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Factors Affecting Habitat Selection of Endangered Steppe Eagle (*Aquila nipalensis*) in Pakistan: Implications for Raptors Conservation

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Abstract: The steppe eagle (*Aquila nipalensis*) is an endangered migratory raptor species that migrates in winter to Pakistan and neighbouring countries. In Pakistan, the species migrate at the end of autumn and utilise different habitats across the country. Very little information is available about the species' population status, distribution, and factors affecting its distribution in Pakistan. In the present study, we predicted the distribution of steppe eagles in Pakistan associated with different environmental variables. We used 149 presence points of the species from an online source (GBIF), published literature, and wildlife photographers. The MaxEnt analysis showed that highly suitable habitats were mostly present in Azad Jammu and Kashmir (AJK), federally administered areas and surrounding areas, southern areas of Sindh Province, and some parts of Khyber Pakhtunkhwa (KP) Province. In addition, some patches were also predicted by MaxEnt in Balochistan Province. Human population density (27.0%), chicken density (16.6%), temperature seasonality (11.1%), and rivers (10.3%) were identified as the main environmental factors that affect the habitat distribution of steppe eagle in Pakistan. Only a small percentage (2.62%) of the total Pakistan area was estimated to be a highly suitable area for steppe eagles, while 20.58% and 7.46% were identified as the least and moderately suitable areas, respectively. Conservation of identified habitats and mitigation of anthropogenic impacts to conserve this endangered eagle species are recommended for immediate and long-term conservation across Pakistan.

Keywords: habitat suitability; birds of prey; migratory birds; Azad Jammu and Kashmir; Sindh

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1. Introduction

Globally anthropogenic pressures on birds, direct persecution, and habitat degradation have devastating impacts on bird populations [1]. Human activities are one of the significant causes of a wide range of non-random deviations in bird community compositions [2,3]. The unrestrained humanisation of planet Earth, followed by the industrial revolution, has led to a new era, the "Anthropocene", which involves the fast vanishing of species, a phenomenon known as the "sixth extinction" [4,5]. The reasons mentioned above negatively impact almost all birds; yet, the ones who suffer the most are the migrant species.

Among different groups of birds, the raptors often occur in low densities and over large ranges and are adapted to different lifestyles, from regional to colonial, strictly sedentary to vagile, or migratory [1]. It is assumed that migrant species usually suffer greatly in cross-border movements due to several factors. Habitat loss is the second most crucial factor after hunting and poaching, driving migratory species to extinction [6]. Therefore, investigating and preserving suitable habitats is a significant challenge in conservation biology in the 21st century [7].

Habitat use, preference, and selection have usually been confused in the literature [8], although most studies' aim, irrespective of the scale of analysis, is to describe habitat suitability. Habitat suitability has usually been achieved by modelling data based on either species records of presence–absence or presence-only datasets as a function of environmental variables [9,10]. However, the species absence data are thought to be hard to achieve and less reliable or strenuous to interpret [7]. Several ecological and species distribution models have been used for habitat evaluation, of which the most advanced and reliable is Maximum Entropy Modelling (MaxEnt). MaxEnt has surpassed other species distribution models because of its solid and accurate predictive powers and compatibility, even with presence-only and tiny datasets [7].

The geographical areas of Pakistan are highly diverse, and the altitudinal variations range from sea level in the south to the world's second highest mountain (K-2) in the north [11]. These highly diverse geographical areas provide habitats to many globally threatened bird species [12–14]. It interestingly provides one of the major flying routes for migratory birds, known as Birds Route Number 4, also called Green Route or more commonly Indus Flyway, extending from Karakoram Range down to Indus Delta in the south, providing attractive stopovers for guest birds. Yet, immense anthropogenic pressures lead to the fast degradation and shrinking of stopovers and the ideal habitats for these guest birds [6]. Many migratory birds, including ducks, geese, cranes, and some raptors, migrate to Pakistan for feeding or breeding purposes, many of which are globally considered endangered [15].

The steppe eagle (*Aquila nipalensis*) is the most common raptor on the central Asian flyway to the Indian subcontinent [16], Indus fly route, over the Karakoram, then from Suleiman mountain ranges to the Indus Delta near the Arabian Sea [17]. Each year the steppe eagles arrive in Pakistan in September, and the numbers increase up to December—reaching up to or more than 2000 individuals—and migrate back at the start of February until March [18]. The steppe eagle's range has decreased over the last two decades [19,20]. During this period, the major parts of its global coverage and population have declined by 58% [21]. This rapid decline is attributed to the direct killing of the species and conversion of steppes to agricultural lands [22,23]. In Asia, the main threats to the species are increased agricultural land use and livestock overgrazing of steppe habitats [24,25]. Due to the threats mentioned above and population decline, this raptor has been listed as 'Globally Endangered' by the IUCN Red List [26].

