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A Step Towards Conserving Biodiversity in Human-Dominated Landscapes: Habitat Evaluation for Red Fox (*Vulpes vulpes*) in North-Western Pakistan

Romaan Hayat Khattak[1], Shakeel Ahmed[2], Liwei Teng[1,3]* and Zhensheng Liu[1,3]*

[1] College of Wildlife and Protected Areas, Northeast Forestry University, Harbin 150040, P.R. China
[2]Carnivore Conservation Lab, Department of Zoology, Quaid-I-Azam University, Islamabad 45320, Pakistan
[3]Key Laboratory of Conservation Biology, National Forestry and Grassland Administration, Harbin, 150040, P.R. China

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ABSTRACT

Due to the expanding human population and subsequent developmental processes, it is crucial to evaluate habitats to design robust conservation strategies. We used maximum entropy modeling (MaxEnt) to identify suitable habitats for red fox (*Vulpes vulpes*) in Nowshera district, Pakistan. MaxEnt was applied to 62 red fox occurrence points and topographical and current bioclimatic variables. The receiver operating characteristic (ROC) values obtained in the present study, i.e., the area under the curve (AUC: 0.828), showed that the results were good and valuable. Of the total area studied (1747 km^2), 272 km^2 (20.15%) and 366 km^2 (25.25 %) were highly and moderately suitable areas, respectively. The highly suitable areas comprised the protected areas (PAs) and their buffer zones; however, the moderately suitable areas mainly occurred in the peri-urban zones and were avoided by red fox. Results revealed that global land cover (glc2009) and poultry (ch_2010da) were the most influential factors defining red fox suitable habitats. Based on the results obtained in the current study, we strongly recommend focusing preservation of highly and moderately suitable areas for red fox in the study area and ensuring the conservation of these near-threatened ecologically important meso-carnivores by reducing human impacts on wild habitats.

INTRODUCTION

Wildlife species are adapted to particular natural environments termed as wildlife habitats (Su *et al*., 2021). According to Johnson (1980), mobile animal species make excursions in search of areas comprising all the resources essential for reproduction and survival all year round referred to as habitat selection. However, anthropogenic activities have largely demolished these natural wild habitats bringing many species to extinction (Khattak *et al*., 2022). Such disturbing effects of human activities have alarmed scientists to safeguard the species by preserving their habitats (Suel, 2019). Hence, studying habitats is crucial for wildlife management and protection, providing scientific foundations for improving conservation strategies (Gerrard *et al*., 2001; Liu *et al*., 2013).

Measuring the ability of a specific habitat to endure a species is called the habitat suitability index (HSI) and is a key ecological indicator reflecting the overall habitat quality (Lu *et al*., 2012). Ecological models, such as habitat suitability models (HSMs), allow the exploration of wildlife associations with habitats and locate potential habitats for species (Verner *et al*., 1986). The HSMs help to assess a specific habitat and describe appropriate alternative habitats for conservation strategies (Suleman *et al*., 2020). HSMs integrate species presence data with climatic and other environmental variables to estimate species-specific environmental suitability across a given spatial extent (Phillips and Dudík, 2008; Bentlage *et al*., 2013).

Of all the ecological niche models (ENMs), maximum entropy (MaxEnt) is extensively used in habitat suitability

* Corresponding author: zhenshengliu@163.com, tenglw1975@163.com
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modeling due to its accurate prediction abilities (Bai *et al.*, 2018). These models are well-matched with both presence/ absence data and presence-only data (Hameed *et al*., 2020). There is a widespread use of species presence/ absence data in biological studies and wildlife management (Tyre *et al*., 2003). However, species absence data are either absent or believed to be ambiguous and challenging to understand (Václavík *et al*., 2009). Nonetheless, species distribution models (SDMs) accomplished on presence-only data are enthusiastically used in ecological studies and planning conservation policies (Syfert *et al*., 2013). MaxEnt has exceeded other classical modeling techniques and is highly compatible even with a small presence-only datasets. Due to its high compatibility even with small amounts of presence-only datasets (Guisan and Thuiller, 2005; Elith *et al*., 2006; Sun and Liu, 2010).

