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Optimized Habitat Modeling for Punjab Urial in the Diverse Landscapes, Pakistan

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ABSTRACT

The Punjab Urial is an indigenous wild ungulate species of Pakistan, which encounters dangers from illegal hunting, together with fragmented environments and expanding human settlements and changing climatic conditions. The research evaluated the habitat potential of this species throughout five regions in Pakistan, including Jhelum, Chakwal, Mianwali, Khushab and Attock. The study utilized the MaxEnt model with GIS technology and field data to identify and display suitable habitats for the species. The study revealed temperature, slope and vegetation cover as primary factors that determine Urial habitat suitability, while the species preferred steep terrain areas. The study used AUC evaluations to confirm its results, which demonstrated strong prediction accuracy in determining appropriate habitats. The species will experience a 6% reduction in its most suitable habitats by the year 2050 based on future habitat suitability models. The results from this study show that protecting habitats with high suitability levels is crucial for both ecological stability and genetic diversity conservation and these findings provide actionable recommendations for saving the Punjab Urial. The maps function as essential tools for conservation planning and protected area creation because they direct efforts to protect the long-term survival of Urial populations across Pakistan's diverse environments.

Key words: HSI, *Ovis vignei*, GIS, Punjab Urial, Arc GIS

INTRODUCTION

The ecosystem's balance and stability depends on biodiversity because it delivers important services like; water purification, along with nutrient cycling, soil fertility, climate regulation and pollination. Pakistan's diverse wildlife and cultural history continue to make it a valuable asset for local populations (Awan 2006). According to Hussain *et al*. (2015), the wildlife population exclusive to Pakistan, including the Punjab Urial contributes vital cultural and ecological importance. The worldwide decrease in biodiversity occurs due to habitat destruction, along with pollution, climate change and human activity growth (Bajwa *et al*., 2023). The environmental exposure of Pakistan's biodiversity-rich regions has intensified conservation efforts to protect species and their habitats (Khan *et al*., 2015).

Understanding a species' environmental needs, population distribution, and adaptations to their environment is essential for the effective implementation of conservation effort (Guisan & Thuiller, 2005). The field of conservation biology depends heavily on habitat modelling methods that forecast species distributions under different environmental scenarios (Suleman *et al*., 2020). The tool MaxEnt processes ecological information together with spatial databases to create probability distribution maps that identify suitable habitats throughout different geographic regions (Phillips *et al*., 2006). The combination of ecological information with Geographic Information Systems (GIS) through MaxEnt modeling allows identification of important habitat characteristics, including elevation levels, vegetation types and climate factors that determine species distribution patterns (Khan *et al*., 2015).

The habitat suitability of Punjab Urial depends on topographic factors together with climate variables and land cover characteristics (Suleman *et al*., 2020). The species selects steep areas filled with dense vegetation, which supplies both food and protection from human activities and predators (Schaller & Mirza, 1974). The fragmentation of these habitats due to human settlements

and different land use practices makes isolated populations at risk of genetic deterioration and environmental strain (Awan, 2006). Climate change creates additional risk to the species as it modifies temperature and precipitation patterns, which affect food and water availability. Future habitat modelling can help to identify important conservation zones, which will help in adaptive management strategies development (Guisan & Thuiller, 2005).
The research used habitat modelling to determine the distribution of Punjab Urial across five main districts of Punjab, including; Jhelum, Chakwal, Mianwali, Khushab and Attock. These districts function as important conservation areas for Urial because they lie within the Salt Range, which serves as a biodiversity hotspot (Mirza *et al*., 1980; Bajwa *et al*., 2023). The study focuses on discovering key environmental parameters that determine habitat suitability and important areas that support Urial long-term survival. With current and Future habitat Suitability modeling, this research outcomes will serve as the practical purposes for conservation strategy development, policy formulation and protected zone establishment alongside land-use programs and community-based conservation support (Shackleton, 2001).