Pakistan is within the non-breeding range of the steppe eagle; yet, during winter (October to end of March), it provides a strong refuge and ideal feeding ground for this endangered and ecologically important raptor [13]. However, the expanding human populations and their increasing needs, coupled with rapid construction and developmental processes, seem to be the primary reasons for steppe eagle habitat degradation—aiding much to its current conservation status (http://datazone.birdlife.org/species/factsheet/steppe-eagle-aquila-nipalensis/details, accessed on 19 September 2022). We presume that the human population and settlements may negatively impact the steppe eagle habitat selection. Nevertheless, unfortunately, no attention has been given to this critical issue in Pakistan. Therefore, keeping in view the conservation status of the steppe eagle and the existing threats, the current study was designed to assess the suitable habitats across Pakistan and suggest mitigation measures for the robust conservation of the steppe eagle and its habitats. We believe that this study will provide benchmark data for the habitat evaluation of endangered raptors in Pakistan and across the globe.

2. Materials and Methods

2.1. Study Area and Species Presence Data

Steppe eagle distribution modelling was carried out in Pakistan. Pakistan is spread over an area of 882,000 km^2, lying between 24° and 37° N, 61° and 75° E. It extends some 1700 km north from the Arabian Sea coast and the mouth of the Indus River to its headwaters in the Hindu Kush and Karakorum ranges of the Himalayan Mountains [27]. The country contains three of the world's eight bio-geographic realms (Indo-Malayan, Palearctic, and Afro-Tropical) and their distinct biotas. It spans four of earth's ten biomes (desert, temperate grassland, tropical seasonal forest and mountain) [28]. The diverse ecological regions of Pakistan support rich biodiversity, particularly in the arid and semi-arid regions, which cover almost 80% of the total land area [27].

Species presence data were obtained from different sources. A total of 288 occurrence data were used in the present study (Figure 1). Out of 288 presence records, 20 were obtained from published literature [13] and about 55 different locations data were obtained from different wildlife photographers, while the remaining 213 presence locations data were retrieved from the GBIF website (https://www.gbif.org, accessed on 21 August 2022), where we included human observations from 2000 to 2021 [29]. The GBIF is an international network and data infrastructure funded by the world's governments and aimed at providing anyone, anywhere, open access to data about all types of life on earth. Worldwide, presence data records for various species have been obtained from GBIF and used in Species Distribution Modelling (SDM) [30,31].

