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Using ensemble modeling to predict breeding habitat of the red-listed Western Tragopan *(Tragopan melanocephalus)* in the Western Himalayas of Pakistan

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ABSTRACT

Quantifying a species geographic range is a necessary requirement for targeted and effective conservation management and planning. The Western Tragopan (*Tragopan melanocephalus*) is a globally threatened Galliformes, endemic to the Western Himalayas. The breeding habitat of the species is believed to be exposed to increased anthropogenic pressures. There is a general lack of empirically-based approaches to protect the breeding habitat of this species. To this end, we used recent records of breeding tragopan to develop an ensemble model of the breeding habitat in Pakistan for this Vulnerable species. The model predicted a total area of 10,410 km^2 as potential breeding habitat for the species nationally. Of this, 2979 km^2 (28.6%) were potentially highly suitable ($P > 0.4$), 2544 km^2 (24.4%) were moderately suitable ($0.2 > P < 0.4$), and 4887 km^2 (46.9%) were of low suitability ($P < 0.2$). The breeding sites of the species were recorded with mean global human modification gradient of 0.33 ± 0.06 which implies that habitat suitability for the Tragopan now appears associated with areas of moderate land modification. Therefore, the predicted highly suitable area (core breeding area) was only 79 km^2 (or 2.6%) of the total predicted area suitable for breeding. Hence, the potential breeding habitat of this species may be degraded owing to human habitat interference. We propose that the remaining pockets of high suitability for breeding which remain free from human impacts are declared as protected areas with immediate effect. Areas of high suitability with already existing human disturbance should receive high attention by conservation managers and policy makers, attempting to reduce further human impact. Our model further suggests that more detailed studies at a landscape level should be carried out urgently to successfully protect this globally threatened species from further habitat deterioration.

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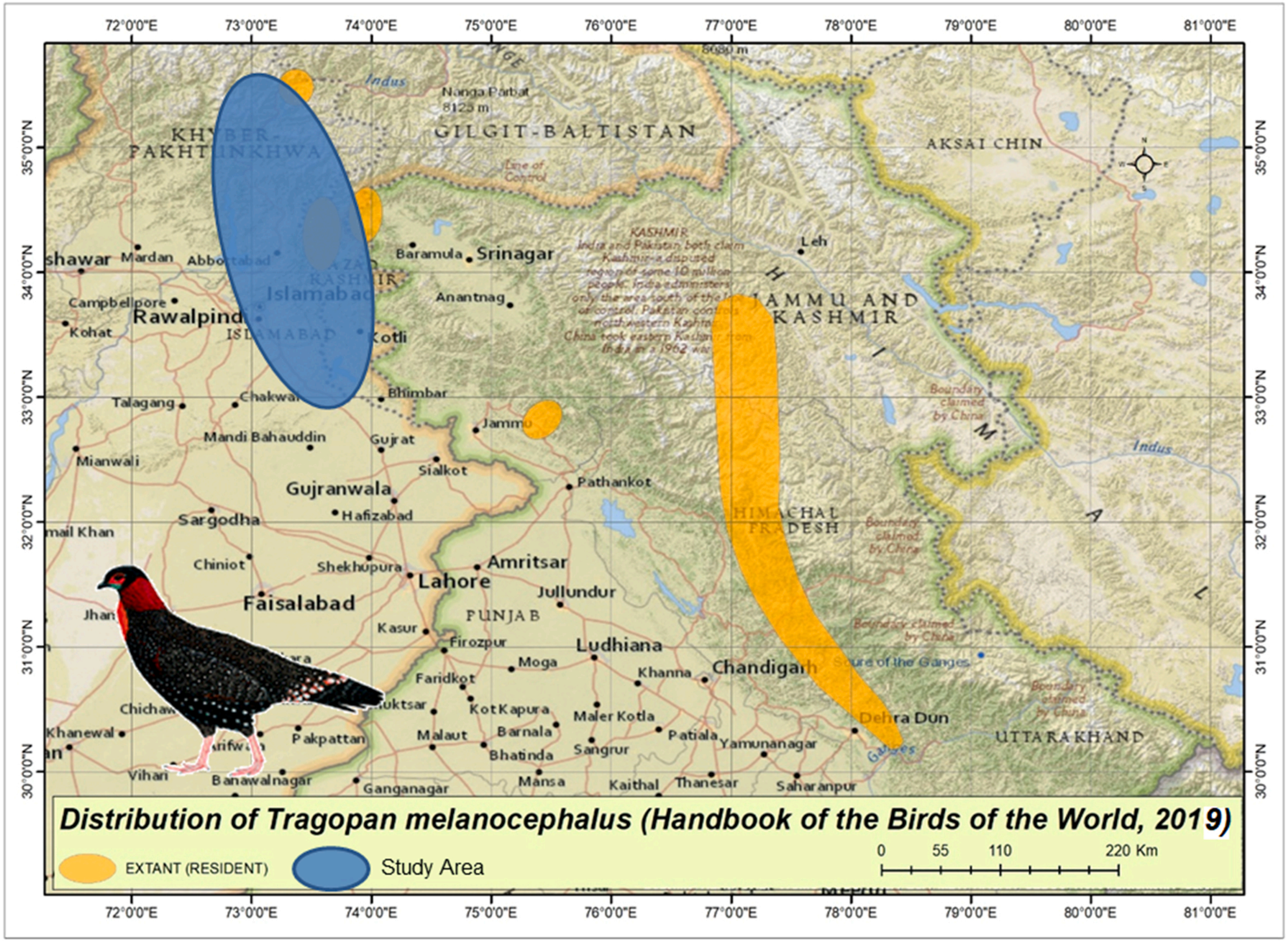

