Pakistan J. Wildl., vol. 16(2), pp 1-12, 2025

Habitat Suitability and Future Projections for Eurasian Otters (*Lutra lutra*) in Pakistan Using Species Distribution Modelling

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Running Title: HSI Model for Eurasian Otter in Pakistan

ABSTRACT

The Eurasian otter (*Lutra lutra*), an important freshwater species that is an indicator of fresh water health, is declining in Pakistan due to habitat loss and climate change. This study applied the MaxEnt model to map current otter habitats and to predict future changes under climate scenarios (RCPs 2.6–8.5) for 2050 and 2070 in Pakistan. Field surveys confirmed 80 otter locations across northern Pakistan's rivers and wetlands, while environmental data (temperature, rainfall, elevation) helped identify key survival factors. The model showed high accuracy (AUC = 0.916), revealing that 9.6 % of Pakistan (76 400 km²)—primarily the Indus Basin, Himalayan streams, and mangroves—is currently suitable for otters. Summer humidity (vapr07) and winter temperatures (tmin12) were the most critical factors, with otters favoring areas where temperatures stay between 5°C and 25°C. However, future projections predict severe declines: habitats could shrink by 85 % by 2070 under RCP 8.5, with connectivity dropping 67%, isolating populations. Northern regions like Kaghan Valley face near-total habitat loss, while coastal mangroves offer limited refuge. Unlike in Europe, Pakistan's otters are highly sensitive to human disturbances (>50 persons/km²), worsened by dams and farming. By safeguarding otters, Pakistan can protect both biodiversity and vital water resources.

Keywords: Climate change, Future SDM, GIS, QGIS, MaxEnt model

INTRODUCTION

A high rate of urbanization and pollution has resulted in the loss of many species of flora and fauna, raising concerns among biologists about protecting near-extinction species by preserving their habitats (Gazetteer, 1990). Several environmental variables associated with species distribution and abundance contribute to species preservation (Debinski *et al*., 1999). Habitat study is crucial for wildlife conservation policy development, evaluation, and conservation (Gerrard *et al*., 2001). Ecological studies like Habitat Suitability models give valuable knowledge about wildlife relations with habitats and potential habitat identification (Temple *et al*., 1986). Habitat mapping is an efficient method for conservation and management, but it isn't easy to calculate species' habitats due to their extensive distribution range. Satellite remote sensing approaches are extensively used for accurate and quick attribute evaluations (Suleman *et al*., 2020). A Geographical Information System (GIS) is a tool wildlife managers and conservationists use to manage and interpret large amounts of spatial data for species protection (Vincenzi *et al*., 2006). In wildlife habitat conservation, GIS allows the development of large-scale databases and analysis for present and future scenarios through evaluation and assessment (Suleman *et al*., 2020). Habitat suitability models help habitat assessment and give alternate strategies based on research studies, previous knowledge, and literature review (Brooks, 1997).
From the mammalian family Mustelidae and subfamily Lutrinae, Otters are semiaquatic carnivores (Hussain, 1999) that are primarily found in freshwater, riparian foliage, and rocky structures. They are considered top predators in freshwater ecosystems and the most important species in wetland ecosystems (Kruuk *et al*., 1994, Mason and Macdonald, 2009). They perform most of their activities in water, but reproduction and resting occur on land (Ullah *et al*., 2012).
The Eurasian Otter has the most extended range in Europe, Asia, and Africa (Reuther, 1993). Pakistan hosts two species of otters (de Silva, 2011), the Eurasian otter in the northern mountainous Khyber-Pakhtunkhwa province, and the Smooth-coated otter in Sindh and Punjab provinces (Khan *et al*., 2009). The wetlands and rivers of Pakistan offer a suitable habitat for the Eurasian otter. The Eurasian otter has vanished from its historical range due to anthropogenic activities such as fish competition, fur trade,

killing, pouching and habitat loss (Saavedra, 2002). Although a currently Ali *et al*. (2025) have estimated the current status of the Eurasian otter in Pakistan but there is still no comprehensive data available about the habitat of this imperial species in Pakistan, which makes it harder to protect and conserve the species effectively. Species distribution models (SDMs) like MaxEnt have been successfully used to predict habitat suitability for otters in Europe and India, but their application in Pakistan remains limited.

In Asia, it is classified as "Near Threatened" by the International Union for Conservation of Nature (IUCN, 2025). Eurasian Otter populations in Pakistan are facing particularly severe threats, and their habitats have been disturbed in the past and brought to decline in restriction; thus, the present study was designed to assess and estimate the potential habitats of the species through species distribution modelling (SDM) and how climate change (under different future scenarios) might affect their habitats by 2050 and 2070. Filling this gap in previous knowledge will help to safeguard the Eurasian otter population and the freshwater ecosystem they inhabit.

MATERIALS AND METHODS

About 960-km² area was studied in eight districts (Swat, Dir, Chitral, Kohistan, Mansehra, Gilgit-Baltistan, and Neelum) of northern Pakistan (Fig.1). The study area was selected based on available diverse freshwater ecosystems (rivers, streams, wetlands), which provide essential habitats for the Eurasian otter (*Lutra lutra*). In the study are there was a wide range of altitudinal gradients from river valleys to mountainous regions, extending up to 2000 m above sea level and characterized by Himalayan moist temperate forests (Roberts, 1997), with coniferous forests providing distinct ecological landscapes for otter distribution. Previous available literature (Ullah *et al*., 2012) and consultations with the Punjab Wildlife and Parks Department and WWF-Pakistan guided site selection, prioritizing perennial rivers and tributaries identified in 1:25 0000 hydrographic maps (Cianfrani, 2010).