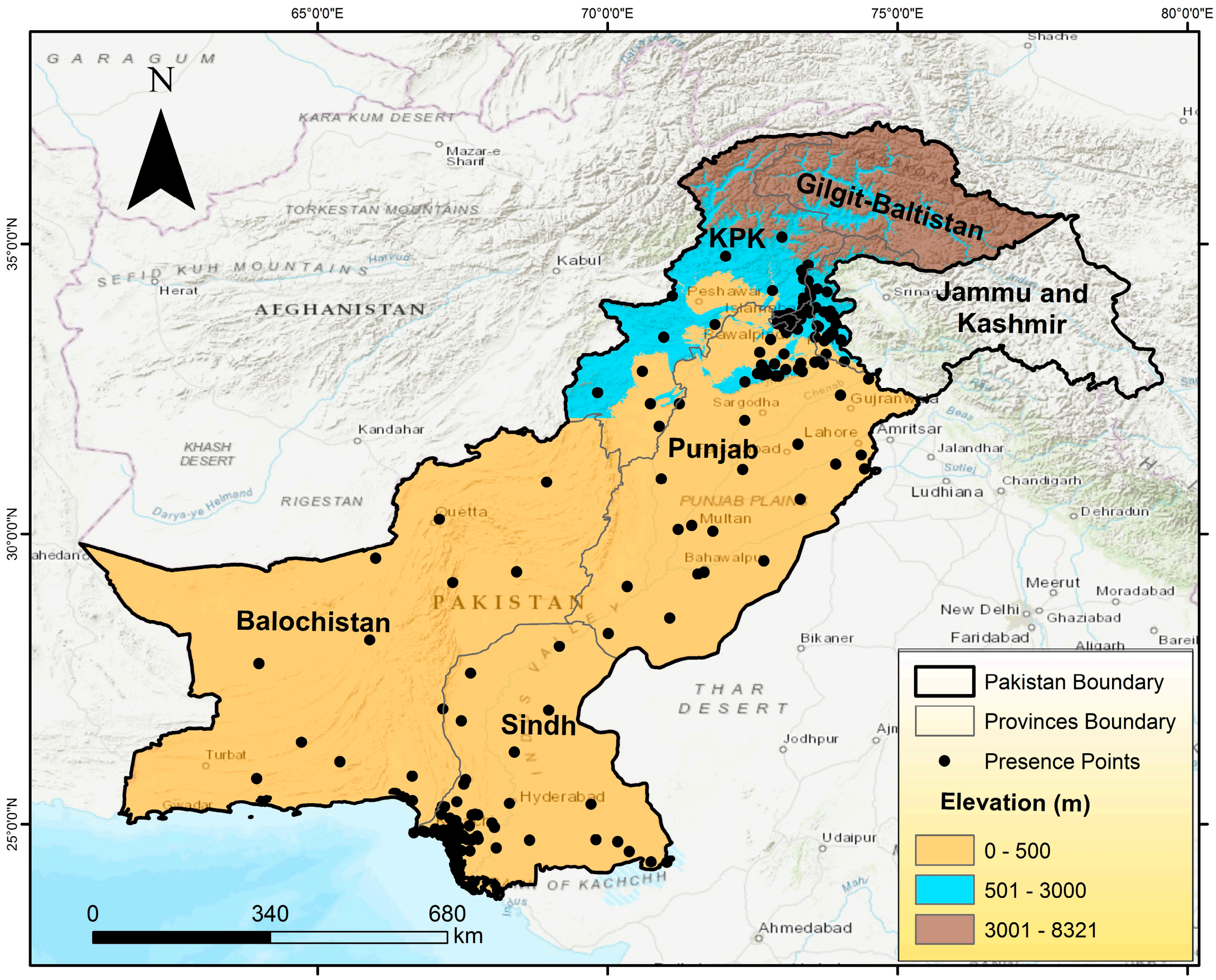

Figure 1. Presence-only data records of steppe eagles in Pakistan obtained from different sources, explained in the Section 2.1.

2.2. Environmental Data

We initially selected a total of 32 environmental variables for the distribution modelling of steppe eagles across the entire range of Pakistan (Table 1). Of these 32 variables, 19 were bioclimatic variables which were downloaded from the WorldClim database (http://worldclim.org/, accessed on 22 August 2022), which is a set of global climate layers derived from over 4000 weather stations that include annual means, seasonality, and extreme or limiting temperature and precipitation data that are likely to influence species' distributions [29,32]. Five variables, slope, and elevation, soil, land cover and rivers, were topographic; seven variables were anthropogenic (livestock population density (goat, sheep, cattle, buffalo, and chicken), human population density, and road network). The vegetation-related variable was the Normalised Difference Vegetation Index (NDVI). The spatial resolution of bioclimatic and topographic variables was 1 km. The resolution of other variables was converted into 1 km using the bilinear resampling technique in ArcGIS 10.8 [7].

Table 1. List of environmental variables used in modelling potential habitats for steppe eagles in Pakistan.

Environmental Variables	Unit	Source
annual mean temperature (bio_1)	Degrees Celsius	https://www.worldclim.org/data/worldclim21.html (accessed on 22 August 2022)
mean diurnal range (mean of monthly [max temp—min temp]) (bio_2)	Degrees Celsius	
isothermality (Bio2/Bio7) (×100) (bio_3)	Percentage	
temperature seasonality (standard deviation ×100) (bio_4)	Degrees Celsius	
maximum temperature of warmest month (bio_5)	Degrees Celsius	
minimum temperature of coldest month (bio_6)	Degrees Celsius	
temperature annual range (Bio_5-Bio_6) (bio_7)	Degrees Celsius	
mean temperature of wettest quarter (bio_8)	Degrees Celsius	https://www.worldclim.org/data/worldclim21.html (accessed on 22 August 2022)
mean temperature of driest quarter (bio_9)	Degrees Celsius	
mean temperature of warmest quarter (bio_10)	Degrees Celsius	
mean temperature of coldest quarter (bio_11)	Degrees Celsius	
annual precipitation (bio_12)	Millimetres	
precipitation of wettest month (bio_13)	Millimetres	
precipitation of driest Month (bio_14)	Millimetres	
precipitation seasonality (coefficient of variation) (bio_15)	Fraction	
precipitation of wettest quarter (bio_16)	Millimetres	
precipitation of driest quarter (bio_17)	Millimetres	
precipitation of warmest quarter (bio_18)	Millimetres	
precipitation of coldest quarter (bio_19)	Millimetres	
human population density (pk_pd_2020)		WorldPop https://www.worldpop.org/doi/10.5258/SOTON/WP00674 (accessed on 23 August 2022)
chicken density (ch_2010Da)		GLW https://dataverse.harvard.edu/dataverse/glw (accessed on 23 August 2022)

Table 1. *Cont.*

Environmental Variables	Unit	Source
goat density (gt_2010Da)		GLW https://dataverse.harvard.edu/dataverse/glw (accessed on 23 August 2022)
cattle density (ct_2010Da)		GLW https://dataverse.harvard.edu/dataverse/glw (accessed on 23 August 2022)
global land cover 2009 (glc2009)		http://due.esrin.esa.int/page_globcover.php (accessed on 24 August 2022)
buffalo density (bf_2010Da)		https://dataverse.harvard.edu/dataverse/glw (accessed on 24 August 2022)
sheep density (sh_2010Da)		https://dataverse.harvard.edu/dataverse/glw (accessed on 24 August 2022)
elevation above sea level	Metre	NASA (SRTM)
slope of the area	Metre	created from SRTM 90m DEM
rivers		line Density tool in ArcGIS 10.8
road networks roads		line Density tool in ArcGIS 10.8
digital soil map of the world		FAO, 2003
normalised difference vegetation index		USGS: http://edcsns17.cr.usgs.gov/glcc (accessed on 24 August 2022)

2.3. Data Analysis

MaxEnt 3.3.3k (http://biodiversityinformatics.amnh.org/open_source/maxent/, accessed on 25 August 2022) was used for data processing and analysis to predict suitable areas for steppe eagles in Pakistan.