Globally carnivore distributions prominently overlap with human-dominated landscapes (Ripple *et al*., 2014). Such landscapes usually sustain populations of several carnivores and consequently offer significant conservation potential (Bender *et al*., 2016). Nevertheless, conservation policies often concentrate entirely on managing protected areas (PAs) (Joppa and Pfaff, 2009), thus ignoring the adjacent potential habitats. Therefore, studying habitats and understanding the factors that allow carnivores persistence outside PAs is vital (Zaman *et al*., 2020).

Family Canidae is represented by two genera *viz. Canis* (wolves and jackal) and *Vulpes* (foxes) in Pakistan. Four species of foxes occur in Pakistan, including the common red fox (*Vulpes vulpes*), Bengal fox (*Vulpes bengalensis*), sand fox (*Vulpes rueppelli*), and king fox (*Vulpes cana*) (Roberts, 1997). All the species of foxes mentioned above are listed as least concerned by the International Union for Nature Conservation (IUCN). However, in Pakistan, three species, including the common red fox, Bengal fox, and king fox, are listed as near threatened, while the sand fox is listed as data deficient (Sheikh and Molur, 2005). Unfortunately, foxes are the least studied species in Pakistan, and there is a severe lack of information on fox ecology and habitat selection.

Foxes are adaptable and highly hunted animals throughout their range, making it very difficult to identify and describe the factors influencing their habitat selection (Lloyd, 1980). We presume that the red fox is a highly adaptable species, yet they tend to avoid human-dominated areas. The conservation status of red fox in Pakistan and rapid habitat degradation warrants baseline research on habitat suitability modeling for meso-carnivores. Therefore, the current study was designed to identify the underlying factors affecting red fox habitat selection. We believe this study will provide benchmark information on red fox habitat selection and recommendations for designing robust conservation policies for threatened and ignored yet, ecologically important meso-carnivores in human-dominated landscapes globally and in Pakistan.

MATERIALS AND METHODS

Study area

The current study was conducted within the Nowshera district (34°0 05500 N, 71°5802900 E) of Khyber Pakhtunkhwa Province (KP). This district encompasses an area of 1748 km^2 comprising an undulating landscape, with a human population density of 870.1 persons/km^2 (https://www.citypopulation.de/en/pakistan/admin/khyber_pakhtunkhwa/618__nowshera/). The study area has a semi-arid climate, with an average annual temperature of 24.4 °C and an average yearly rainfall of 532 mm. Scrub forests dominate the study area–providing refuge for 21 species of mammals and more than 40 bird species (Khattak *et al*., 2021). The government have established protected areas (PAs) (three wildlife parks and several game reserves) in the Nowshera district (Fig. 1).

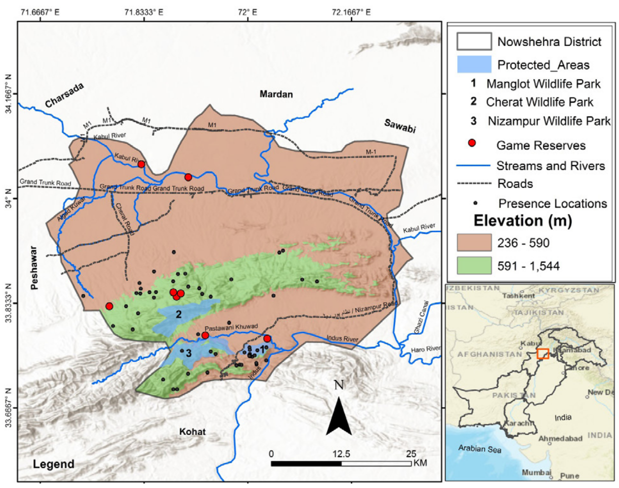

Fig. 1. Study area map, depicting recorded presence and protected areas in the study area.

Study methods

Field surveys were conducted from 01-20 May 2022. Both parallel and successive line transects were placed throughout the study area for coverage and intensive survey, mainly on human foot tracks (Barja *et al*., 2004). We employed multiple methods to record the red fox presence, including signs (scats), direct sightings (Fig. 2), and vocalizations. Binoculars (10 × 50, Bushnell) were used to scan the area, and the Camera (D1300, 70 × 300 mm, Cannon) was used to photograph the red fox when seen. Presence locations were recorded with a global positioning system (GPS) (Maverick v2.8).