Fig. 1. The global distribution range of Western Tragopan (BirdLife International, 2019). Areas in orange show the species extant global range, the area in blue highlights the area described in this study. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article)

1. Introduction

The remote valleys of the Western Himalayas are indicative of the inaccessibility of the Himalaya global biodiversity hotspot (Mittermeier et al., 2011). However, despite its remoteness the region has come under increasing pressure in recent decades due to an increasing population (Government of Pakistan, 2012; Awan et al., 2016). The impacts of this are: habitat degradation due to unsustainable forestry (Ali and Nyborg, 2010; Awan et al., 2020), and fragmentation through unsustainable development (Awan et al., 2020); over exploitation of natural resources with increased harvesting of non-timber products such as mushrooms, intensive grazing by increased numbers of livestock, and hunting (Awan and Buner, 2014; Cochard and Dar, 2014).

The Western Tragopan (*Tragopan melanocephalus*) is endemic to the Western Himalayas, with a disjunct global range extending in a relatively narrow band from the Indus River in mid-north-eastern Pakistan to Dehradun in north-western India (BirdLife International, 2019; Fig. 1). The tragopan inhabits remote, difficult to access mountain forests and is naturally found at low population densities (Awan et al., 2016; Singh et al., 2020). It is classified as globally Vulnerable due to its small population size, although recent evidence suggests that this may be the result of insufficient survey and monitoring data (Awan et al., 2016).

It is an elusive bird, mostly active during dawn and dusk (BirdLife International, 2019). Being very specific in its habitat requirements, it is considered a bio-indicator for pristine mountain forests within the Western Himalayas (Fuller and Garson, 2000; Miller, 2010).

In Pakistan, the Western Tragopan is an altitudinal migrant that habituates shrubby steep slopes of montane forests at an altitudinal range of 2150–2500 m.a.s.l. during the winter months and up to 3600 m.a.s.l. during summer (Roberts, 1991; Awan et al., 2016). Within its most westerly range in Pakistan, the Western Tragopan seems to prefer pockets of broadleaved forests dominated by *Quercus semecarpifolia*, *Betula utilis*, *Acer caecium* and *Juglans regia* in association with their typically dense broad-leaved understory, in amongst the more dominating conifer forests typical at these altitudes, dominated by *Pinus wallichiana*, *Picea smithiana*, *Cedrus deodara* and *Abies pindrow* (Mirza, 1978; Awan, 2008; Miller, 2010). The breeding season is spent on steep, forested slopes during April – June (Ali and Ripley, 1987; Mirza et al., 1978; Roberts, 1991; Awan et al., 2016) with dense understory and little or no disturbance (Ramesh, 2003). In Pakistan, the exposition of the breeding habitat, based on extensive call-count surveys in spring ranges predominantly from north to north-east or north to north-west (Awan et al., 2016).

Indication of range contraction of the Western Tragopan has been reported in Azad Jammu and Kashmir (Awan et al., 2016), with plausible reasons linked to ongoing forest degradation caused by increased browsing of understory by an increasing number of livestock, increased tree cutting for animal fodder and fuel wood, as well as increased collection of medicinal plants, wild vegetables and mushrooms, especially *Morchella* spp. and pheasant eggs (Awan and Buner, 2014; BirdLife International, 2019).

Ample knowledge of a species distribution is one of the most important prerequisites for the successful conservation and management action and related investment (Cushman and Huettmann, 2010; Rabinowitz and Zeller, 2010; Viña et al., 2010; Drew et al., 2011). For rare or little-known species or species found in highly remote and difficult to access areas, such data are often not readily available or hard to collect. In this context, predictive habitat and species distribution modelling (Guisan and Zimmermann, 2000; Elith et al., 2006; Qiao et al., 2015), has become an important conservation tool helping to prioritise conservation and management action (Guisan and Zimmermann, 2000). Such studies can also be helpful in projecting minimal occurrence data of little-known species thus saving considerable time and resources for intensive monitoring schemes which would be required otherwise (Gwena et al., 2010; Ohse et al., 2009; Kandel et al., 2015; Regmi et al., 2018). Furthermore, reliable species distribution models (further called SDMs) can guide future surveys to areas where a species is predicted to occur.

For a species like the Western Tragopan, which is elusive and difficult to detect, other than from calling cues during the breeding season, SDMs seem the ideal framework on which to base future conservation actions, including confirming species occurrence (Ramesh, 2003). Of particular importance for the long-term survival of a threatened species is the identification of (potential) breeding habitat areas, which are contributing directly to a species reproductive output (Drew et al., 2011; Han et al., 2017). While SDMs may suffer large variance and bias especially when the data are scarce, ensemble models offer a solution to reduce such aberrations through combining several modeling techniques into a single predictive model (Siders et al., 2020).

Previously presented habitat suitability models for Western Tragopan provide general habitat suitability maps (Awan et al., 2016). The present study used an ensemble modeling to improve current knowledge of the species breeding habitat across its extent occurrence in Pakistan. We hope that this new insight will provide the baseline for future research and the conservation management of this species across its natural range.