2.3.1. Selection of Presence Data and Environmental Variables

Initially, we obtained a set of 288 presence records of steppe eagles. The presence-only records were screened in ArcGIS 10.8 (SDM toolbox) for spatial autocorrelation using the reduce spatial autocorrelation tool to remove spatially correlated data points (located within 5 km) and to ensure independence [29]. After spatial autocorrelation, we obtained a final set consisting of 149 presence records of steppe eagles for MaxEnt analysis. We set the environmental variables per the requirement of the MaxEnt protocol. After the spatial transformation of environmental layers into 1 km using the bilinear resampling tool in ArcGIS, we clipped the environmental variables according to the study area boundary using the clip tool in ArcGIS 10.8. After clipping, we converted the clipped layers to ASCII using the conversion tool. We ran the Pearson correlation coefficient test in Program R [33], intending to remove highly correlated variables from the analysis [34]. The correlation analysis delivered 16 non-correlated variables (Table 2) that were retained ($r < 0.7$) [7].

2.3.2. Model Simulation and Evaluation

Steppe eagle presence data were arranged in CSV format, and the final set of environmental variables was adjusted to the arrangements mandatory for MaxEnt software (v 3.3.3k). A random seed option was used, and the random test percentage was kept at 25%. Ten replicates were run with a typeset as a sub-sample. The rest of the settings were retained as default, comprising 10,000 randomly produced background points, 500 maximum iterations with a convergence threshold of 0.00001, and a regularisation multiplier of 1. Each variable importance and contribution were determined with a jackknife estimator. Sensitivity analysis was performed for each variable with a logistic output format. The achievement of the MaxEnt model was confirmed by receiver operating characteristic

(ROC) values: rejected with a ROC value of 0.5–0.6; poor with 0.6–0.7; average with 0.7–0.8; good with 0.8–0.9; and excellent with 0.9–1.0 [7,35–37]. The output results were used to reclassify the suitable habitat distribution for the steppe eagle. The ASCII outputs format file was imported into ArcGIS 10.8 for conversion into raster data to produce a habitat suitability map, subsequently reclassified into four classes and then converted to a vector file to develop a suitability index map and calculate the area [7].

Table 2. Percent contribution of variables in determining suitable habitat of steppe eagle in Pakistan.

S.NO	Variable	Percent Contribution	Permutation Importance
1	human population density	27.0	28.1
2	Chicken density	16.6	12.6
3	temperature seasonality	11.1	7.2
4	rivers	10.3	5.3
5	landcover	8.4	1.3
6	precipitation of wettest month	7	7
7	buffalo density	4.9	11.9
8	soil	3.3	2
9	precipitation seasonality	2.4	0.6
10	precipitation of driest month	2.4	6.6
11	ndvi	1.5	4.8
12	slope	1.4	1.4
13	Road networks	1.4	3.9
14	mean diurnal range (mean of monthly [max temp—min temp])	1.1	1.2
15	elevation	0.6	4
16	goat density	0.6	2.1

3. Results

3.1. MaxEnt Prediction Evaluation

The current study obtained a valid and valuable model based on the area under the curve (AUC) value. The ROC results showed an average AUC value of 0.847, indicating that the predictions obtained from the MaxEnt model were good. The standard deviation was 0.024.

3.2. Influential Factors Determining Habitat Suitability

The MaxEnt model determined the contribution of each variable in predicting steppe eagle habitat selection (Table 2). The analysis shows that human population density highly contributed to the habitat selection of steppe eagles (Figure S1). Other variables with the highest contribution to the habitat selection of steppe eagles were chicken density, temperature seasonality, and rivers (Table 2). The least contributing variables were elevation and goat density (Table 2).

MaxEnt generated response curves for each of the 16 variables that provide information on how each variable impacts the steppe eagle habitat preference. These response curves plot probability of species presence or suitable habitat against a range of values within each variable. Response curves also provide insight into the individual variable and their thresholds. Flatness in the curves indicates that differences in the value of the variable did not have any effect on the probability of species' suitable habitat presence. In the current study, three variables have shown a high impact on the steppe eagle's suitable habitat selection (Figure 2). Among these three variables, the highest important variable is human population density. The human population density response curve demonstrates that species habitat suitability increases with human population density; however, after a certain point, the curves flatten, and the variable no longer has any influence on species habitat selection. Similarly, the habitat selection of steppe eagles increases as chicken density increases, but the positive correlation reverses itself when chicken density exceeds 0.9×10^6. Temperature seasonality and steppe eagle habitat preferences are negatively correlated.