MATERIALS AND METHODS

A total of 8990 km2 area was studied to identify the distribution and habitat status of the Punjab Urial in Pakistan. The study area lay in five districts (Mianwali, Chakwal, Attock, Jehlum and Khushab) of Pakistan (Suleman *et al*., 2020). Dry subtropical semi-evergreen scrub forests and extreme seasonal temperature variations, ranging from 5.7 °C to 39 °C, characterised the study area (Awan *et al*. 2006). Following Suleman *et al*. (2020), Punjab Urial potential habitats were identified through available published literature and secondary sources, i.e. official documents of Wildlife departments and local Hunters. After the identification of potential habitats, twenty-five field surveys were conducted between January and June 2023 (Suleman *et al*., 2020). After the confirmation of species presence at a specific site, the GPS coordinates were recorded using a Garmin Map 76 device. The GIS laboratory at Gatwala, Faisalabad Region, was used for Geospatial data integration.
The study used 120 spotting points (Fig. 1) and two types of variables: topographical variables (Digital Terrain Model (DTM) and present-day bioclimatic variables) for Maxent modelling. The DEM layer was obtained from the USGS website, while the bioclimatic variable information was obtained from the World Clim database for the designated research zone. The DEM, slope, and aspect were integrated into a unified dataset with a resolution of 1 square kilometre. The datasets were converted to ASCII format using the Arc Toolbox Conversion tool within the ArcGIS software suite. ArcGIS 10.8's spatial analysis tool was employed to excerpt slope and aspect from DEM and transformed into World Geodetic System (WGS) 1984 (UTM) zone 43 north (Suleman *et al*., 2020). The Maxent model was used to predict the species' suitable habitat, employing 15 replicates for accuracy. The Maxent 3.4.4.k version was used with a random seed option, 500 iterations, and 10,000 test maximum points. The study also used secondary data to forecast the species' suitable habitat. The cartographic representation of the Urial across five districts of Punjab, Pakistan, features azure lines tracing water channels and crimson demarcations delineating district boundaries. The regal purple lines encircle the study area, a meticulously defined realm of exploration (Suleman *et al*., 2020).
Thirteen environmental variables (Table 1) were selected for modelling the ecological preferences and habitat requirements of the Punjab Urial. These variables were downloaded from WorldClim (Version 2.1) at a spatial resolution of 30 arc-seconds (~1 km²) and vegetation indices from MODIS (Suleman *et al*., 2020). . Topographic variables were derived from a Shuttle Radar Topography Mission (SRTM) Digital Elevation Model. The datasets were resampled to 1 km resolution and converted to ASCII format for MaxEnt modelling. A multicollinearity test was performed using Pearson correlation coefficients to minimise redundancy and overfitting(Suleman *et al*., 2020).
The study used MaxEnt version 3.4.4 to model the habitat suitability of Punjab Urial in Pakistan. The model was robust in handling presence-only species data and produced high-quality predictive maps. The model settings included default feature types, a regularization multiplier, and 5000 iterations for convergence. A k-fold cross-validation approach was adopted with 10

replicates, with occurrence data randomly partitioned into training and testing sets. 10,000 background points were generated to represent the environmental space. The model was calibrated using 75% of the occurrence data for training and 25% for testing, with 500 iterations and 10,000 background points (Suleman *et al*., 2020). The model performance was evaluated using the Area Under the Curve (AUC), with additional metrics like variable contribution percentages and omission rates providing further validation. Future habitat projections for 2050 used CMIP6 climate data under the SSP245 scenario that underwent 1 km resolution downscaling while MESS analysis detected major deviations between future and present-day climates. The trained model was projected onto these future climate layers to predict habitat suitability changes (Suleman *et al*., 2020).