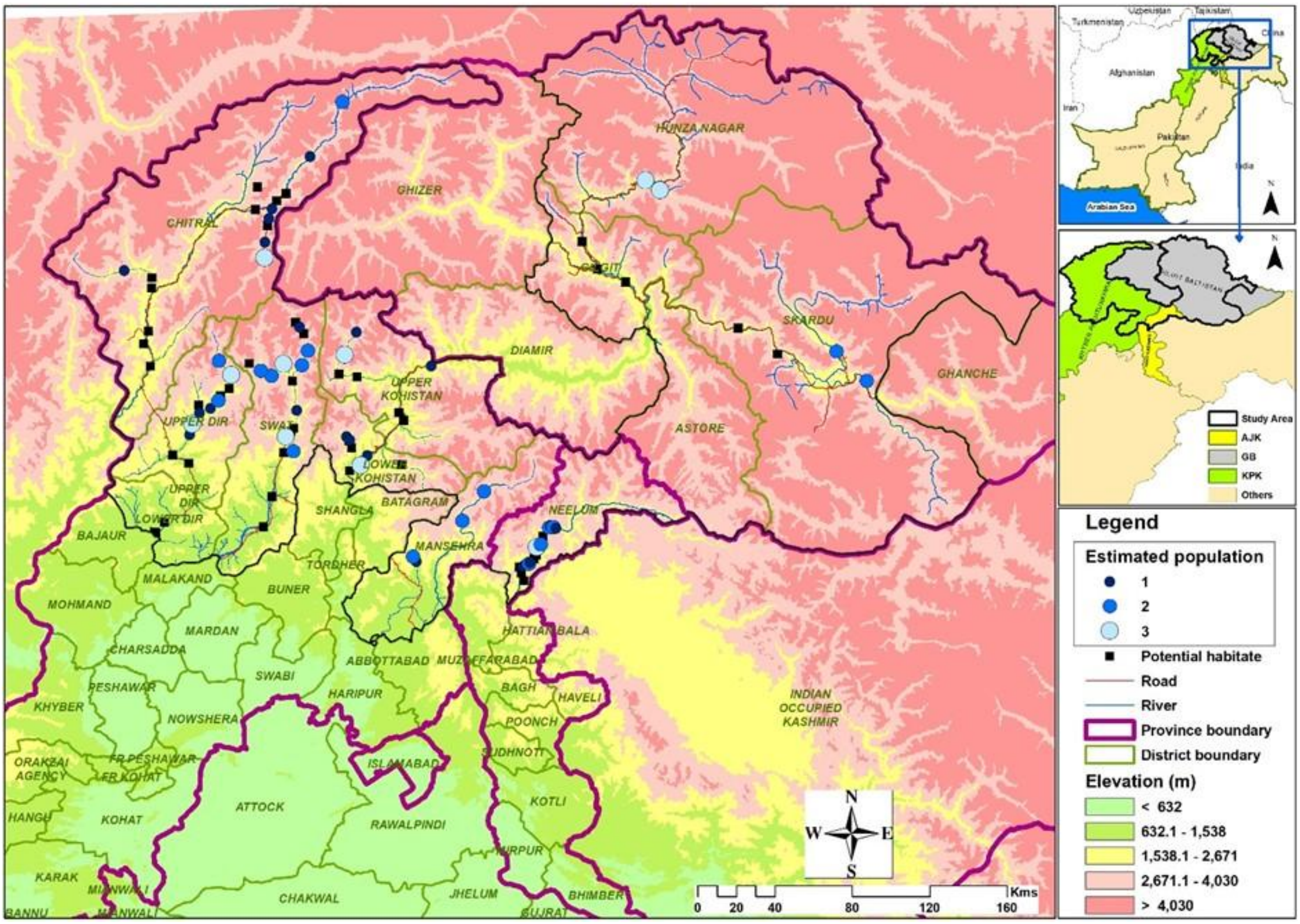

Figure 1: Current distribution of Eurasian Otter in pakistan

94 field surveys were conducted across the study area from April 2021 to September 2023, to confirm otter presence and assess habitat suitability. Presence was established through direct observations, spraints, and footprints (Loy *et al*., 2009). For each observation, geographic coordinates were recorded using a Garmin Map 76 GPS device. Habitat features such as riparian vegetation (classified via CORINE land cover) (Fernández *et al*., 2014), water availability (perennial/intermittent), and evidence of human disturbances (e.g. proximity to roads and settlements) were systematically documented at each site. The field surveys provided critical baseline data for further habitat modelling. Data were cross-validated using GIS tools at the Laboratory of the Punjab Wildlife and Parks Department, Lahore, Pakistan.

The study categorized environmental variables for the Eurasian otter into climatic, topographic, and anthropogenic factors. Bioclimatic variables, such as annual precipitation and temperature seasonality at 1 km2 resolution, were sourced from WorldClim (Fick and Hijmans, 2017). Topographic factors included slope, aspect, and elevation, derived at 30m from a Digital Elevation Model (Suleman *et al*., 2020). Steep slopes were prioritized as potential den sites (Kruuk, 2006), while areas above 2000 m a.s.l. were deemed unsuitable due to reduced prey availability (Khan *et al*., 2009). The study used municipal records and Open Street Map to extract human population density (1 km buffer around rivers) (Tian *et al*., 2005) and road networks, while land cover types (e.g., urban, agriculture) were classified using MODIS data (Usman *et al*., 2015).

The data was prepared for MaxEnt modelling software, removing duplicate or erroneous records during the cleaning phase. Environmental variables were standardized to match the study area's resolution and extent of the study area. A correlation analysis using the Variance Inflation Factor (VIF) test was conducted to eliminate highly correlated variables, retaining a final set of fourteen uncorrelated variables (VIF <10) for modelling (Cheng *et al*., 2022). All data layers were converted into ASCII format using ArcGIS 10.5 for input into MaxEnt. The data was standardised to a spatial resolution of 1 km and projected using the World Geodetic System (WGS) 1984 Universal Transverse Mercator (UTM) Zone 42 North (Suleman *et al*., 2020).