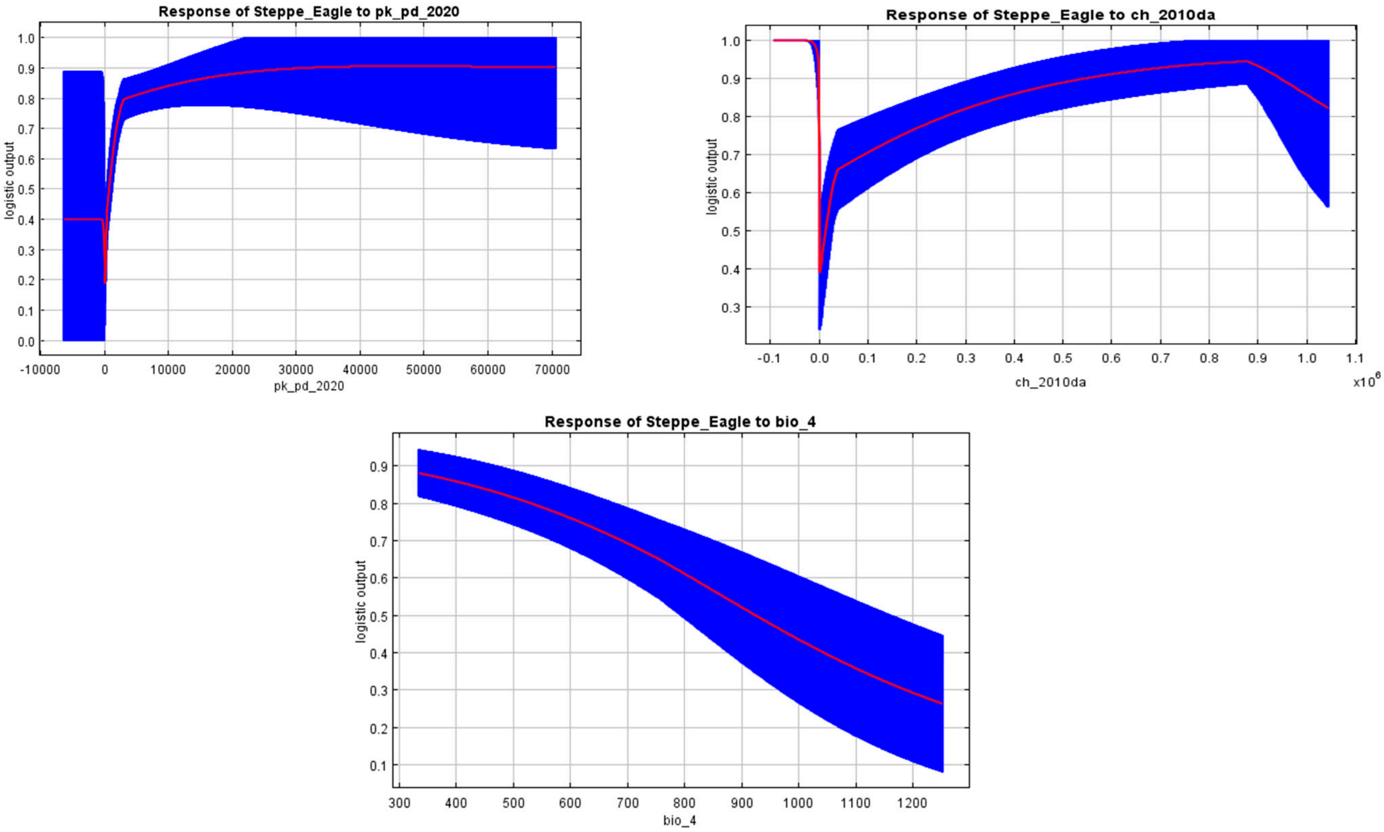

Figure 2. Steppe eagles habitat selection response curves for highly contributing variables. Response curves of predictors for steppe eagle occurrence in Pakistan. Note: The red curves show the mean response of the ten replicate MaxEnt runs, while the mean +/− one standard deviation is indicated by blue (two shades for categorical variables). The predicted value of habitat suitability (logistic output) is shown on the Y-axis, while the range of the environmental predictors is shown on the X-axis.

Results of the jackknife test showed that the environmental variable with the highest gain, when used in isolation, is human population density, which therefore appears to have the most useful information. The environmental variable that decreases the gain the most when omitted is human population density, which therefore appears to have the most information that is not present in the other variables. The values shown are averages over replicate runs (Figure 3).

3.3. Distribution of Suitable Steppe Eagle Habitat

The habitat suitability map generated through MaxEnt modelling shows that highly suitable habitats of steppe eagles are present in the Azad Jammu and Kashmir (AJK) federally administered area and surrounding areas, and southern areas of Sindh Province. Patches of highly suitable areas are also present in northern Punjab and central Punjab along the Indus River and other main rivers (Ravi, Chenab, and Sutlej). Most of the moderately suitable habitats of the steppe eagle fall in Khyber Pakhtunkhwa (KP), northern Punjab, and southern parts of Sindh. MaxEnt detected the least suitable areas for steppe eagles in Balochistan, Punjab, and Sindh. Unsuitable habitats were found in northern Pakistan, Balochistan Province, northern Sindh, and central Punjab (Figure 4). Land cover categorisation of the identified suitable habitats is given in Figure S2.