2. Materials and methods

2.1. Study area

The study area is described by the potential distribution of Western Tragopan in Pakistan, located between 72.13–74.07°N and 34.44–35.62°E (BirdLife International, 2017). The area includes the Districts of Haveli, Hattian, Lower Kohistan, Mansehra, Muzaffarabad, Neelum and Swat (Fig. 1). The region's thermic gradient ranges from hot subtropical valley bottoms indicative of the colline zone to the snow-covered naval zone above 4800 m. The months of May to June and September to November are the driest, while the majority of precipitation is received during the monsoon season from February to April. June is the hottest month, with average temperatures exceeding 32^0 C, with winter temperatures dropping to 0–10^0 C (Khan and Hasan, 2019).

2.2. Tragopan records and environmental predictors

We collated records of tragopan presence from breeding call count surveys conducted for this study from 2017 to 20 (37 confirmed locations) and in Awan et al. (2016); 30 locations; Fig. 2). All call count surveys followed a standardized methodology, and as outlined in Gaston (1980). We extracted a further 159 confirmed tragopan locations from the Global Biodiversity Information Facility (GBIF; https://www.gbif.org). We only included georeferenced records for the time frame of (2017–2020). Clearly incorrect georeferences were excluded from the final dataset (Maldonado et al., 2015). A total of 226 confirmed locations comprised the response variable used to model potential tragopan breeding habitat based on a suite of bioclimatic, topographic and remote sensing based predictor variables (Table 1). All data were resampled to a 1-km resolution for habitat predictions.

The bioclimatic predictors consisted of 19 variables (Table 1) extracted at a 1-km square resolution from climatic data held at WorldClim (http://www.worldclim.org/bioclim), and considered potentially significant in defining species distribution models (Graham and Hijmans, 2006; Murienne et al., 2009). Since, the species is highly selective in altitude and aspect during the breeding season (Awan et al., 2016), we included a range of topographic variables in the prediction modelling: elevation ('Elev'), slope and transformed aspect value ('Aspv') based on Shuttle Radar Topography Mission (SRTM) data, continuous heat-insolation load index ('Chin'), global advance land observing satellite (ALOS) landforms ('Alf'), and ALOS global topographic diversity ('Tdiv'). We extracted all topographic variables from the Earth Engine Data Catalogue (Gorelick et al., 2017). We also included remote sensing derived normalized difference vegetation, snow, built-up, and wetness indices (NDVI, NDSI, NDBI and NDWI, respectively) based upon cloud-free median values of Sentinel-2 satellite data from 2020 and resampled at 1-km resolution (Copernicus Sentinel data, 2021, https://sentinel.esa.int/).

2.3. Predictor variable selection for the models

We initially ran a MAXENT model to determine the percentage contribution of potential predictor variables to the models. Variables with ≤2% contribution in the MAXENT model were discarded from further analysis, which left 13 predictor variables (Fig. 3).

To avoid over fitting models, we tested for collinearity between the remaining 13 variables using Pearson's correlation coefficient

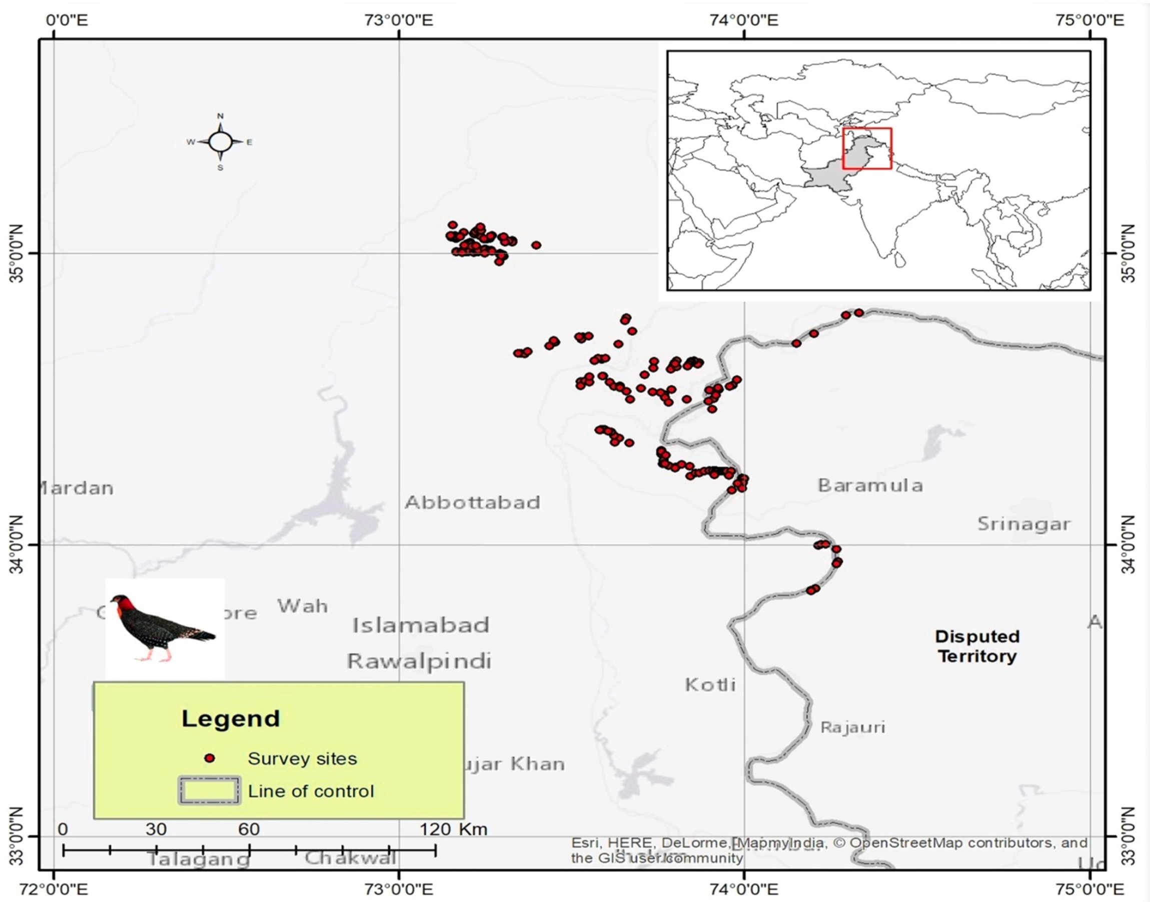

Fig. 2. Breeding call count locations (black dots) used to develop the breeding habitat models.