The MaxEnt version 3.3.3k (Phillips *et al*., 2006) was used for habitat suitability modelling, which was applied to 96 confirmed otter locations and 2500 randomly selected background points within a 20 km radius of each presence location. The model was calibrated using fifteen replicates, 500 iterations, and a random seed to ensure robust predictions. Approximately 20 % of the dataset was reserved for model testing. Variable importance was assessed using jackknife tests and permutation importance metrics to identify key predictors of otter distribution. On the resulting maps, the study area was categorized into four suitability classes: low (0.0–0.2), medium (0.2–0.4), high (0.4–0.6), and optimal (>0.6). These classifications provided a gradient of habitat preferences for the Eurasian otter based on environmental conditions.

The MaxEnt model was evaluated for its predictive performance, with a high discriminatory power between suitable and unsuitable habitats. The model's accuracy in explaining otter distribution patterns was further validated through independent presence/absence data collected during field surveys (Suleman *et al*., 2020). Habitat connectivity was analyzed to understand the spatial continuity of suitable habitats for the Eurasian otter (Thomas *et al*., 2022). Two dimensions of connectivity were considered: longitudinal connectivity along river systems and lateral connectivity between river catchments. Longitudinal connectivity metrics were calculated to evaluate habitat fragmentation along rivers, while lateral connectivity was assessed using a least-cost path analysis. Fragmentation metrics were calculated using FRAGSTATS, and the least-cost paths between catchments were modelled using Linkage Mapper.

Following Jamwal (2021), future projections were generated under four Representative Concentration Pathways (RCPs 2.6, 4.5, 6.0, and 8.5) for 2050 and 2070 using the HadGEM2-ES climate model (Azareh *et al*., 2022). Climate layers were downscaled to 1 km² resolution and processed in QGIS version 3.28. Binary presence-absence maps were created using the 10th percentile training presence threshold, a conservative approach to reduce over-prediction. Spatial analyses and visualizations were conducted in QGIS and R version 4.3.1, utilizing the dismo and raster packages for data extraction and response curve generation.

The final habitat suitability map was generated by converting MaxEnt outputs into raster format and reclassifying the data into suitability classes (Suleman *et al*., 2020). Regions identified as highly suitable were prioritized for conservation planning, while moderately suitable areas were designated as potential buffer zones.

RESULTS

The MaxEnt model demonstrated high predictive performance, as indicated by an Area Under the Curve (AUC) value of 0.9558 for the training dataset and the regularized training gain of 1.9091 further validated the significance of the selected environmental variables in predicting habitat suitability (Fig. 2). Permutation importance and jackknife tests identified vapor pressure, minimum winter temperature, and gentle slopes as the most influential predictors for otter distribution (Table 1).

Table 1: Percentage contribution of the used Environmental Variable

Variables	Variables name	Contribution (%)	Permutation importance
vapr07	Vapor Pressure (July)	49.5	57.8
tmin12	Minimum Temperature (December)	13.1	0
Slope	Slope	11.3	4.5
srad12	Solar Radiation (December)	6	5.2
srad07	Solar Radiation (July)	4.1	11.8
prec12	Precipitation (December)	2.2	1.7
tmax12	Maximum Temperature (December)	2.2	12.9
Aspect	Aspect	2.1	0.7
bio12	Annual Precipitation	1.6	0
tavg07	Average Temperature (July)	1.5	0
prec07	Precipitation (July)	1.5	1.1
vapr12	Vapor Pressure (December)	1.3	0.2
elevation_dem	Elevation (Digital Elevation Model)	1.2	0.2
tmin07	Minimum Temperature (July)	1	3
tmax07	Maximum Temperature (July)	0.9	0.3
wind12	Wind Speed (December)	0.4	0.2
tavg12	Average Temperature (December)	0.1	0
bio07	Temperature Annual Range	0.1	0.4
wind07	Wind Speed (July)	0	0