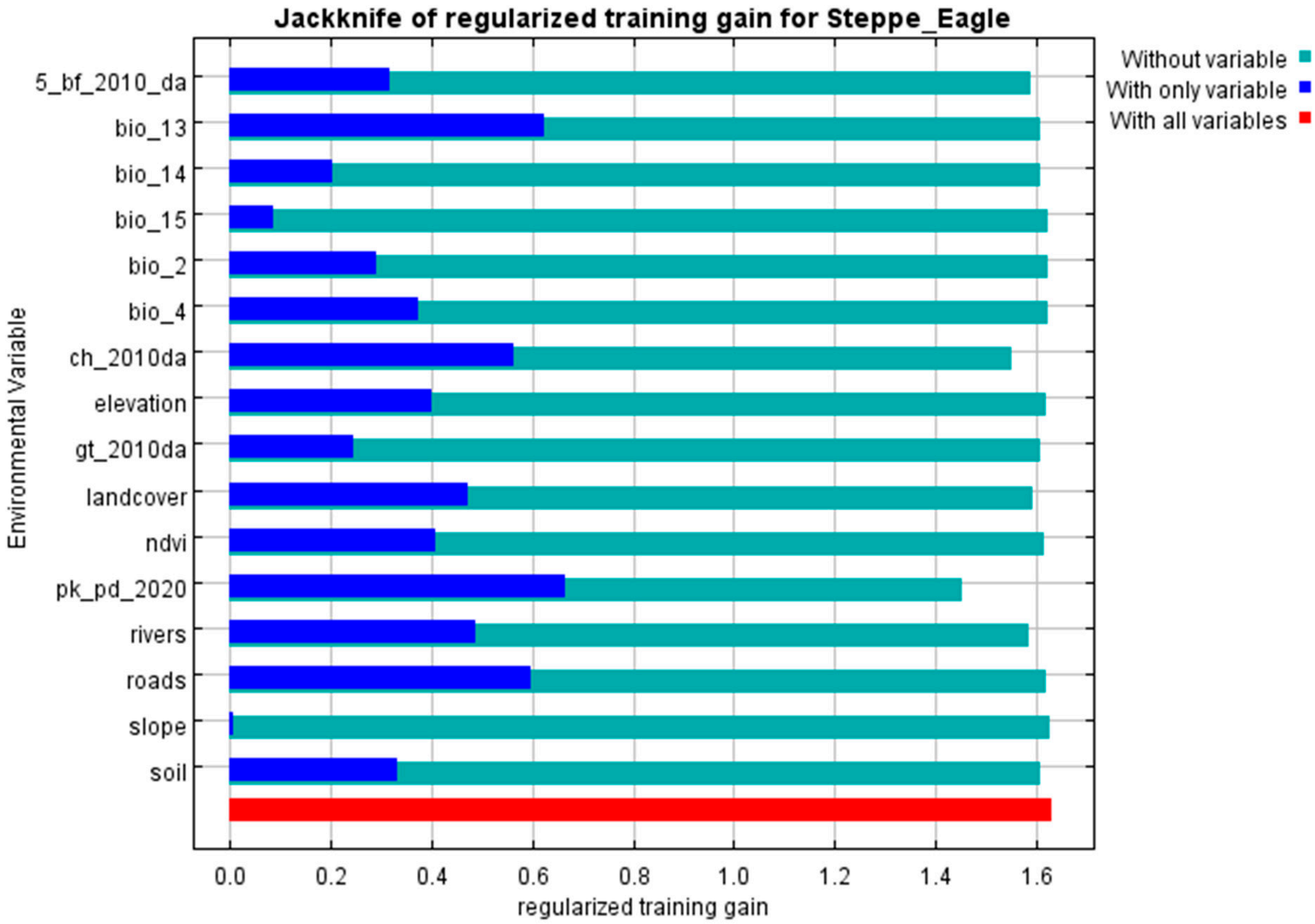

Figure 3. Jackknife test of regularised training gain of variables tested in the steppe eagles habitat suitability model.

3.4. Suitable Area

The habitat suitability map generated by MaxEnt was categorised into four classes based on the thresholds: unsuitable (0.00–0.08), least suitable (0.09–0.23), moderately suitable (0.24–0.49), and highly suitable (0.50–0.99) areas. Results obtained by processing the reclassified map revealed that the unsuitable area in our study area constituted 612,248 km^2 (69.34%), the least suitable area was 181,754 (20.58%), the moderately suitable habitat was 65,849 km^2 (7.46%), and highly suitable habitat was 23,151 km^2 (2.62%).