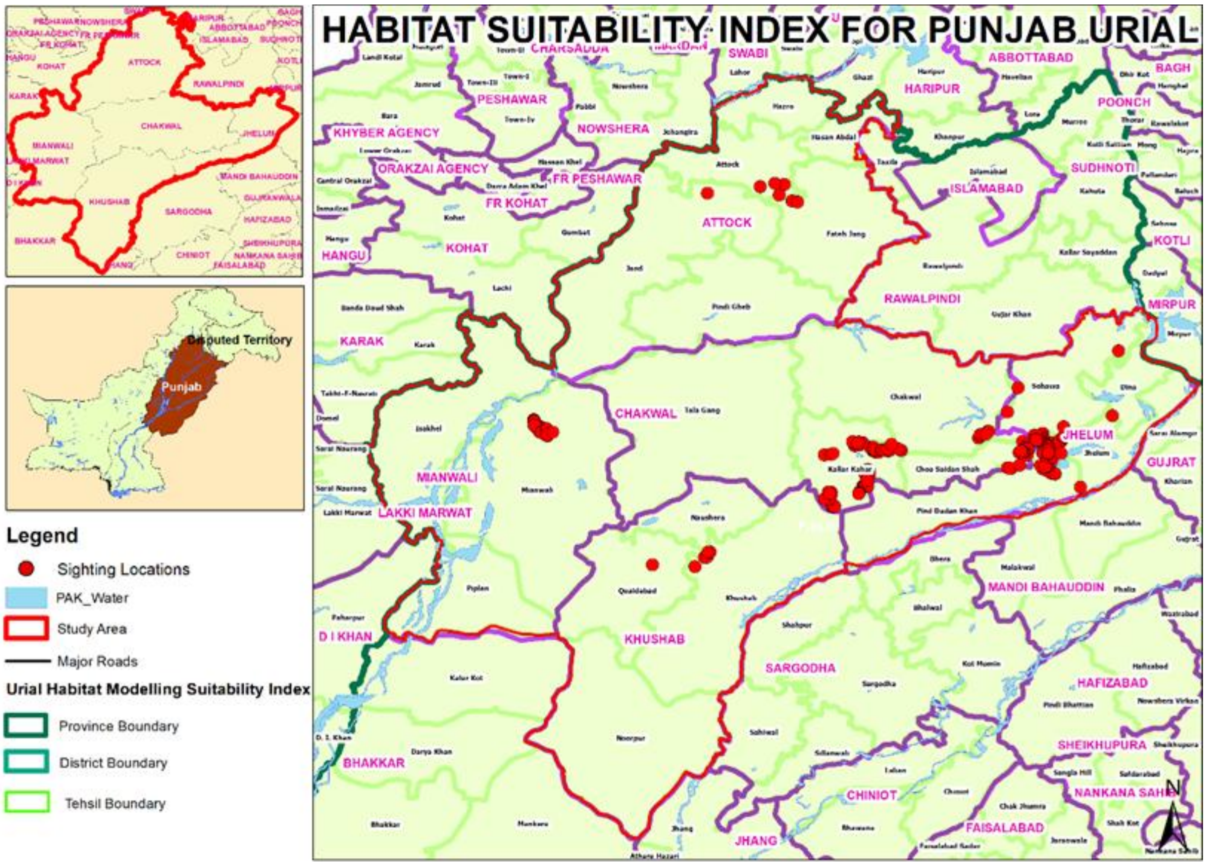

Fig. 1 Current distribution of Punjab Urial (*Ovis vignei*) in Pakistan

The model's performance was assessed using the Area Under the Receiver Operating Characteristic Curve (AUC) metric, which measures its ability to distinguish between presence and background locations. AUC values closer to 1.0 indicate excellent performance. The model's stability was checked by examining the standard deviation of AUC scores across cross-validation replicates. Variable importance was assessed using percent contribution and permutation importance, with Jackknife tests conducted to understand the individual and combined importance of variables (Suleman *et al*., 2020). .

The continuous MaxEnt output was converted into habitat suitability maps through threshold application which divided the areas into high and moderate and low suitability zones based on their probability values. The spatial analysis and conservation planning process used ArcGIS to join district boundaries with protected area layers and habitat suitability maps. The statistical methods used in this study showed how species interact with their environment and which environmental factors matter most (Suleman *et al*., 2020). The methodology proves strong because it uses detailed data sets together with field observation evidence combined with remote sensing technology. The study compared its findings against other research to discover specific

ecological factors, which drive Punjab Urial distribution mainly through the strong effect of slope. Anticipation of potential range shifts is critical for long-term species conservation. Thus, this approach offers a comprehensive framework for current and future habitat suitability assessment. This also supports targeted conservation strategies for a targeted species. By integrating bioclimatic shifts expected under moderate climate change, future habitat projections were modelled using Representative Concentration Pathway (RCP) 4.5 climate scenarios for 2050.
Future Habitat Suitability mapping:
The study used seven environmental variables for future habitat suitability modeling, including topographic and bioclimatic layers (Table 1). Topographic variables were obtained using Shuttle Radar Topography Mission data at a resolution of 30 meters, which was later resampled to 1 square kilometer (Fick & Hijmans, 2017). Bioclimatic variables were obtained from WorldClim version 2.1 (Fick & Hijmans, 2017) for Representative Concentration Pathway (RCP) 4.5 scenario projections for 2050. Due to its suitability for presence-only data and robust performance in ecological niche prediction, MaxEnt version 3.4.4 (Phillips *et al*., 2006) was used for species distribution modelling (Elith *et al*., 2010). The model run with 500 maximum iterations, 10,000 background points, and 15 replicate runs. All raster layers were standardized to a 1-km² resolution and clipped to the study extent using ArcGIS 10.8. The environmental variables were converted to ASCII format for compatibility with MaxEnt. The model was evaluated with the Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) curve, with AUC values >0.9 indicating excellent model performance (Swets, 1988). The model outputs were generated in logistic format, providing the probability of suitable habitat ranging from zero (unsuitable) to one (highly suitable).
The contributions and permutation importance of each variable were assessed, and a jackknife test was applied to determine the relative importance of environmental predictors. Response curves were also generated to explore the marginal effect of each variable on habitat suitability. Model outputs were generated in logistic format, which provides the probability of suitable habitat ranging from zero (unsuitable) to one (highly suitable). Several threshold values were tested to evaluate model sensitivity and specificity, including the "maximum training sensitivity plus specificity" and "10 percentile training presence" thresholds (Liu *et al*., 2013). Final habitat suitability maps were georeferenced in ArcMap and overlaid with district boundaries to visualize spatial predictions for conservation planning.

Results
The habitat suitability evaluation of Punjab Urial through the MaxEnt model demonstrates excellent prediction results. The model obtained its highest Training AUC (Area Under the Curve) score at 0.9678 showing its outstanding prediction capabilities (Table 1). The performance metric AUC shows perfect habitat differentiation when it reaches values close to one. The model obtained Regularized Training Gain of 1.981 and Unregularized Gain of 2.342, which was slightly higher. The values shows how well the model can determine suitable habitats while keeping the model simple. The analysis included 148 occurrence records and 10,107 background points, which ran through 500 iterations to generate robust results (Table 1).