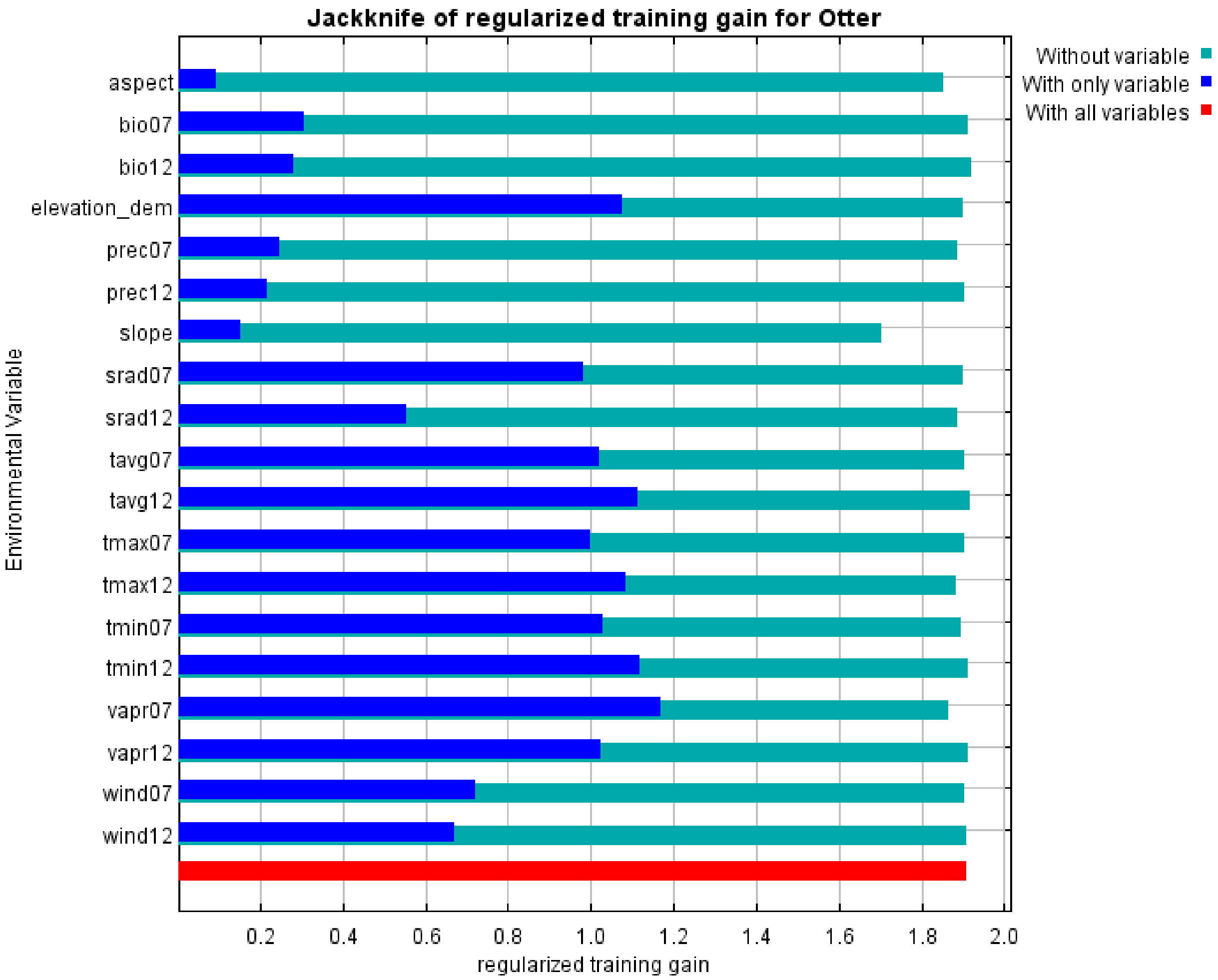

Figure 2: Jacknife of regularized training gain and area under curve (AUC) for Eurasian Otter

The model results (Fig. 3) classified the study area into four classes: low suitability (0.0–0.2), medium suitability (0.2–0.4), high suitability (0.4–0.6), and optimal suitability (>0.6). About 19.25 % (2167 km²) of the study area was highly suitable (Table 2). It mainly exists near riverine systems and wetlands in northern Pakistan. These regions have been rated for optimizing values of critical environmental factors such as vapour pressure, steady water flow, and aquatic vegetation. Moderately suitable habitats covered 32.81 % of the land area, 3692 km², and were transitional zones between highly suitable and low-suitability areas (Table 2). Low-suitability habitats, covering 47.94 % or 5400 km² (Table 2), were steep slopes, had low vapour pressure, and were characterized by unfavourable climatic conditions.

Table 2: Suitable area for Eurasian Otter distribution in Pakistan.

Suitability Zone	Suitability Range	Total Area (km²)	Total Area (%)
High-Suitability Zone	> 0.6	2167	19.25
Moderate-Suitability Zone	0.3 – 0.6	3692	32.81
Low-Suitability Zone	< 0.3	5400	47.94
Total	—	11 259	100