Table 1
Descriptives for the 19 bioclimatic predictor variables extracted from WorldClim.

Predictor	Biological meaning[a]	Mean ± SD	Range
Bio01	Mean annual temperature	71.5 ± 26.76	13–167
Bio02	Mean diurnal range (mean of monthly temperature)	86.0 ± 6.77	74–118
Bio03	Isothermality (Bio02 / Bio07 * 100)	28.5 ± 2.23	24–38
Bio04	Temperature seasonality (* 100)	7624.4 ± 424.31	5374–8530
Bio05	Maximum temperature of warmest month	220.0 ± 27.73	148–321
Bio06	Minimum temperature of coldest month	-76.9 ± 29.01	-144–14
Bio07	Annual temperature range (Bio05 – Bio06)	296.8 ± 12.49	243–322
Bio08	Mean temperature of wettest quarter	124.0 ± 56.74	0–217
Bio09	Mean temperature of driest quarter	39.1 ± 26.01	-19–128
Bio10	Mean temperature of warmest quarter	164.7 ± 24.44	96–250
Bio11	Mean temperature of coldest quarter	-31.9 ± 30.11	-99–72
Bio12	Annual precipitation	889.8 ± 172.70	690–2064
Bio13	Precipitation of wettest month	128.9 ± 46.57	93–514
Bio14	Precipitation of driest month	20.8 ± 3.56	16–29
Bio15	Precipitation seasonality	44.6 ± 4.93	40–87
Bio16	Precipitation of wettest quarter	318.5 ± 105.42	248–1210
Bio17	Precipitation of driest quarter	92.5 ± 13.83	77–162
Bio18	Precipitation of warmest quarter	296.4 ± 70.30	197–710
Bio19	Precipitation of coldest quarter	176.4 ± 24.79	145–334
NDBI	Normalized difference built-up index	-0.4 ± 0.09	-0.60 to − 0.15
NDSI	Normalized difference snow index	-0.2 ± 0.20	-0.48–0.46
NDVI	Normalized difference vegetation index	0.6 ± 0.15	0.09–0.84
NDWI	Normalized difference wetness index	-0.5 ± 0.12	-0.72 to − 0.07
Alf	ALOS landforms	25.9 ± 5.96	14–41
Chin	Continuous heat load index	161.4 ± 64.35	52–254
Tdiv	Topographic diversity	1.0 ± 0.02	0.88–1.0
Aspv	Cos transformed aspect value	0.1 ± 0.09	-0.01–0.3
Elev	Elevation (m)	2927.9 ± 359.04	1451–3782
Slope	Slope (°)	19.8 ± 7.80-	3.0–34.5

[a] Temperature variables are in °F, precipitation variables are in mm.

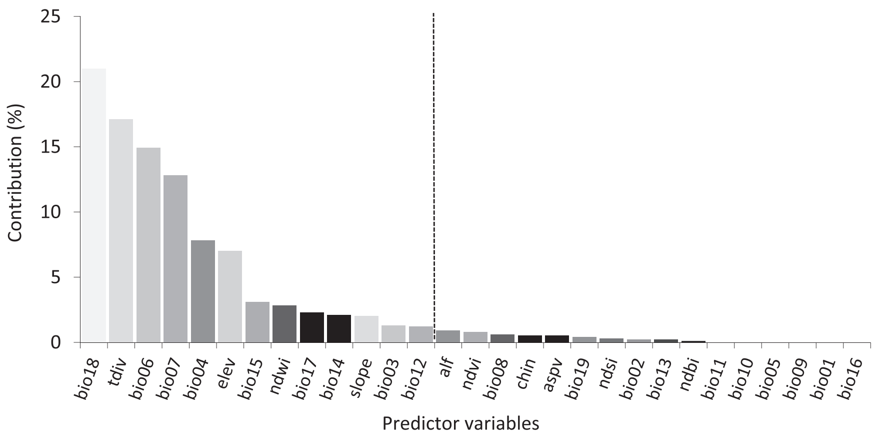

Fig. 3. Percentage contributions of predictor variables in the initial screening using a MAXENT model. Variables to the left of the vertical dashed line (>2% contribution) were retained at this stage; variables to the right were discarded (≤2%).

(r_p; Table 2). We retained those variables with bivariate correlation coefficients within the range + /−0.700, removing the highly correlated variables from the final modeling process. This left six final variables for ensemble modeling: Bio06, Bio15, Bio18, NDWI, Tdiv and Slope.