Table 1: MaxEnt Model Performance Metrics for Punjab Urial

Metric	Value
Training AUC	0.9678
Regularized Training Gain	1.981
Unregularized Training Gain	2.342
Maximum Iterations	500
Training Sample Size	148
Background Points	10,107

The model's prediction accuracy was affected by different environmental variables (Table 2). The terrain slope (future slope) held the greatest percent contribution at 39.3% but exhibited low permutation importance at 1.4%, which means it, played a role in model structure but was not crucial as a standalone factor. The permutation importance scores for bioclimatic factors (future bioclim) and minimum temperature (future tmin) reached 41.4% and 21.3% respectively, which shows their essential roles for habitat suitability assessment. Elevation (future dem) and precipitation (future prec) also significantly contributed to the model (Table 2). The MaxEnt output divided habitat suitability into four distinct categories according to Table 3 which are highly suitable (>0.8), moderately suitable (0.6–0.8), low suitability (0.4–0.6), and unsuitable (<0.4). These classifications represent different ecological conditions, which vary from the most favorable to environments that probably fail to maintain Urial populations in the long term.

The model's thresholds and omission rate were analyzed to assess performance reliability (Table 4). The lowest omission rate (0) occurred at a fixed cumulative threshold value of one with a Clog threshold of 0.014, indicating near-perfect prediction. As thresholds widened, omission rates increased. For example, the 10-percentile training presence threshold showed an omission rate of 9.5%, suggesting a decline in model accuracy at broader thresholds. Figure (2) illustrates this relationship between omission rate and predicted area, with omission rates calculated using both training and test datasets. Ideally, predicted and observed values should align closely to ensure accurate performance.

Table 2: Environmental Variable Contributions to the MaxEnt Model

Environmental Variable	Percent Contribution (%)	Permutation Importance (%)
Future slope	39.3	1.4
Future tmin	18.2	21.3
Future bioclim	15.1	41.4
Future dem (elevation)	14	11.6
Future prec (precipitation)	10.2	15
Future aspect	1.7	0.3
Future tmax	1.5	9.1

Table 3: Habitat Suitability Classification Based on MaxEnt Output

Suitability Class	Probability Range	Ecological Interpretation
Highly Suitable	> 0.8	Optimal areas with preferred terrain/climate
Moderately Suitable	0.6 – 0.8	Likely suitable but with some constraints
Low Suitability	0.4 – 0.6	Marginal habitat
Unsuitable	< 0.4	Not suitable for long-term occupancy

Table 4: Summary of Threshold and Omission Rates

Threshold Type	Cumulative Value	Clog Threshold	Omission Rate
Fixed cumulative value 1	1	0.014	0
Fixed cumulative value 10	10	0.101	0.027
10 percentile training presence	25.94	0.377	0.095
Max training sensitivity plus specificity	20.676	0.272	0.041

Figure (3) presents the Receiver Operating Characteristic (ROC) curve, which shows model performance based on predicted areas rather than actual commission errors. As a result, the AUC never reaches a full value of one, though it remains high. Figure (4) displays the jackknife test results, which evaluate the importance of each environmental variable. This analysis helps identify which variables most strongly influence Urial distribution in the study area. Table (5) presents the comparison of habitat suitability under current conditions with future climate predictions based on 2050 RCP 4.5 projections. The results indicate a reduction in highly suitable habitats from 18% to 12%

(a 6% decrease), and moderately suitable areas decline by 3%. As a result, low suitability and unsuitable zones grow by 3% and 6%, respectively. The observed alterations indicate that climate change will probably cause suitable areas for the Punjab Urial to decrease.