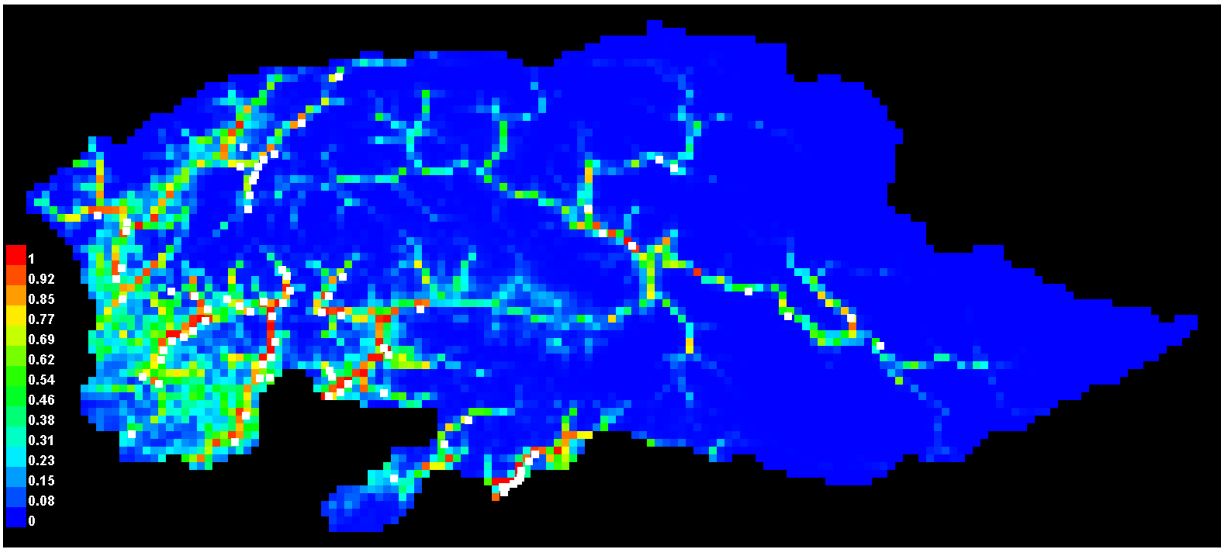

Figure 3: MaxEnt model output for Habitat Suitability Index for Eurasian Otter

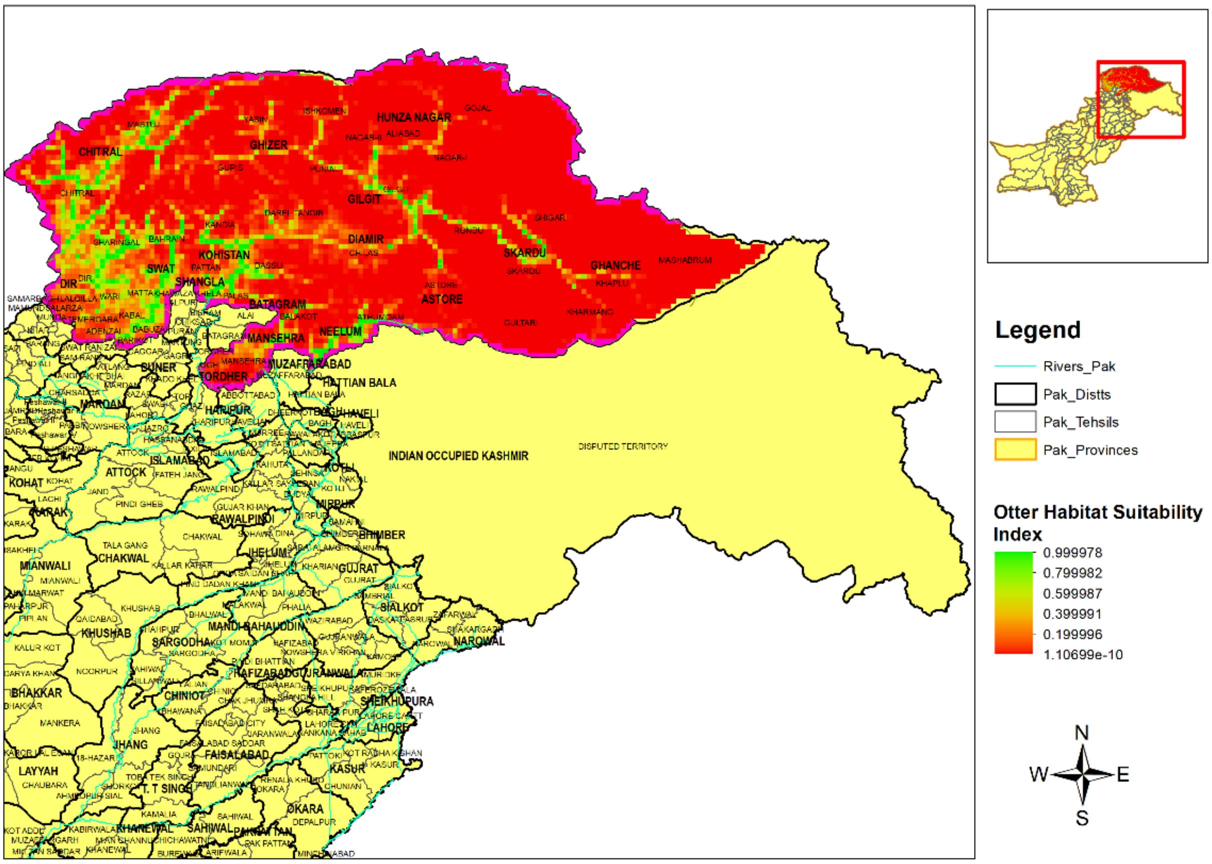

Figure 4: Habitat Suitability Index for Eurasian Otter

Fig. 5a is a habitat suitability index map that graphically represents the spatial distribution of the zones. Zones were categorized with high-resolution colour gradients; red for high-suitability habitats, yellow for moderate-suitability habitats, and blue to represent low-suitability habitats.

Among the environmental variables analyzed, vapour pressure in winter (vapr07) contributed the most to habitat suitability, accounting for 49.47 % of the model's explanatory power. Other significant variables included minimum winter temperature (13.12%), slope (11.33%), and solar radiation in December (6.01%). These variables highlight the otter's preference for habitats with stable water availability, moderate climatic conditions, and gentle slopes (Table 1, Fig. 4, 5a & b).

Connectivity analysis revealed a fragmented distribution of suitable habitats, particularly along river systems. Longitudinal connectivity within river networks was assessed using metrics such as the number of patches (NUMPs) and mean patch size (MPSs). Highly suitable patches were often fragmented by human activities and natural barriers, limiting the otter's ability to disperse and establish sustainable populations. Lateral connectivity between river catchments was evaluated using least-cost path analysis, which identified several permeable patches serving as important corridors for movement.

Approximately 9.6 % of Pakistan's land area (76 400 km²) is suitable for Eurasian otters, primarily present in the Indus River basin, Himalayan tributaries, and coastal mangrove ecosystems (Fig. 2). However, future projections under all Representative Concentration Pathways (RCPs) predict significant habitat contraction in Pakistan. By 2050, suitable areas are projected to decline by 30 % (RCP 2.6) to 45 % (RCP 8.5), with decreasing intensity to 60–85 % by 2070 (Table 3, Fig. 6, 7a,b). The most severe reductions occurred under RCP 8.5, where only 1.4 % of the current habitat (11 200 km²) is expected to remain suitable by 2070. Fragmentation of remaining habitats were pronounced in northern regions, while coastal zones exhibited localized suitability due to stable precipitation patterns (Fig. 7a, b).