2.4. Breeding habitat models

We constructed breeding habitat models for Western Tragopan in R software (R Development Core Team 2017) using the packages 'dismo' (Hijmans et al., 2011), 'e1071′ (Dimitriadou et al., 2006) and 'randomForest' (Liaw and Wiener, 2002) for implementing Maxent, Support Vector Machine (SVM) and Random Forest (RF) distribution modelling, respectively. We trained all habitat models using the 226 presence records and 500 pseudo-absence points acquired by random sampling across the study region to provide a

Table 2
Correlation matrix showing bivariate correlations between the shortlisted predictor variables (>2% MAXENT model contribution) ($p < 0.01$).

	bio03	bio04	bio06	bio07	bio12	bio14	bio15	bio17	bio18	ndwi	tdiv	elev	slope
bio03	1												
bio04	-0.71	1											
bio06	0.97	-0.80	1										
bio07	-0.07	0.72	-0.23	1									
bio12	-0.08	-0.56	0.08	-0.96	1								
bio14	-0.30	-0.30	-0.17	-0.82	0.93	1							
bio15	0.40	-0.74	0.51	-0.59	0.49	0.20	1						
bio17	-0.13	-0.48	0.01	-0.91	0.98	0.98	0.35	1					
bio18	0.00	-0.65	0.16	-0.97	0.97	0.83	0.66	0.91	1				
ndwi	-0.45	0.35	-0.44	0.02	0.09	0.21	-0.23	0.13	0.02	1			
tdiv	-0.01	0.32	-0.06	0.47	-0.48	-0.40	-0.42	-0.45	-0.50	0.05	1		
elev	-0.73	0.68	-0.77	0.29	-0.20	-0.03	-0.45	-0.17	-0.25	0.40	0.09	1	
slope	0.14	0.28	0.04	0.58	-0.64	-0.65	-0.29	-0.65	-0.60	-0.12	0.41	0.10	1

Table 3
Newly identified areas which comprise highly suitable habitat for Western Tragopan in Pakistan (based on habitat-suitability model).

Site number	Locality	Suitable habitat (km^2)
1	Torwali Reserve Forest	22.8
2	Mushkun Reserve Forest	86.0
3	Gurnai Reserve Forest	46.0
4	Lilowanai	14.8
5	Near areas 4 and 6	9.9
6	Near Ajmeer	15.5
7	Near Kafir Banda	17.6
8	Near Besham city	140.0
9	Malam Jabba	12.0
10	Near Batagram	10.5
	Total	**375.1**

representative landscape sample.

We then built an average ensemble of the three models to classify tragopan breeding habitat suitability (Araujo and New, 2007; Hardy et al., 2011). The use of a simple average of > 1 model has been shown to perform as well as more sophisticated approaches, and including a single model approach (Armstrong 1989), while the application of ensemble modelling of species distributions to species conservation and biodiversity management has proven useful (Drew et al., 2011; Gael et al., 2011; Xuesong et al., 2017). Finally, based on the probability of prediction, we classified breeding habitat suitability in to four categories: 1. Unsuitable ($P \leq 0.20$); 2. Low suitability ($0.20 < P \leq 0.40$); 3. Moderate suitability ($0.40 < P \leq 0.60$); and 4. High suitability breeding habitat ($P > 0.60$).

We evaluated model performance using area under the curve (AUC) of a receiver operating characteristic curve (ROC). We followed the threshold independent method of Pearce and Ferrier (2000) for calculating AUC, where an AUC > 0.5 indicates a better fit than a random classification. To remove spatial sorting bias, we used a point-wise distance sampling technique (Hijmans, 2012). The final model was projected in GIS to produce the potential breeding habitat map.

2.5. Assessing human modification of breeding habitat

To elucidate a tolerance threshold of Western Tragopan to anthropogenic disturbance, we used the coordinates of each positive location to extract the corresponding human modification values from the Global Human Modification dataset (HMc) in the Earth Engine Data Catalog (Gorelick et al., 2017). The HMc dataset provides a cumulative measure of human modification at 1 km^2 spatial resolution, with values varying from 0.0 to 1.0 and representing the proportion of a given location (pixel) modified anthropogenically. These values are calculated based on five major anthropogenic stressors mapped using 13 individual datasets, including: human settlement (population density/built-up areas); agriculture (cropland, livestock); transportation (major, minor, and two-track roads; railroads); mining and energy production; and electrical infrastructure (power lines, nighttime lights; Kennedy et al., 2019).

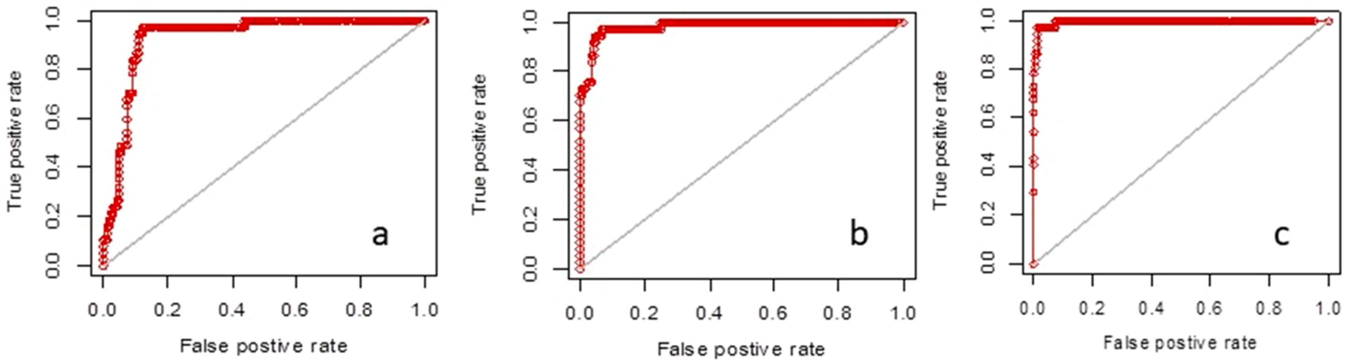

Fig. 4. ROC curves (with sensitivity plotted against specificity) for the three models; a. RF, b. MaxEnt, and c. SVM.