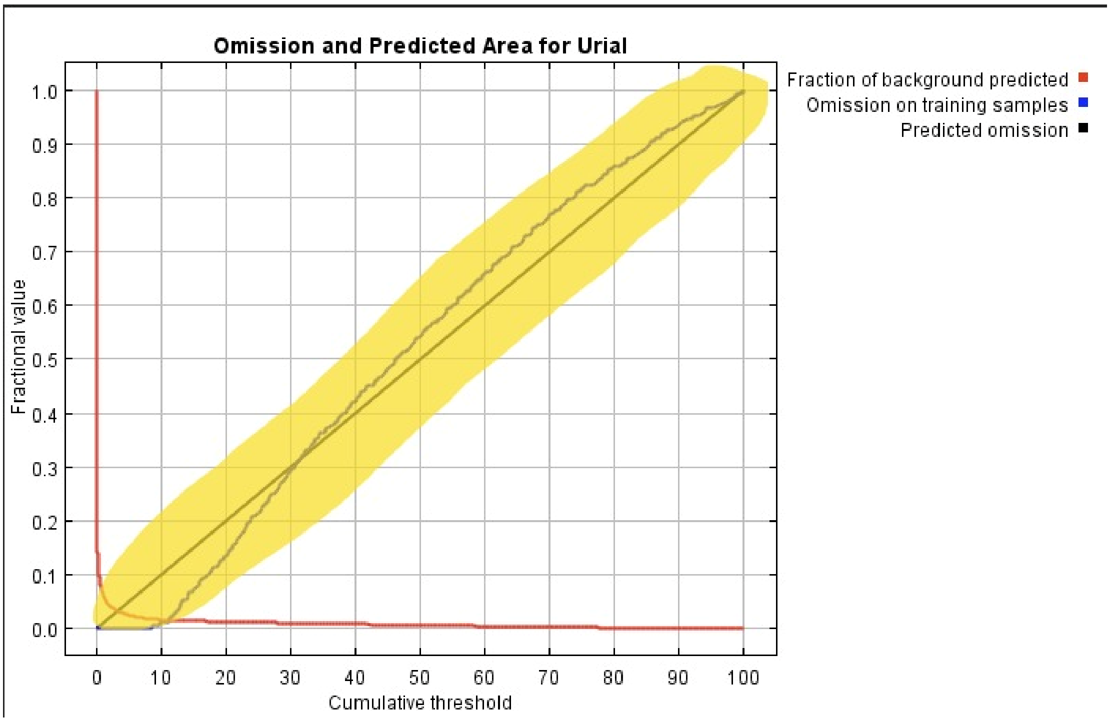

Fig. 2: Average omission and predicted area relative to the cumulative threshold

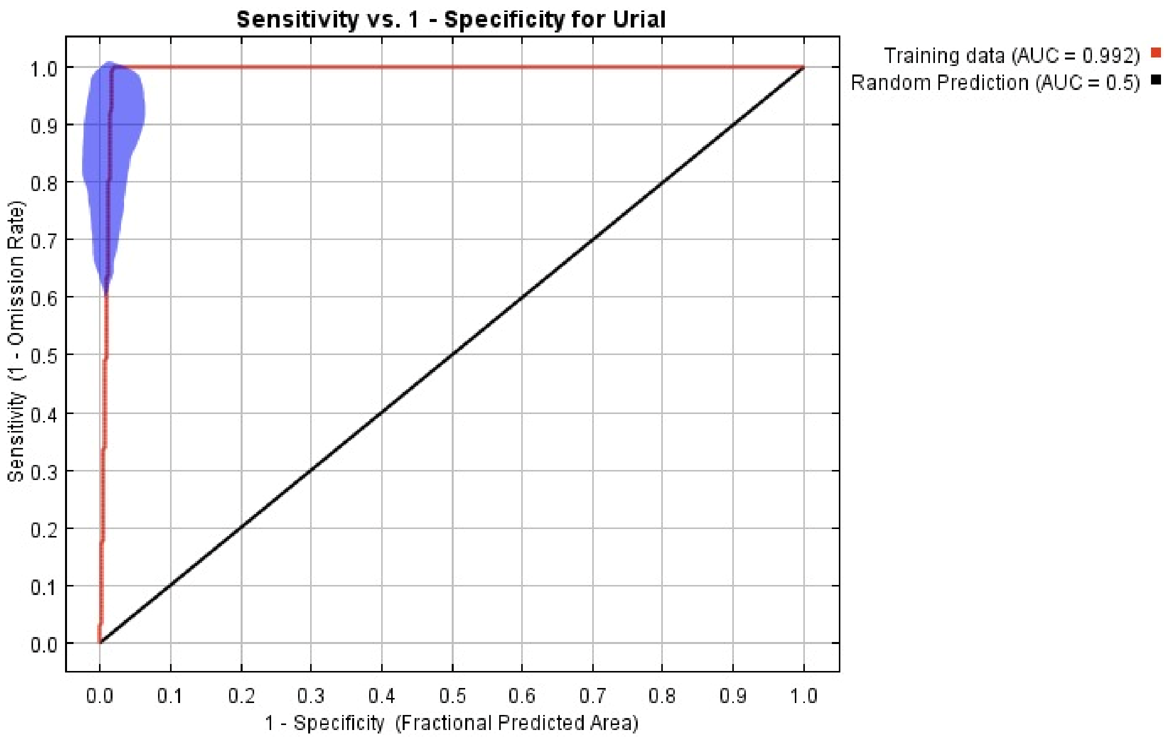

Fig. 3: Receiver Operating Characteristic (ROC) curve for Punjab Urial prediction