MaxEnt 3.3.3k (http://biodiversityinformatics.amnh.org/open_source/maxent/) was used for data processing and analysis to predict suitable areas for red fox in the study area.

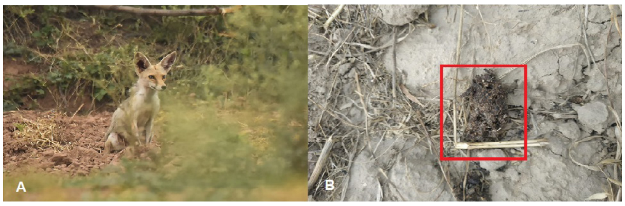

Fig. 2. (A) Red fox photographed in the study area (Photo credit: Abdul Hadi), (B) Red fox scat in the study area.

Selection of presence data and environmental variables

We transformed all the environmental layers to the same size and resolution, i.e., 1×1 km. Red fox presence points were converted into a vector file in ArcGIS 10.8. Red fox presence records were screened in ArcGIS 10.8 (SDM toolbox) for spatial autocorrelation using average nearest neighbor analysis to remove spatially correlated data points (located within 5 km) and to ensure independence (Bosso *et al*., 2016). After spatial autocorrelation, 12 distinct locations produced red fox current habitat suitability models in the study area. Initially, a set of 30 environmental variables was considered (Table I). Pearson correlation matrix was used in program R (version 3.6.2) to remove highly correlated variables from the analysis (Welch *et al*., 1994). After this procedure, ten variables were retained (r < 0.7) (Khattak *et al*., 2022).

Table I. Variables contributing in determining suitable habitat for red fox in the study area.

S. no	Variable	Percent contribution	Permutation importance
1	glc2009	46.2	33.8
2	ch_2010da	24.6	54.7
3	soil	9.9	0
4	elevation	9.2	2.6
5	pk_pd_2020	3.4	0
6	wc2.1_30s_bio_15	3.3	2.4
7	wc2.1_30s_bio_13	1.8	4.2
8	wc2.1_30s_bio_4	1	0
9	slope	0.5	1.5
10	wc2.1_30s_bio_6	0.1	1

Given below are the environmental variables used in the current study: bio1, annual mean temperature; bio2, mean diurnal range (mean of monthly [max temp—min temp]); bio3, isothermality (Bio2/Bio7) (*100); bio4, temperature seasonality (standard deviation*100); bio5, maximum temperature of warmest month; bio6, minimum temperature of coldest month; bio7, temperature annual range (Bio5-Bio6); bio8, mean temperature of wettest quarter; bio9, mean temperature of driest quarter; bio10, mean temperature of warmest quarter; bio11, mean temperature of coldest quarter; bio12, annual precipitation; bio13, precipitation of wettest month; bio14, precipitation of driest month; bio15, precipitation seasonality (coefficient of variation); bio16, precipitation of wettest quarter; bio17, precipitation of driest quarter; bio18, precipitation of warmest quarter; bio19, precipitation of coldest quarter; pk_pd_2020, human population density; ch_2010Da, chicken density; gt_2010Da, goat density; ct_2010Da, cattle density; glc2009, global land cover 2009; elevation, elevation above sea level (m); Slope, slope of the area; river, density of rivers (m); road, density of roads (m); soil, digital soil map of the world; ndvi(MODIS), normalized difference vegetation index (https://www.worldclim.org/data/worldclim21.html; WorldPop; https://www.worldpop.org/doi/10.5258/SOTON/WP00674; GLW https://doi.org/10.7910/DVN/SUFASB; GLW https://doi.org/10.7910/DVN/OCPH42; GLW https://doi.org/10.7910/DVN/GIVQ75; http://due.esrin.esa.int/page_globcover.php; NASA (SRTM); created from SRTM 90m DEM; line Density tool in ArcGis 10.8; line Density tool in ArcGis 10.8; FAO, 2003; USGS: http://edcsns17.cr.usgs.gov/glcc).

Model simulation and evaluation

Red fox presence data and designated variables were adjusted to the arrangements mandatory for MaxEnt software (v 3.3.3k). A random seed option was used, and 5% of the data were kept for random tests. Five 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 regularization multiplier of 1. Each variable importance and contribution was 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 (Bai *et al*., 2018). The output results were used to reclassify the suitable habitat distribution for the red fox. The ASCII outputs format file was imported into ArcGIS 10.8 for conversion into raster data to produce a habitat suitability map–subsequently reclassified to calculate the area (Khattak *et al*., 2022).