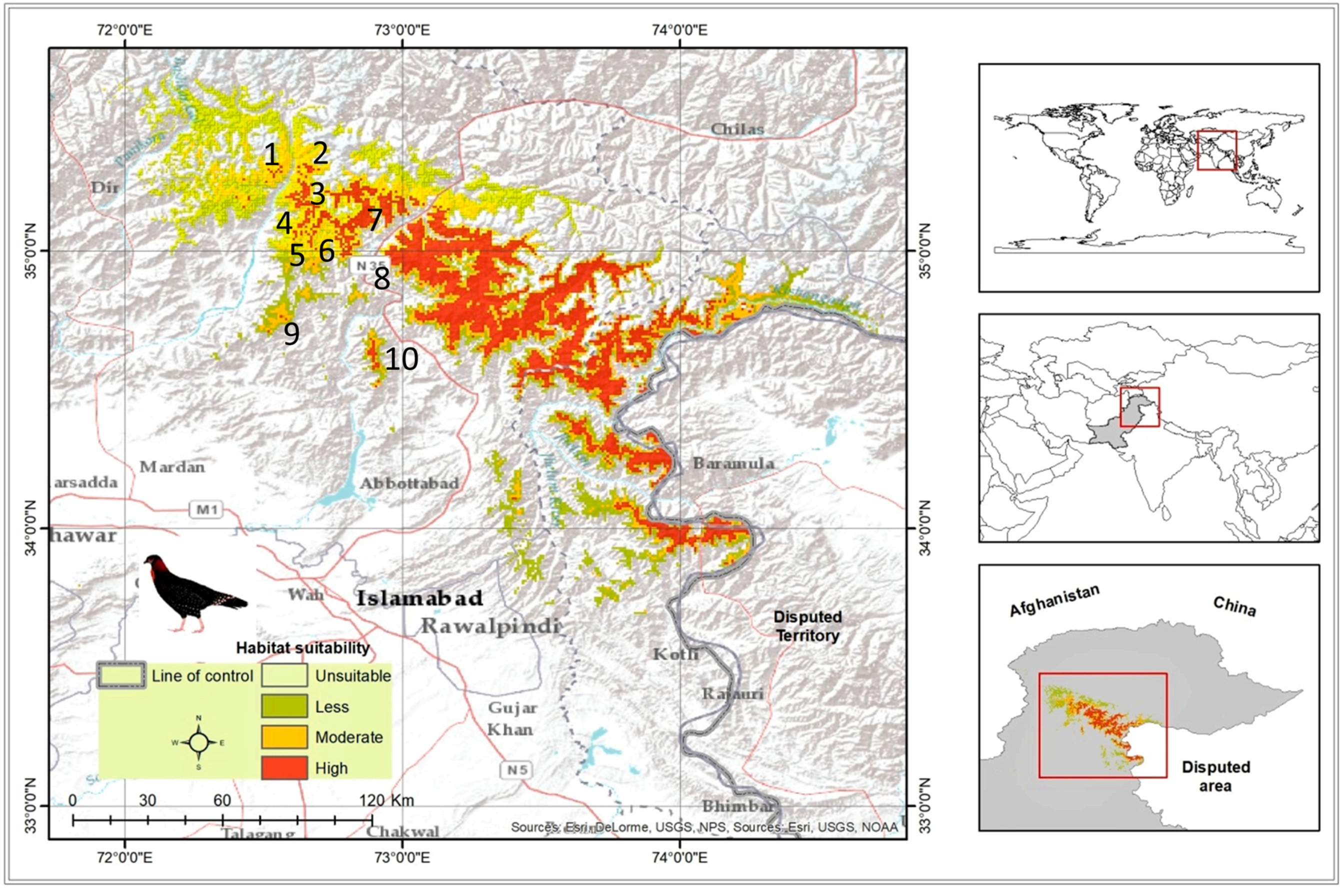

Fig. 5. Potential breeding habitat suitability for Western Tragopan in the Western Himalayan landscape, Pakistan. Numbers indicate new locations predicted to contain highly suitable habitat (see Table 3).

We then calculated the 95% confidence intervals (CIs) for the mean HMc for breeding call count locations and calculated the predicted area of the ensemble model in various categories (high, moderate and low suitability areas) that fell within this range. We assumed that the area beyond 95% CIs of the mean would be disturbed habitat in the context of breeding habitat of Western Tragopan.

3. Results

3.1. Model assessment and validation

Model performance was assessed using the AUC of the ROC curves (Fig. 4). All three models demonstrated comparatively high sensitivity at low specificity, with AUC values of 0.997, 0.984 and 0.931 for the RF, MaxEnt and SVM models, respectively, representative of good model performance (Pearce et al., 2000) and indicating discriminating power capable of distinguishing between true species presence and absence in at least 93% of cases (<7% false positive rate) based on the environmental dataset used.