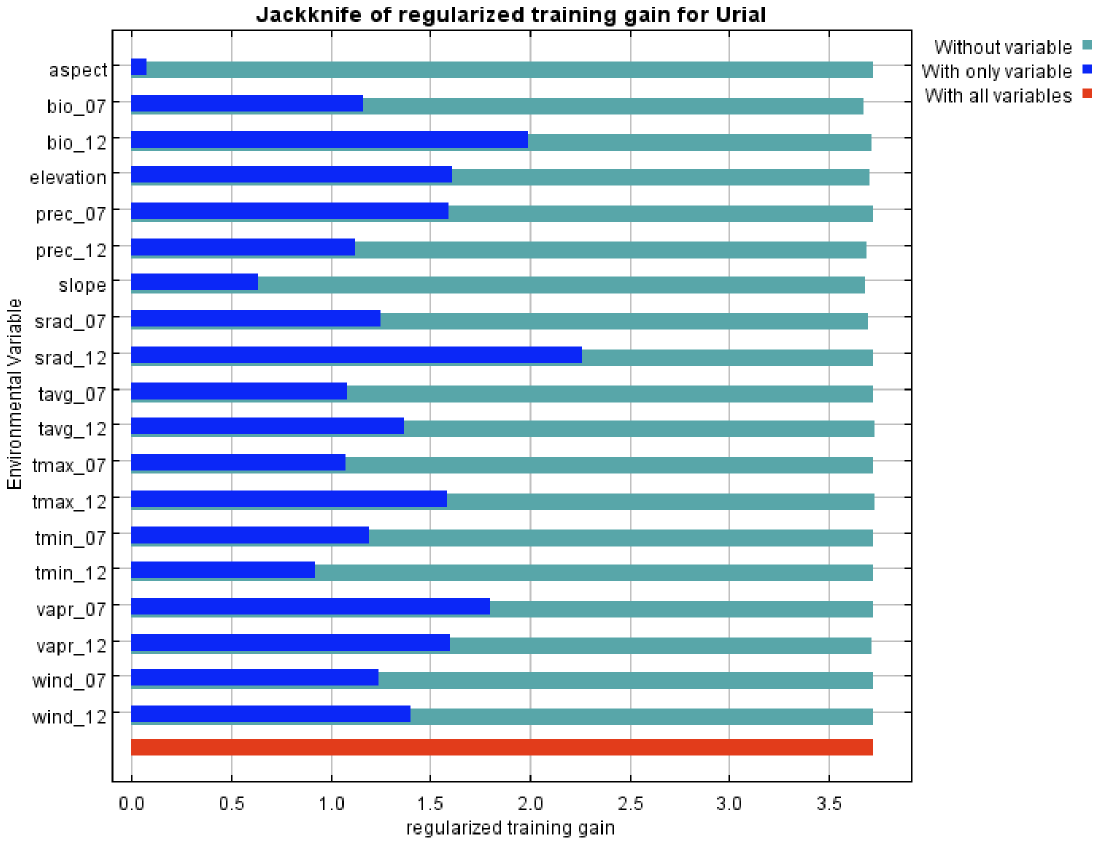

Fig. 4 Jackknife model of Urial revealing slope as both the most informative standalone and complementary environmental variable

To enhance spatial accuracy, the MaxEnt output was georeferenced in ArcMap using GIS shape files of district boundaries. The final habitat suitability map integrates model predictions with district outlines, offering a clear and reliable visual tool for identifying priority conservation zones. Figures (5, 6) shows the MaxEnt habitat prediction model. Warmer colors in these figures represent areas with higher habitat suitability. White and violet dots indicate training and test presence locations, respectively. According to the maps the most suitable locations for Urial survival exist within the study area of Punjab in Jhelum Chakwal Mianwali Khushab and Attock. The model accurately represents the distinct elevation range of the Salt Range (200–1,000 meters) because this feature strongly affects habitat suitability through its rocky landscape and appropriate plant life.

Table 5: Estimated Suitable Area Percentages (Current & Future Scenario)

Suitability Class	Range		Estimated % Area		Change from Current to 2050 Habitat Change Summary
	Current Scenario	Future Scenario - 2050, RCP 4.5	Current Scenario	Future Scenario - 2050, RCP 4.5	
Highly Suitable	> 0.8	> 0.8	18%	12%	↓ 6%
Moderately Suitable	0.6 – 0.8	0.6 – 0.8	24%	21%	↓ 3%
Low Suitability	0.4 – 0.6	0.4 – 0.6	28%	31%	↑ 3%
Unsuitable	< 0.4	< 0.4	30%	36%	↑ 6%