RESULTS

Species presence records

In the current study, 62 confirmed presence locations were recorded (Fig. 1). After excluding the spatially correlated locations, 12 points were used to generate the current SDM of the red fox in the study area.

MaxEnt prediction evaluation

The current study obtained a valid and valuable model based on the value of the area under the curve (AUC). The ROC results (Fig. 3) showed an average AUC value of 0.828, indicating that the predictions obtained from the MaxEnt model were good. The standard deviation was 0.051.

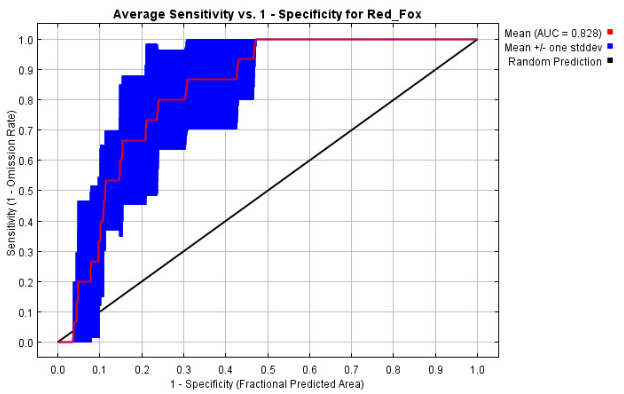

Fig. 3. ROC verification of distribution of suitable red fox habitat in the study area.

Influential factors determining habitat suitability

The MaxEnt model determined the contribution of each variable in predicting red fox habitat selection (Table I). The analysis shows that global land cover contributed 46.2% to the habitat selection of red fox. Other variables with highest contribution in habitat selection of red fox were ch_2010da (24.6%), soil (9.9%), elevation (9.2%), pk_pd_2020 (3.4%), bio15 (3.3%%) and bio13 (1.8%). The least contributing variables were bio6 (0.1%), slope (0.5%), and bio4 (1%) (Table I**,** Fig. 4).

Results of the jackknife test showed that the environmental variable with the highest gain, when used in isolation, was ch_2010da, which appeared to have the most helpful information. The environmental variable that decreases the gain the most when it is omitted is land cover, which therefore seems to have the most information that isn't present in the other variables. The values shown are averages over replicate runs (Fig. 5).

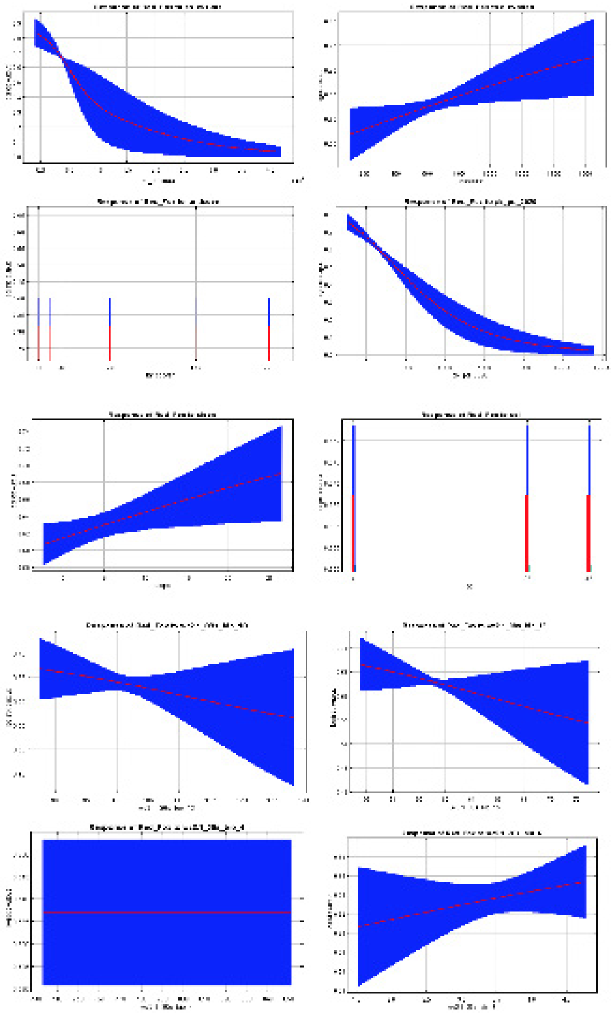

Fig. 4. Response curves of predictors for red fox occurrence in the study area. The red curves show the mean response of the five replicate MaxEnt runs, while the mean +/– one standard deviation is indicated by blue (two shades for categorical variables). The predicted value of habitat suitability (logistic output) is shown on the Y-axis, while the range of the environmental predictors is shown on the X-axis.