3.2. Assessment of potential breeding habitat

Our ensemble modeling was based on predicting potential breeding habitat across an area of 10,409.85 km^2 (Fig. 5). Of this, 2979 km^2 (28.6%) was categorized as highly suitable or core breeding areas, 2544 km^2 (24.4%) as moderately suitable, and 4887 km^2 (46.9%) as low suitability (Figs. 5, 6). The total areas of habitat suitability under different categories predicted by the contributing models is presented in Fig. 6.

3.3. Human impact

The predicted breeding habitats of Western Tragopan had HM_C values ranging from 0.12 to 0.44 (mean = 0.33 ± 0.06). This implies that habitat suitability for the tragopan now appears associated with areas of moderate land modification ($0.10 < HMc \leq 0.40$; Kennedy et al., 2019). For wider context, the mean *HMc* for the Western Himalayan subalpine conifer forests ecoregion is 0.45, with nearly 44% categorized as highly or very highly anthropogenically modified (Kennedy et al., 2019). The *HMc* analysis demonstrates that of the 2978.8 km^2 of highly suitable breeding habitat, only 78.9 km^2 (2.64%) is free from human disturbance. Similarly, of the 2543.9 km^2 of moderately suitable habitat, 129.3 km^2 (5.08%) is not anthropogenically disturbed, while only 36.9 km^2 (0.75%) of low suitability areas appear free from human disturbance (Fig. 7).

3.4. Identification of new areas for the conservation of Western Tragopan in Pakistan

Aside from the three known main regions where Western Tragopan is known to occur in Pakistan (Azad Kashmir, Kaghan Valley and Palas Valley), our ensemble modelling predicted 10 new areas where neither historic records nor recent surveys confirm presence-absence (Fig. 5). Together, these areas comprise an estimated 375.1 km^2 of highly suitable habitat for the species (Table 3). In addition to these ten newly identified areas, there are a number of additional new areas which fall into the moderate to low suitability habitat categories. Most of these areas are associated with the newly identified areas of highly suitable habitat.

4. Discussion

The extinction crises of globally threatened species demand effective conservation action more than ever (Brooks et al., 2006): Funds are limited, and time is running out for many species facing extinction. In this context, conservation action for little-known threatened species such as the globally Vulnerable Western Tragopan (the species is widely regarded as an indicator for pristine

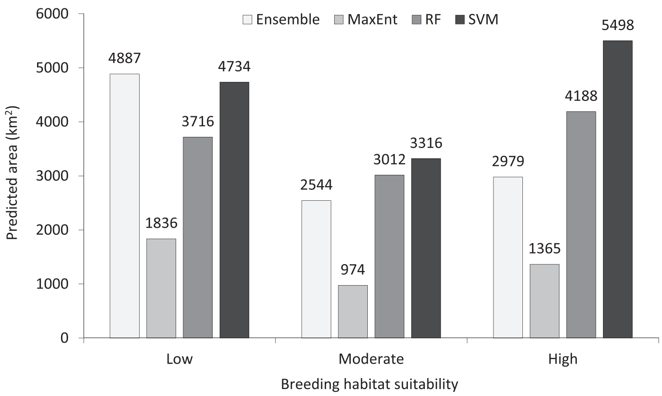

Fig. 6. Areas of breeding habitat suitability (areas attached to bars) predicted by the overall ensemble model and contributing models (Low, $0.20 < P \leq 0.40$; Moderate, $0.40 < P \leq 0.60$; High, $P > 0.60$).