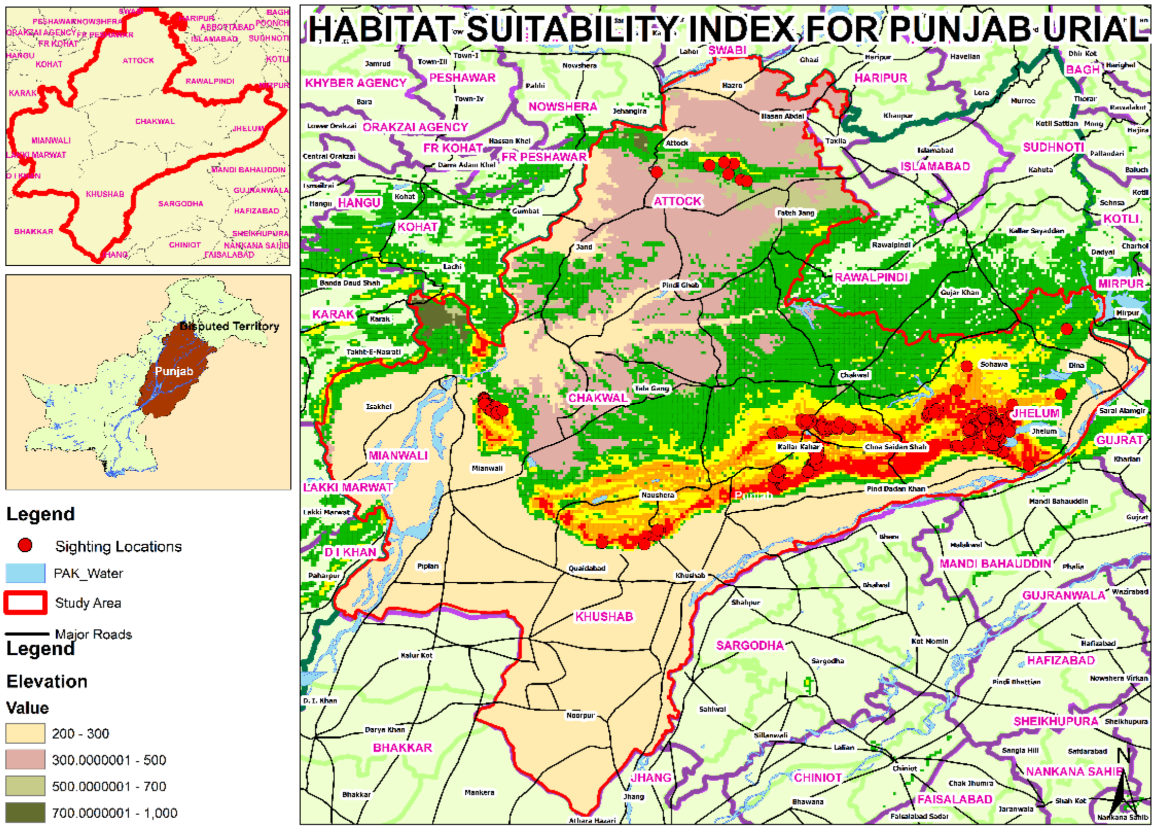

Fig. 5: Habitat Suitability Index for Punjab Urial in Pakistan

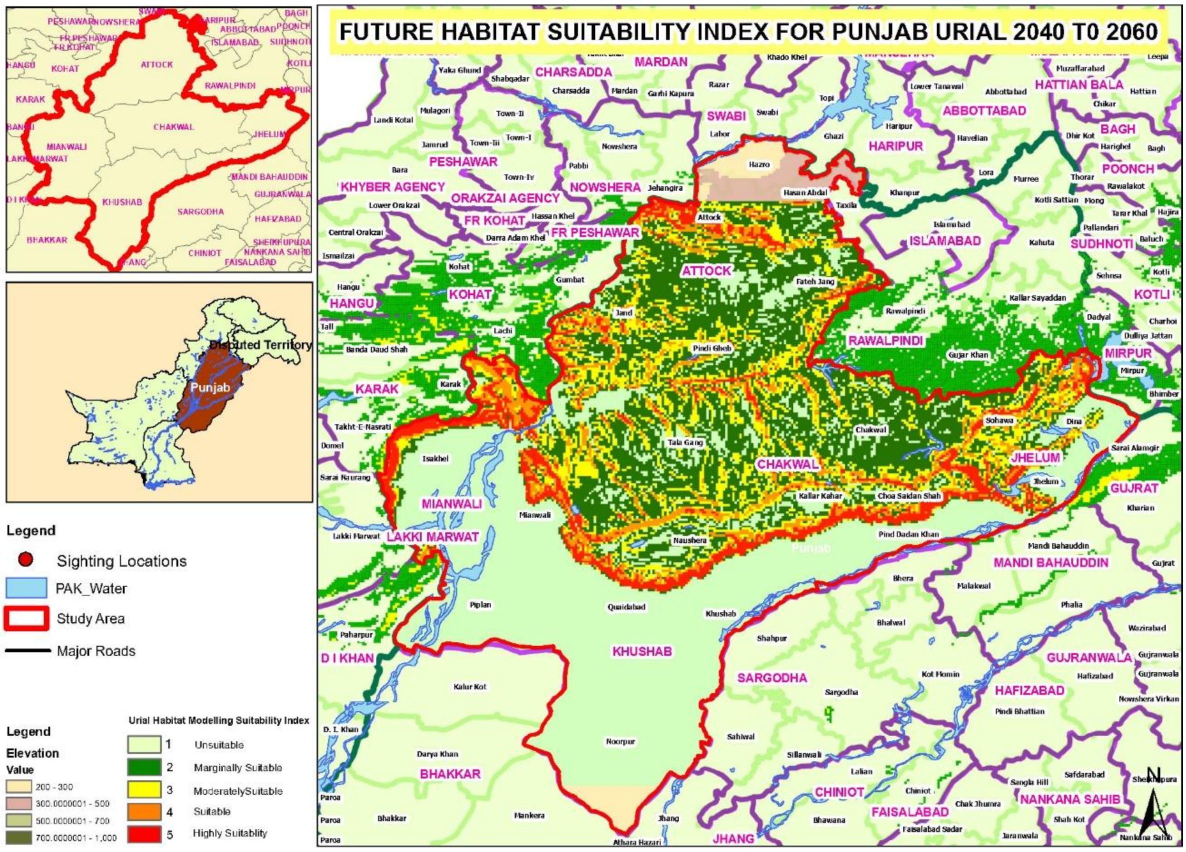

Fig. 6: Future Habitat Suitability Index for Punjab Urial in Pakistan

DISCUSSION

The Punjab Urial (Ovis vignei punjabiensis) is present in specific locations throughout Pakistan including Attock, Khushab, Jhelum, Kohat, Mianwali and Chakwal (Suleman *et al*., 2020; Iqbal *et al*., 2012; Khan *et al*., 2015; Hussain *et al*., 2015; Habiba *et al*., 2015; Arshad & Hussain, 2018). There is a potential habitats habitat for the species in other areas, which include Rawalpindi, Sargodha, Gujrat, Mardan, Swabi, Nowshera, Haripur, Karak, North Waziristan, Bannu, Dera Ismail Khan, Lakki Marwat and select areas of Azad Kashmir including Bhimber and Mirpur (Suleman *et al*., 2020). According to literature, a viable population of Punjab Urial existed in these potential habitats (Malik, 1987; Awan *et al*., 2004c; Suleman *et al*., 2020) but due to many anthropogenic factors, the species had been vanished from these habitats. Since the year 1976, the geographical territory of the Punjab Urial has decreased by 70 percent (Awan *et al*., 2004a, b; Suleman *et al*., 2020).

The MaxEnt-grounded niche felicity model of this study shows a high predictive performance, with an AUC score of 0.968. This shows the effectiveness of MaxEnt in modelling the distribution of species using presence-only data, particularly for hovered and disintegrated populations (Elith *et al*., 2010; Merow *et al*., 2013). The model predicted the slope as the most affecting environmental factor on Punjab Urial distribution. This also suggests a strong preference of the Punjab Urial for steep, rugged terrain, as they provide refuge from predators and human activity. These preferences are consistent with field compliances in protected areas where animals live at elevations between 500 and 1,000 meters, such as the Soan Valley and Diljabba-Domeli Game Reserve (Schaller & Mirza, 1974; Khan *et al*., 2015; Habiba *et al*., 2015). The present model supports the idea that Temperature influences physiological functions, food availability, and seasonal migration in mountain ungulates (Brodie *et al*., 2015), as minimum temperature (future tmin) contributed 21.3% to the model. Therefore, with the temperature rise, the suitable habitat may shift to a higher elevation, as most of the Himalayan species respond to warming climates (Paudel & Kindlmann, 2012).

Precipitation supports the growth of the semi-arid vegetation that forms the Urial's primary food source. Therefore, the changes in bioclimatic variables like precipitation and annual temperature also play a significant role in habitat distribution in the Punjab Urial (Suleman *et al*., 2020). Contributions from future bioclimatic variables (15.1%) and precipitation (10.2%) highlight the sensitivity of Urial habitats to changes in rainfall. As monsoon variability increases across the Salt Range and northern Pakistan, these changes may further fragment suitable habitat areas (Boone *et al*., 2006; Ali *et al*., 2019). With a 14% contribution, elevation role is significant in habitat selection for the species, while Aspect (17% contribution) showed limited influence in this model.

