1.031	4.335	1	0.037	0.117
NW	–2.8114	1.069	6.911	1	0.009	0.060
Canopy density			63.132	3	<0.001	
0–10%	4.1827	0.747	31.339	1	<0.001	65.547
10–40%	4.1827	0.662	18.595	1	<0.001	17.362
40–100%	–0.9165	0.715	1.642	1	0.200	0.400
Distance to shola	–0.0165	0.003	38.545	1	<0.001	0.984
Distance to drainage	–0.0048	0.002	8.003	1	0.005	0.995
Distance to settlements	0.0004	0.00025	3.504	1	0.061	1.000
Shola patch (indicator)	4.3404	0.727	35.681	1	<0.001	76.743
Constant	0.3273	0.878	0.139	1	0.709	1.387

Table 3. Patch sizes of suitable habitat of the Nilgiri Laughingthrush

Range (ha)	Frequency	Percentage	Cumulative percentage
0–0.50	418	30.92	30.92
0.50–5	598	44.23	75.15
5–50	237	17.53	92.68
50–500	86	6.36	99.04
500–5000	13	0.96	100.00
Total	1352	100.00	

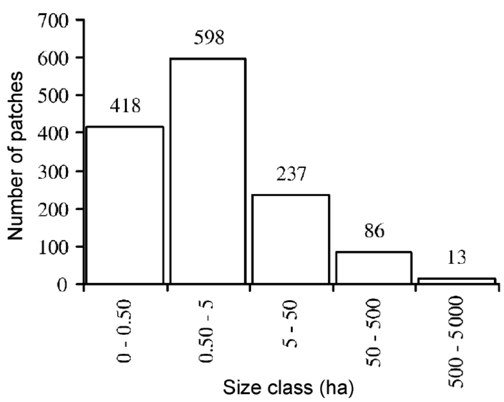

Figure 3. Size-class distribution of potentially suitable habitat patches for the Nilgiri Laughingthrush.

are generally not used by the Nilgiri Laughingthrush. To demonstrate this effect, the variable 'distance from the nearest shola edge' has been incorporated as one of the ten variables for the model. Thus, a wattle patch located far from the shola is predicted unsuitable, unlike the one located adjacent to the shola. The negative correlation of the suitable site with increasing distance from the shola edge observed in the results is thus quite expected.

The effects of topographic features, aspect of slope, appear to have a significant impact in the model. Such an effect may not be a direct influence, because of the occurrence of shola over some aspects. Slope of terrain, elevation and distance to settlements also appear to have significant influence in suitable habitat selection. For finer scale modelling, terrain and human influences are suggested to be significant predictors[2]. The results clearly indicate that the occurrence and distribution of the Nilgiri Laughingthrush is influenced by the landscape features. Even common birds are reported to be sensitive to variation in the habitat and landscape.

The Nilgiri Laughingthrush does occupy moderately disturbed shola patches close to settlements, but avoids highly disturbed urban settings. The results also indicate a negative influence of the proximity of roads on site selection. This has been reported for many other birds such as willow warblers, *Phylloscopus trochilus*[15]. This was one of the factors for the concentration of suitable patches towards the west and southeast of the study areas, which face minimal anthropogenic pressures owing to few settlements and a relatively low road density.

Implications of fragmented habitat for Nilgiri Laughingthrush

Habitat fragmentation is the most critical conservation concern to conservation biologists, particularly in regions with tropical rainforests, which are the greatest living treasuries of biological diversity on earth[16]. Enormous literature exists on the effects of habitat fragmentation on plant and animal communities in the tropics[17,18]. The effects of forest fragmentation on avian populations have been assessed by various researchers[19,20]. Most of such work was focused on the breeding season or the Neotropical migrants, with fewer studies directed towards permanent resident species, especially during the non-breeding season[19].

The Nilgiri Hills typify many of the conservation problems posed by habitat fragmentation. A recent estimate puts the loss and conversion of the original natural vegetation of the Western Ghats during 1920–90 to be around 40%, with an annual rate of deforestation to be around 0.57% and a fourfold increase in the number of fragments[21]. The leading causes of fragmentation in the study are tea, wattle and *Eucalyptus* plantations. Although most of the shola patches in the Nilgiris are naturally small, there is considerable human-induced fragmentation mainly in the vicinity of the settlements.

A great majority of the total 1352 fragments found potentially suitable were curiously small islands in a vast section of non-suitable habitat. While there may be some patches of good habitat that act as a source or exporter of surplus birds to maintain the 'sink' population throughout the rest of the range, there might also be some unoccupied suitable habitat patches. Some birds might also live in sub-optimal habitats towards the edge of the distribution range, while many suitable patches may remain unused.

Non-occupancy of some of the suitable habitats may be due to a combination of a series of local processes, including local extinction, loss of connectivity with neighbouring patches, coupled with low colonizing capability of the Nilgiri Laughingthrush due to its short flight distance. Possibly, site fidelity of the Nilgiri Laughingthrush and fragmented nature of its suitable habitat, may lead to its confinement in a given area, regardless of the availability of suitable sites elsewhere.