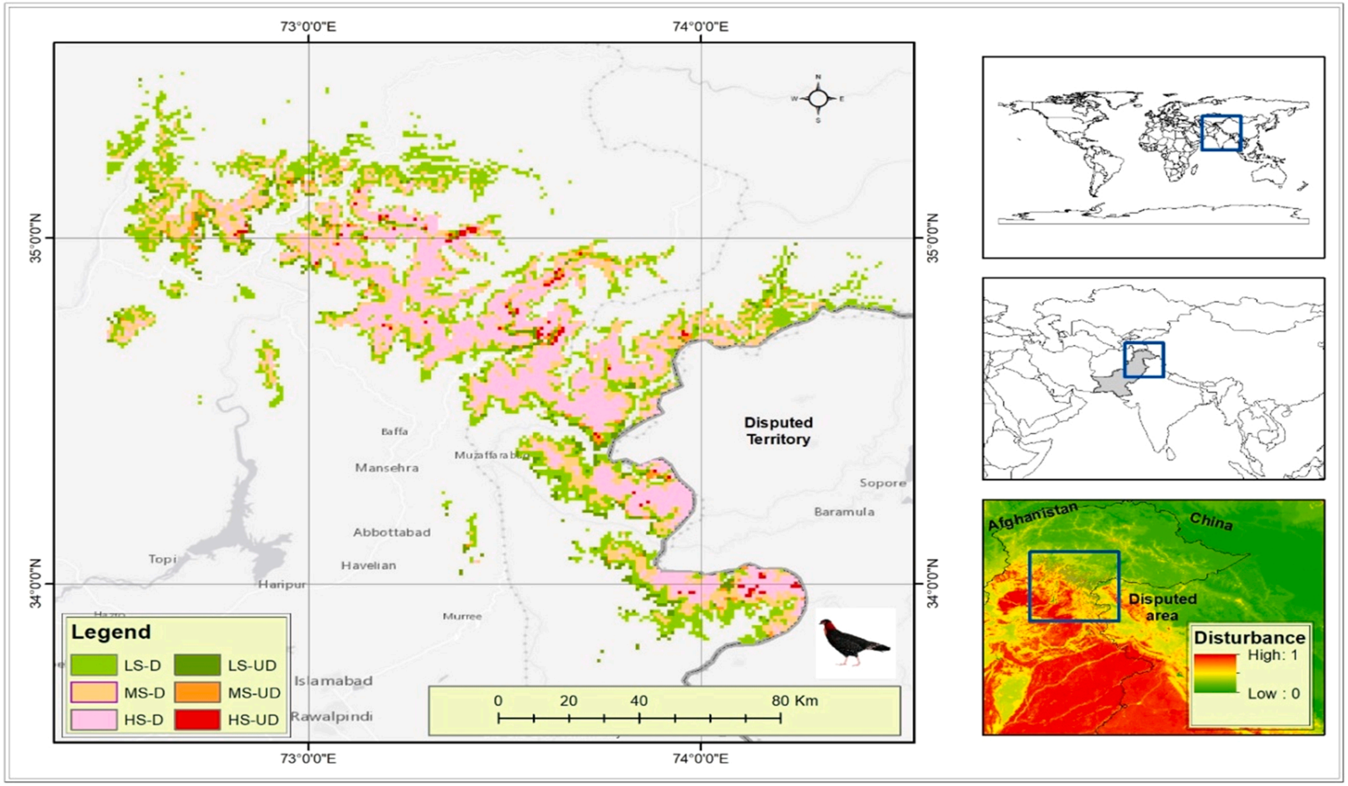

Fig. 7. Human modification imprint within the predicted breeding habitat of Western Tragopan in the Himalayan landscape of Pakistan. LS = Low suitability, MS = Moderate suitability, HS = High suitability; D = Disturbed, UD = Undisturbed.

high-altitude Western Himalayan Mountain forests), is often based on subjective ad-hoc decision-making processes. On the one hand, this is due to a lack of funds and manpower available to obtain even the most basic survey information such as distributional range, population size and population trends. On the other hand, because the available species information, often doesn't make into the decision-making process of policy makers or even conservation managers. In Pakistan for example, the protected areas network, consisting of National Parks and Game Reserves, targets mainly big game species such as Snow leopard (*Panthera uncia*, VU), Common leopard (*Panthera pardus*, VU), Asiatic black bear (*Ursus thibetanus*, VU), Brown bear (*Ursus arctos*), Musk deer (*Moschus chrysogaster*, EN), Kashmir grey langur (*Semnopithecus ajax*, EN) and Himalayan ibex (*Capra sibirica*). As a result, only 2% of the total predicted breeding habitat based on this study, is currently under some form of protection. Today, all areas where the Western Tragopan is protected by Pakistani law are purely accidental, despite the species high profile as globally vulnerable status.

Our study indicates that the knowledge of the species distribution in Pakistan, based on numerous targeted surveys over the past decades together with citizen science information taken from the Global Biodiversity Information Facility, are likely to draw an incomplete picture of the species true distribution. This because our Ensemble model predicted at least ten new areas of suitable breeding habitat, previously unknown to the science and conservation manager community in Pakistan. This opens new opportunities for Western Tragopan research in Pakistan by pinpointing to previously unexplored areas with high likelihood of confirming the species in the wild.

Habitat loss has been identified as one of the main threats to the Western Tragopan (BirdLife International, 2019). Our breeding habitat model therefore presents a suitable baseline to monitor and further assess the effects of anthropogenic disturbance within the species breeding range, which already seems to have negatively impacted this globally important biodiversity hotspot by the effects of increased livestock herding, logging, and foraging for food and medicinal plants (Awan et al., 2016; Awan and Buner, 2014; Cochard and Dar, 2014). As described by Awan and Buner (2014), a typical day at an alpine settlement starts at daybreak when women release their livestock and herding dogs and start collecting firewood, edible and medicinal plants; noisy young children accompany their mothers or sisters to help with these tasks, all of which make up a major part of their daily routine. The sum of these activities are likely to cause considerate disturbance to the breeding pheasants and other wildlife, worsened by the looming climate crisis (Osborne and Osborne, 1980; Sekercioğlu et al., 2012).

In a country where only around 2% of the landcover consists of forest (Government of Pakistan, 2000; FAO, 2010), significant demands are being made on this natural resource, deteriorated by illegal logging (Awan, 2008; Ali and Nyborg, 2010; Awan and Buner, 2014; Awan et al., 2016). Hence, the results from this study are expected to be of importance to relevant authorities like the Forest and Wildlife departments, to improve the protection of the remaining pockets of pristine mountain forests in Pakistan.

5. Conservation implication

Our analysis provides the first comprehensive overview of the Western Tragopan's available breeding habitat within Pakistan (Fig. 5), adding several previously unknown areas to its known distribution. This new knowledge is of high conservation value as it allows for better-informed and more targeted conservation action of this globally Vulnerable species. For example, our human disturbance analysis highlighting the remaining pockets of pristine mountain forests, free from human disturbance (Fig. 7), provides a clear intimation to conservation managers to target their management plans to the few remaining areas of highest biodiversity value within the Western Himalayas.

6. Conclusions

Western Tragopan, a species of global conservation concern needs clear picture of its abundance and distribution which is very important for its conservation purpose. Clearly identified site with its potential distribution provide guidelines for further research and conservation management. An effort done to model breeding habitat of the species provides a new horizon for future research and conservation in Pakistan. This model can also be replicated in other parts of the species distribution range to get a clear picture on species global breeding habitat availability which will further help to estimate breeding habitat of the species on global level.

Declaration of Competing Interest

The authors declare that they have no financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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