A comparison of historical and current distribution maps shows a persisting trend of habitat loss (Arsha d & Hussain, 2018). Present habitat modelling suggests that many earlier habitat areas by the species still have moderate habitat suitability, which shows a potential for species reintroduction. The model identifies regions in Chakwal, Khushab, and Attock as being extremely stable for conservation planning and management of Punjab Urial. To improve gene flow and lessen inbreeding in isolated populations, these areas should be given priority for protection, restoration, and possible individual relocation. Our results give key spatial data to direct conservation management efforts because the Punjab Urial is still vulnerable anyhow of current conservation programs and defended areas. Use of both ex-situ and in-situ conservation approaches in these regions could help support recovery. This aligns with strategies for Meta population management in fragmented habitats (Frankel & Soulé, 1981).

The model also shows a northward suitable habitat shift of species in the future, under the RCP 4.5 climate scenario for 2050, with shrinking availability in current core zones. Since this tendency may reduce the species' ability to tolerate environmental shocks, creating habitat corridors is becoming more and more essential. Connecting fragmented areas, especially those linking the Salt Range to adjacent northern areas, could support population movement and climate adaptation. Trophy hunting practices in northern Pakistan serve as an example of effective conservation through local community involvement because they simultaneously protect species and generate benefits for local residents (Shackleton 2001).

The research contributes essential information to national biodiversity programs and helps fulfill Pakistan's obligations toward the Convention on Biological Diversity (CBD) and Sustainable Development Goal 15. Regional wildlife management plans should include the habitat maps together with model outputs. The MaxEnt model possesses certain limitations because it excludes ecological relationships together with disease dynamics and detailed human effects such as roads and settlements (Kittle *et al*., 2008). Pseudo-absence data usage carries the risk of creating bias that requires careful management (Barbet-Massin *et al*., 2012). The collection of multi-seasonal data together with GPS collar tracking of individuals represents an approach that researchers should adopt for enhanced conservation planning. The integration of MaxEnt with Random Forest or Bioclim models should help deliver better prediction results (IUCN SSC, 2013).

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