Table 3: Mean (±SE) values for body weight of five breeds of female rabbits as recorded on 19 weeks at slaughter*

Scenario	2050 (% Loss)	2070 (% Loss)
RCP 2.6	30 %	50 %
RCP 4.5	35 %	60 %
RCP 6.0	40 %	70 %
RCP 8.5	45 %	85 %

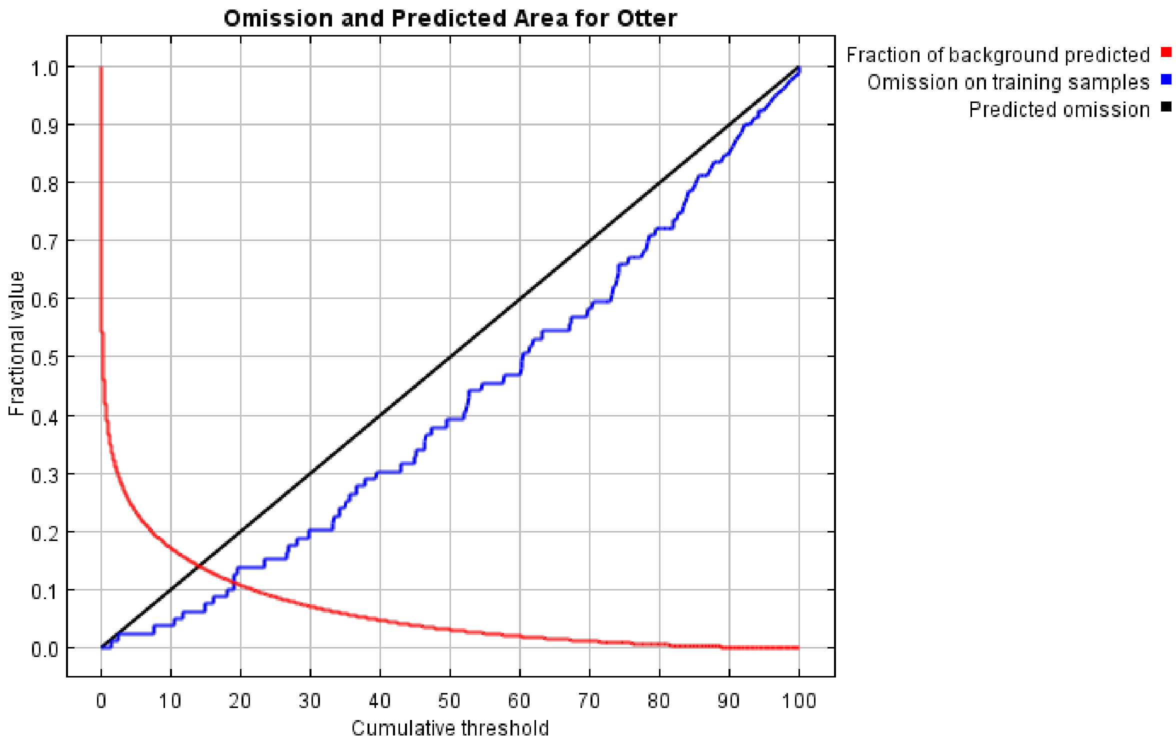

Figure 5(a): Average Omission and Predicted Area

Figure 5(b): Receiver Operating Characteristic (ROC) curve for Eurasian Otter prediction