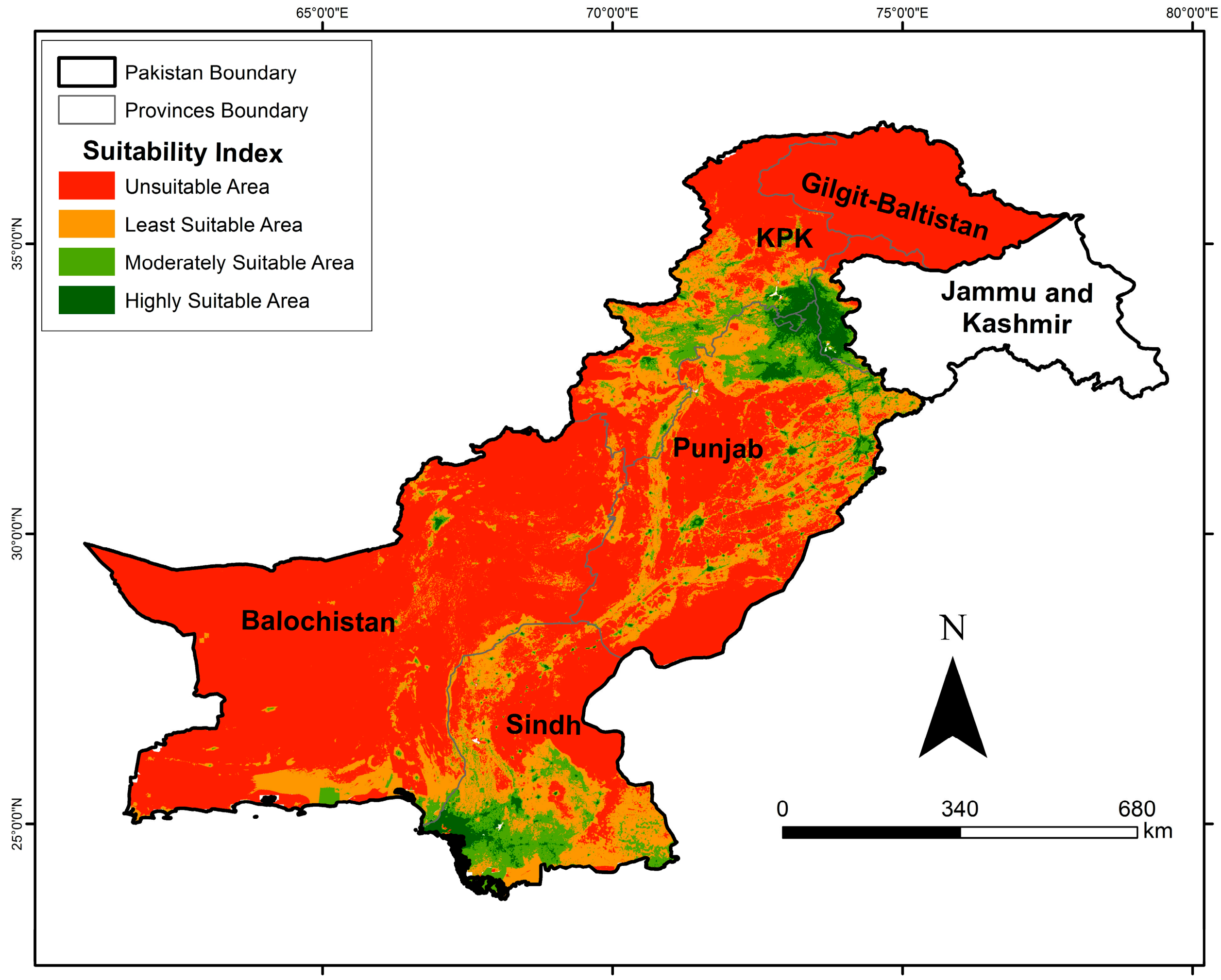

Figure 4. Distribution of different types of suitable habitats for steppe eagles in Pakistan based on MaxEnt modelling using presence-only data.

4. Discussion

This study presents the first attempt at modelling the distribution of any raptors species in Pakistan. Our results indicated that the habitat suitability of the steppe eagle was influenced by several factors, of which human population density was the most influential (27%), followed by chicken density (16.6%), temperature seasonality (11.1%), and rivers (10.3%). The human population density variable has shown a higher percentage effect on the habitat selection of this endangered eagle species (Table 2). This direct effect of human population density on steppe eagle habitat selection is due to the higher tendencies of the species toward communities' dumpsites and slaughterhouses [13]. It is believed that steppe eagles are well-known for switching food types and prefer areas that provide multiple varieties of edible resources [38]. We believe that the steppe eagle prefers to stay near human settlements due to the easy and round-the-clock availability of livestock caresses and slaughterhouse remains [39]. Keijmel et al. [40] observed approximately 6,000 steppe eagles at a dump site at Shaqra-Ushaiqer in Saudi Arabia. Our results indicated that (Figure 2) the steppe eagle showed a strong positive correlation with human population density. We presume that this trend is because of the steppe eagles' search for more dumpsites and livestock remains; yet, the indirect threat from humans in the form diclofenac sodium used for livestock persist.