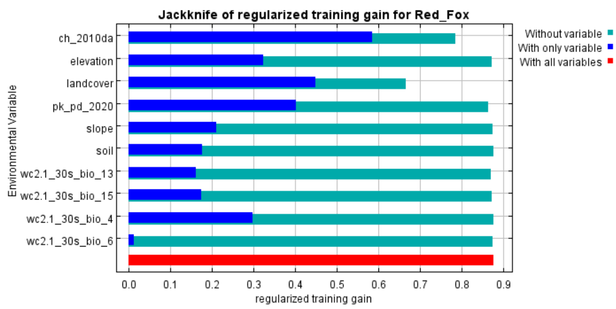

Fig. 5. Jackknife test of regularized training gain of variables tested in the red fox habitat suitability model.

Distribution of suitable red fox habitat

The habitat suitability map generated through MaxEnt modeling shows that highly suitable habitats of red fox are present in the southern and south-western parts of the study area, i.e., in and around protected areas. Most of the moderately suitable habitats of red fox are located in the central, southern, and south-eastern parts of the study area. Unsuitable habitats are restricted to western, northern, and eastern parts of the study area (heavily human-dominated parts of the district) (Fig. 6).

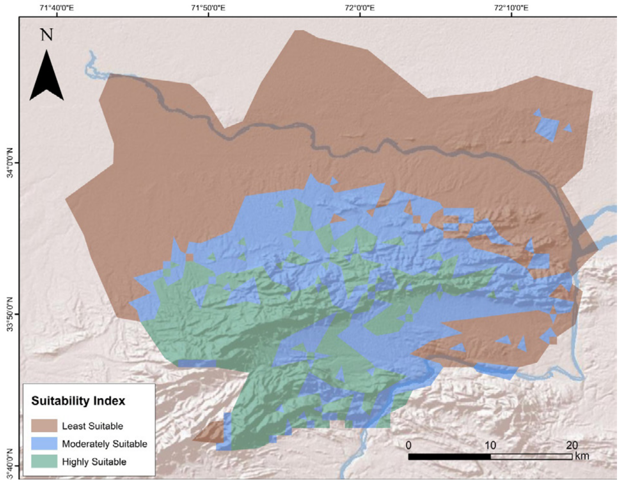

Fig. 6. Distribution of different types of habitats in the study area based on MaxEnt modeling using presence-only data.

Suitable area

The habitat suitability map generated by MaxEnt was categorized into three categories based on the thresholds: unsuitable (0.00-0.19), moderately suitable (0.20-0.45), and highly suitable (0.46-0.92) areas. Results obtained by processing the reclassified map revealed that the unsuitable area in our study area constituted 1109 km^2 (54.59%), moderately suitable habitat was 366 km^2 (25.25 %), and highly suitable habitat was 272 km^2 (20.15%).

DISCUSSION

To the best of our knowledge, the current study is the first-ever ambitious study on meso-carnivores habitat modeling in Pakistan. Findings in the present study support our hypothesis. Based on the red fox occurrence records, most of the highly suitable areas predicted by MaxEnt are located in and around the rural areas of the district. In the Nowshera district, the human population density is 870.1/km^2 (https://www.citypopulation.de/en/pakistan/admin/khyber_pakhtunkhwa/618__nowshera/). However, despite having the same population density but due to clustered and concentrated settlements, we believe that rural areas provide refuge to wildlife. It is believed that foxes can best withstand the human impacts and are adaptable; thus, their presence does not reveal the true suitability of the area (Lloyd, 1980). Moreover, the red fox, an unfussy omnivore, is considered much more confident in urban areas, attracted by the novel habitats and anthropogenic resources. According to Gil-Fernández *et al*. (2020), high vegetation cover is an important factor even for urban foxes to behave more confidently. Our results showed that red foxes prefer peri-urban and rural areas with dense forest cover, i.e., in and around protected areas in the Nowshera district (Fig. 6). Another reason we believe is the cornering of the red fox into remote parts due to excessive killing by humans in the study area (Khattak *et al*., 2021). Thus, despite being highly adaptable to humans-dominated landscapes, seeking safe refuge seems to be the primary focus of the red fox.