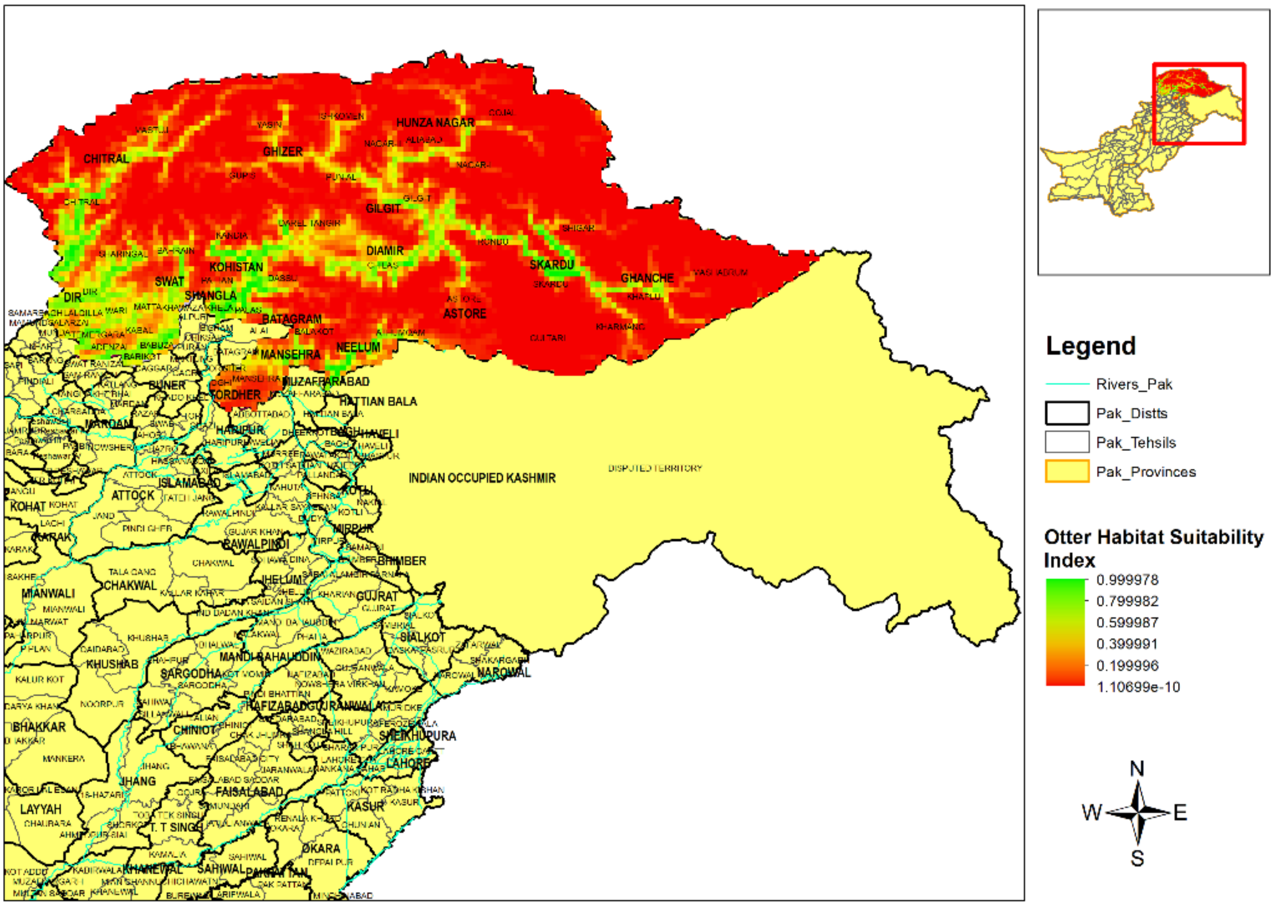

Figure 6: Future prediction for the Suitable Habitat for the Eurasian otter in Pakistan

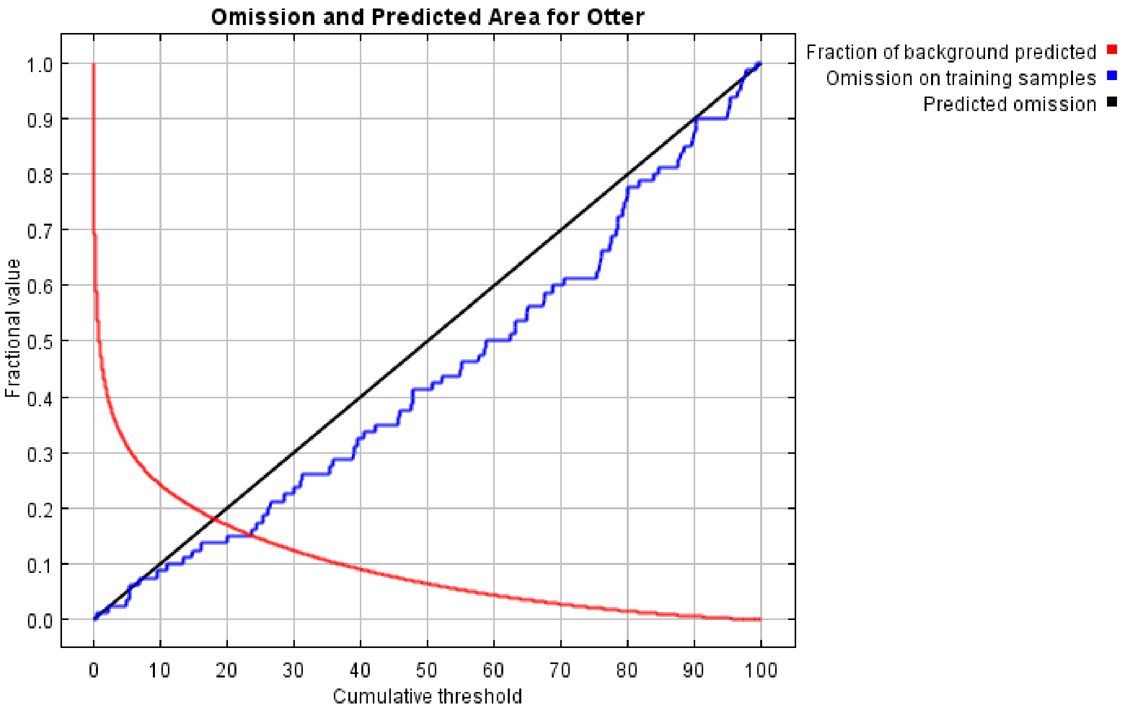

Figure 7(a): Average Omission and future Predicted Area

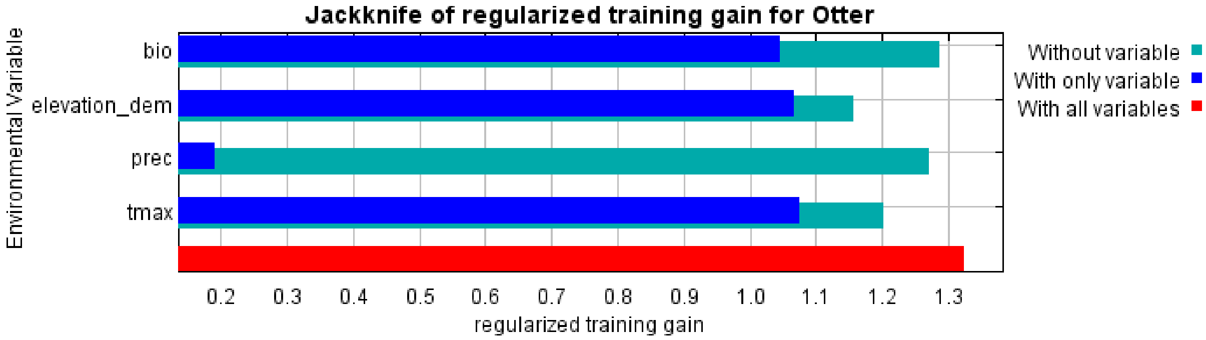

Figure 7(b): Jacknife of regularized training gain and area under curve (AUC) for Eurasian Otter

DISCUSSION

The present study developed a Habitat Suitability Index (HSI) model to assess the ecological needs. This study used a Habitat Suitability Index (HSI) model to assess where Eurasian otters can survive in Pakistan and how climate change might affect them. The results show that 19.25 % (2167 km²) of northern Pakistan—particularly riverine and wetland areas—provides highly suitable habitats due to gentle slopes (<20°), stable climates, and low human disturbance. These findings align with global patterns where otters depend on freshwater systems with abundant prey and vegetation (Kruuk 2006, Mason and Macdonald 2009). In contrast, southern Pakistan's arid plains, with extreme temperatures and water scarcity, were poorly suited, reinforcing the species' vulnerability to climate stress (Reuther *et al*., 2001).