It has been suggested that the presence or absence of a species in a particular fragment can result not only from the size and structure of the fragments itself, but also from the characteristics of the surrounding landscape[22]. Thus, distribution of the Nilgiri Laughingthrush may not be related only to the fragment size but also to the spatial distribution of the habitat fragments, the distances from the source populations and occurrence of suitable microhabitats.

Monoculture plantations in the study area have a predominantly detrimental effect on the habitat of rainforest-dependent bird species. Thus the importance of retaining natural rainforest cover is paramount for the conservation of rainforest bird communities[23,24]. Further impoverishment of the Nilgiri Laughingthrush population in the fragments is likely to occur in the event of loss of the any of the remaining large suitable fragments. For the conservation of fragmented landscape such as in this case, conservation of ALOSS (all large and several small) remnants of natural habitats has been suggested instead of the SLOSS (single large or several small fragments)[24].

Possible implications of restricted range and anthropogenic influences for Nilgiri Laughingthrush conservation

The restricted geographical distribution of the Nilgiri Laughingthrush indicates its vulnerability to increasing human impacts, particularly through habitat destruction. A larger part of the Nilgiri Laughingthrush habitat was submerged by the hydroelectricity reservoirs, converted to tea, timber plantations and settlements, including for the repatriates from Sri Lanka (under the Sastri-Srimavu Pact) during the 20th century. Metapopulation models predict that there is a threshold level of habitat destruction that can drive a species extinct (when population density falls to zero), despite the survival of remnant patches of suitable habitat[25].

On an average, contemporary population abundances and size of the geographical range of the species are not independent entities[26,27]. In other words, geographically widespread species tend to have greater local abundances at sites where they occur, than do more restricted species. An interesting discussion on this subject is summarized in Lawton[26]. Also, species able to exploit a wide range of resources (species with 'broad niches') become both widespread and locally abundant[28]. Several theoretical fragmented population (metapopulation) models[27,29] predict that species with higher dispersal rates should be more widespread for a given average local abundance than those with poorer powers of dispersal. Neither Brown's model[28] nor the metapopulation models have unequivocal support from field studies[26]. The Nilgiri Laughingthrush does not support their predictions too, because it is locally common in shola patches and has a narrow geographical range too, primarily in the Nilgiri hills.

Most shola patches in the non-protected areas have been fragmented, degraded and encroached. Such structural changes of the shola may affect the recruitment rates by increasing the risk of egg and chick predation during the nesting season, resulting in local population decline. Numerous studies on natural and artificial nests have shown that forest fragmentation increases nest predation and reduces breeding success[30,31]. Forest edges harbour a species-rich assemblage of nest predators than do forest interiors[32], and songbirds may suffer high nest predation at the forest edges[33]. Not surprisingly, the breeding success of the Nilgiri Laughingthrush recorded during a four-year study by the AAZ (unpublished results) was an alarming low of 33% (partly contributed by predation), much lesser than that reported for the species two decades ago (*c*. 60%)[34], and in general for the open nesters (45% (ref. 35); 39% (ref. 36) for Neotropical migrants). Predators around the nesting habitat of the Nilgiri Laughingthrush include jungle crow (*Corvus macrorhynchos*), house crow (*Corvus splendens*), crow-pheasant (*Centropus sinensis*), dusky palm squirrel (*Funambulus sublineatus*), brown palm civet (*Paradoxurus hermahroditus*), small Indian civet (*Viverricula indica*), common mongoose (*Herpestes edwardsii*), and stripe-necked mongoose (*Herpestes vitticollis*).

Conclusion

The multiple logistic regression model for habitat suitability of the Nilgiri Laughingthrush successfully predicted the suitability of the habitat in the Nilgiris, with most of the variables found to be significant predictors. Although the total suitable area is quite reasonable in proportion (25% of the study area), it is heavily fragmented with most of the fragments below 0.5 km^2. This is alarming because deforestation and fragmentation have been implicated in the local and regional decline of the songbirds in many parts of the world[37].

Although it remains to be seen how much proportion of the area remains suitable for the Nilgiri Laughingthrush during its breeding season (given the changing preferences of the species over seasons), the results of this model allow us to make general recommendations aimed at supporting a healthy Nilgiri Laughingthrush population in the Nilgiris. The maintenance of most of the shola habitat (big and small) fragments is critical to the continued survival of the species in its curiously restricted range. A longstanding proposal to declare the uninhabited parts of the Nilgiri North and South Forest divisions as protected and their inclusion in the Mukurti National Park (currently only 78 km^2) should be considered by the Government authorities. There is also an immediate need to study the minimum fragment size requirement of the Laughingthrush for breeding and a minimum threshold distance of small fragments from the nearest source populations for maintaining an ecologically and biologically viable population.

As many fragments continue to be disturbed through fuel-wood collection and tree-felling, strategies should be worked together with the involvement of the local communities to minimize such impacts on the remaining suitable habitats. More importantly, active conservation of habitat structure and composition is needed for conservation of the Nilgiri Laughingthrush and other rainforest birds in the region. While our model focused on Nilgiri Laughingthrush, the biological inferences to be drawn from this study can be used extensively for other threatened and endemic avifauna of the Western Ghats.

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