The poultry sector is an important and vibrant segment of agriculture in Pakistan, with a significant contribution to the national Gross Domestic Product (GDP), i.e., (1.3%) [41]. In Pakistan, free-range chicken farming is highly encouraged due to having ideal and vast open areas. Poultry is one of the main favourite sources of food for raptors [42], either by hunting live chickens or consuming remains of the dead individuals along with poultry wastes from farms. The contribution of poultry in the current SDM for steppe eagles validates the statement mentioned above. Therefore, considering the poultry status in Pakistan, we strongly believe that this country provides promising stay sites for the steppe eagle.

Our results also indicated that temperature seasonality plays a key role in determining steppe eagle habitat selection. The annual average winter temperature of Pakistan ranges between 18–20 °C. The breeding grounds of the steppe eagle are located in European Russia, from the Republic of Kalmykia across Kazakhstan into Kyrgyzstan, China, and Mongolia [21,23]. However, winters, due to an extreme downfall in temperature in these areas, initiate the migration of this species [13]. The ideal winter temperature of Pakistan provides a good refuge, making it one of the favourite destinations for the steppe eagle.

The steppe eagle is the commonest species on the central Asian flyway to the Indian subcontinent [16]. In Pakistan, the Indus flyway is the main route for migratory birds and is one of the seven fly zones in the world [15]. This fly zone starts from the north and stretches alongside River Indus to the coasts of the Arabian Sea in the south. Our results indicated that water bodies (rivers, 10.3%) also play an important role in the steppe eagle habitat selection. We presume that this pattern is caused by several reasons, such as the availability of abundant natural prey in the form of other migratory birds, including ducks, geese, etc., availability of animal carcasses flowing with the river waters, and agricultural lands on the bank and peripheries of water bodies, thereby providing a habitat to rodents, lizards, etc., which could be important prey species for steppe eagles.

In the current SDM, the highly suitable areas were mostly found on or in the River Indus buffer zones (Figure 4). The highly suitable areas for steppe eagles were predicted in AJK in the north, northern and north-western parts of KP Province, scattered patches in Punjab Province, and the coastal areas of Sindh Province. The Balochistan Province of Pakistan was predicted mostly as unsuitable for the steppe eagles, except for some fragments in the coastal areas (Figure 4). However, the extreme highlands of north and central Pakistan were predicted as unsuitable for the steppe eagle. We believe that the steppe eagle avoids the extreme northern parts due to the very low winter temperatures, almost similar to those of the breeding grounds. However, in the case of central Pakistan, we believe that, although the temperature is favourable, the steppe eagle prefers to inhabit the Indus Delta due to the frequent and abundant supply of food in the form of natural prey bases, livestock caresses, and poultry.

Model Constraints

Although useful, yet, our model has certain limitations, i.e., lack of primary data. We believe that repeated surveys during the migratory seasons of steppe eagles may yield much more presence data, so as to obtain a more robust identification of suitable habitat across the country.

5. Conclusions

Using MaxEnt, we identified potential habitats for the endangered steppe eagle across Pakistan. Presence-only data in the current study revealed that the migratory steppe eagle prefers to primarily inhabit the areas alongside the Indus River and its buffer zones. The reason behind this is the large human population on both sides of the Indus River, which provides multiple feeding opportunities in the form of community dumpsites, livestock carcasses, and wastes from poultry and slaughterhouses. In addition, these areas serve as promising habitats, harbouring large natural prey bases for the steppe eagle. However, the expanding industrialisation and enormous use of pesticides, along with the use of diclofenac sodium in livestock, are causing potential threats to the survival of this endangered and ecologically important bird [39]. Based on the findings obtained in the current study, we strongly believe that Pakistan is one of the destinations that provides extensive wintering habitat for the steppe eagle. Yet, the threats mentioned above also hover, which need to be tackled by reducing the use of the aforementioned chemicals and safeguarding the promising habitats alongside the Indus River.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d14121135/s1, Figure S1: Results map depicting the identified suitable habitats for steppe eagles with respect to human population density; Figure S2: Land covers categorization of the identified suitable habitats (MaxEnt), and used habitats by steppe eagles as per presence points.

Author Contributions: Conceptualisation, S.A. and R.H.K.; methodology, S.A. and R.H.K.; software S.A. and R.H.K.; validation, R.H.K., L.T. and Z.L.; formal analysis, R.H.K. and S.A.; investigation, S.A. and K.K.; resources, L.T. and Z.L.; data curation, K.K.; writing—original draft preparation, S.A. and R.H.K.; writing—review and editing, S.A., R.H.K., L.T. and Z.L.; visualization, R.H.K., S.A.; supervision, L.T. and Z.L.; project administration, L.T.; funding acquisition, L.T. and Z.L. All authors have read and agreed to the published version of the manuscript.

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