The MaxEnt model performed well (training AUC = 0.956), with climate variables being the strongest predictors. July vapour pressure (vapr07, 49.47 %) and minimum winter temperatures (tmin12, 13.12 %) were the most critical factors, highlighting the importance of humidity and thermal stability for wetland health and prey availability. Gentle slopes (11.33 %) further confirmed the otter's preference for accessible riverbanks, consistent with studies in Nepal and India (Acharya, 2011). Solar radiation and precipitation also played a role, reflecting seasonal water dynamics essential for aquatic ecosystems.

Unlike in Europe, where otters adapt to human-modified landscapes (Hanrahan *et al*., 2019), Pakistan's otters show high sensitivity to human disturbances (>50 persons/km²). This is likely due to historical habitat loss and overexploitation along the Indus River tributaries (Ullah *et al*., 2012). Connectivity analysis shows that dams and agriculture create bottlenecks, similar to issues in Spain and Italy (Saavedra, 2002, Hanrahan *et al*., 2019), threatening genetic diversity. In Gilgit-Baltistan and Khyber-Pakhtunkhwa, the key habitats as ecological corridors under Pakistan's Biodiversity Action Plan is urgently needed.

Conservation priorities should include wetland restoration, pollution control, and regulating sand mining in high-suitability areas. Moderately suitable zones (32.81 % of the study area) could be buffers to reconnect fragmented populations. Community-based programs, like those in Nepal (Acharya, 2011), could reduce human-wildlife conflicts while promoting habitat protection. Climate projections suggest future water scarcity, so measures like artificial dens and assisted migration may help (Wilson and Namaskari, 2020).

Under RCP 8.5, otter habitats could decline by 85 % by 2070—far worse than in Europe, where similar scenarios led to 40–60 % losses. This difference likely stems from Pakistan's faster warming and weaker freshwater protections. Northern areas like Kaghan Valley and Swat River may lose habitats entirely, mirroring declines in Nepal's Himalayas. Coastal mangroves, while more resilient due to maritime climates, still face threats from sea-level rise and pollution, as seen in Bangladesh's Sundarbans (Islam and Bhuiyan, 2018).

Habitat fragmentation poses a major risk to genetic diversity. Connectivity between the Indus Delta and Himalayan rivers may drop by 67%, increasing inbreeding risks, similar to isolated otter populations in Spain (Saavedra, 2002). Restoring riparian vegetation and removing barriers like dams, as done in the Danube Basin (Hein *et al*., 2016), could help. The model's conservative threshold (0.292 logistic value) might underestimate adaptability—otters in Iran survive in artificial reservoirs, a behavior not captured here (Hadipour *et al*., 2011). Future models should include such refuges.

This study highlights the Eurasian otter's precarious future in Pakistan, signaling broader freshwater ecosystem threats. Immediate action—focusing on habitat connectivity and climate adaptation is crucial to prevent local extinction, as seen in 60 % of its Asian range (Cianfrani *et al*., 2018). Combining MaxEnt with expert-based HSI improved habitat identification, but future research should integrate dynamic factors like prey availability and competition, possibly using eDNA sampling (Kang *et al*., 2024).

Projected habitat losses in Pakistan mirror global trends. In Bangladesh's Sundarbans, 40 % of mangroves may drown by 2050 (Das, 2023), similar to risks in Pakistan's Indus Delta. Unlike European otters that shift to higher altitudes, Pakistan's otters have limited options due to scarce high-altitude freshwater systems. Genetic erosion from fragmentation could worsen, as seen in Spain, where isolated populations had 30 % lower genetic diversity (Mucci *et al*., 2010).

Human-dominated landscapes intensify threats—62 % of suitable habitats in the Indus Basin overlap with farms where pesticides have cut fish stocks by 40 % since 2000 (WWF-Pakistan, 2021). Similar declines occurred in China's Yangtze after dam construction (Li and Chan, 2018). This study is the first to quantify these "double jeopardy" effects in Pakistan, where climate and human pressures combine.

Methodological strengths include using local hydrological data and human disturbance indices, offering a model for arid regions. Identified thermal thresholds (5–25°C) can guide policy, for example, riparian shading (proven to cool water by 3–5°C in California (Beschta, 1997) or mangrove restoration (which reduces temperatures by 2–3°C in Bangladesh (Uddin *et al*., 2023).

Protecting the Indus Delta and Himalayan refuges is vital. Establishing corridors like Taunsa Barrage Wildlife Sanctuary, inspired by Nepal's Koshi Tappu Reserve (Thapa *et al*., 2021), could stabilize populations. Otters also serve as bio indicators—their protection aligns with UN SDGs for clean water (SDG 6) and climate action (SDG 13). Ecotourism, like Uganda's otter-watching industry (Higginbottom *et al*., 2004), could provide economic incentives.

The model excludes urbanization impacts, which have destroyed 15 % of Pakistan's wetlands since 2010 (Chakraborty *et al*., 2023). Future studies should integrate land-use change data, as done for Amazon jaguars (Zeilhofer *et al*., 2014). Additionally, otters may adapt to human-made waterways, a factor not yet studied in Pakistan.

The Eurasian otter's decline in Pakistan reflects a looming freshwater biodiversity crisis. Proactive measures—habitat restoration, pollution control, and climate adaptation—are essential not just for otters but for millions relying on these ecosystems. By acting now, Pakistan can protect both its wildlife and water security for future generations.

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