Our results revealed that several environmental variables influenced the habitat suitability, of which the most influential was glc2009 (46.2%), followed by ch_2010da (24.6%), soil (9.9%), and elevation (9.2%). Glc2009 is a major input dataset and categorical variable that comprises and defines a variety of land covers, *viz*. forests, shrubs, water bodies, herbaceous and sparse vegetation, etc. (Khattak *et al*., 2021). Our results showed that level 14 of glc2009 (rainfed croplands) had the highest significant contribution (Fig. 4). Interestingly the highly suitable areas predicted by MaxEnt in our study area comprised rain-fed agricultural lands. The red fox diet menu is diverse, including small mammals, birds, insects, serpents, arachnids, and many plant materials, including cereals and fruits (Basuony *et al*., 2005). The agricultural lands provide plenty of the resources mentioned above, which we believe is the main reason for selecting these sites by the red fox. The results further revealed that level 30 of glc2009 which corresponds to mosaic vegetation (grassland, shrubland, and forest), was influential yet insignificant. Following Gil-Fernández *et al*. (2020), we believe that red foxes primarily use these sites for harborage in our study area. However, there were no distinctive features of any substantial difference between the other levels of glc2009 *viz*. level 11 (post-flooding or irrigated croplands), level 20 (mosaic cropland), level 70 (needle-leaved evergreen forest), level 140 (closed to open grassland), level 200 (bare areas), and level 210 (water bodies).

Our results further revealed that the second most influential factor was ch_2010da (chicken density). It has been reported that poultry is one of the primary sources of income for rural farmers and locals in the Nowshera district, and the red fox was held accountable for an average yearly economic loss of USD 360 (PKR 57,240)–predating poultry (Khattak *et al*., 2021). The significant role of ch_2010da (chicken density) in red fox habitat selection in the current study agrees with Khattak *et al*. (2021).

According to the AUC values, the results were encouraging (Bai *et al*., 2018). We revealed that the highly suitable habitat of the red fox was mainly located within PAs and their buffer zones (Fig. 6). These habitats include the areas with thick scrub forests, tall grasses, and cultivated lands, providing plenty of resources and comparatively less human disturbance–thereby providing 272 km^2 of highly suitable refuge for red fox. On the contrary, the moderately suitable areas predicted by Maxent, which constituted 366 km^2, mainly fell within the study area's peri-urban areas. The unsuitable areas (1109 km^2) indicated by MaxEnt included the peri-urban and urban areas of the study area. Keeping in view the results obtained from the MaxEnt modeling, we believe that red fox prefers to exist in remote and rural parts, avoiding peri-urban and urban areas also evident from the occurrence records of red fox in the study area (Fig. 1).

CONCLUSIONSANDRECOMMENDATIONS

Using MaxEnt, we identified priority landscapes for red fox in the Nowshera district. Presence-only data obtained in the current study revealed that red fox populations primarily inhabits the PAs and buffer zones however, avoiding several moderately suitable habitats mainly comprising the peri-urban areas. We assume that this trend is due to the high impacts of human activities in urban and peri-urban areas and the enormous availability of poultry in rural areas. However, the safety of red fox, even in the highly suitable regions in the Nowshera district, which are the strongholds of the red fox, is not ensured because of (1) the absence of a defined protection level for red fox in the provincial wildlife act, and (2) conflicts of red fox with local communities and its retaliatory killing in response to poultry predation. Keeping in view the ecological importance of the red fox, we strongly recommend providing certain protection levels to this locally threatened species and to preserve the predicted suitable habitats for maintaining a healthy ecosystem. Moreover, for robust conservation of meso-carnivores in the Nowshera district, we also recommend in-depth studies to investigate the population status of red fox and its conflicts with humans.

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Statement of conflict of interest

The authors have declared no conflict of interest.

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