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Identifying core habitats and connectivity paths for the conservation of mouflon (*Ovis gmelini*) in Western Iran

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ABSTRACT

Connectivity among conservation areas helps to alleviate the negative impacts of habitat fragmentation. Mouflon (*Ovis gmelini*) as a near threatened species has an unclear habitat connectivity status among conservation areas in the west of Iran. This study was carried out on mouflon with the aim of modeling the habitat suitability and connectivity among core habitats in the west of Iran. An ensemble of three machine-learning models and a factorial least-cost path were used for identifying core habitats and corridors between them, respectively. Our results revealed that grassland density, elevation, slope and distance to roads were the most influential variables for predicting the occurrence of mouflon in the study area. Five core habitats were identified for mouflon in the study area, about 90% of which was covered by conservation areas. The core habitat in the north of the study area is the highest priority for conservation. Conservation areas in the northern and western parts of the study area had the best connectivity for mouflon. To prevent mouflon poaching, the protection of corridors among conservation areas should be considered. In addition, predicted corridors of connectivity modeling in areas crossed by roads, could be investigated for the conservation of mouflon by wildlife managers.

1. Introduction

Habitat fragmentation (i.e., altering a large natural habitat to several smaller separated patches) reduces landscape connectivity and leads to species population decline (Ewers and Didham, 2006; Crooks and Sanjayan, 2006; Makki et al., 2013). Conservation areas (CAs) protect critical habitat patches and, therefore, they are important for biodiversity conservation (Chape et al., 2005; Mohammadi et al., 2021a; Malakoutikhah et al., 2020). However, CAs are increasingly fragmented into small and isolated patches because of land-use changes by humans outside CAs (Santini et al., 2014). Consequently, CAs isolation and reducing population viability of the species lead to biodiversity loss (Crooks and Sanjayan, 2006; Ahmadi et al., 2020). Connectivity (i.e., corridors) reduces the adverse impacts of habitat fragmentation by maintaining or facilitating the movements of species individuals among the CAs (McRae and Beier, 2007; Mohammadi et al., 2022). Indeed, by identifying connectivity paths among the CAs, we help to survive threatened species restricted to the CAs and consequently, this makes the conservation process promote (Ahmadi et al., 2020). There are several methods to assess landscape connectivity, including least cost path (Adriaensen et al., 2003), resistant kernels (Compton et al., 2007), circuit theory (McRae et al., 2008), centrality analyses (Estrada and Bodin, 2008) and factorial least cost path (Cushman et al., 2009). Previous studies have applied factorial least cost path as a helpful framework for connectivity modeling (e.g., Khosravi et al., 2018;

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Shahnaseri et al., 2019; Kaszta et al., 2020; Kaboodvandpour et al., 2021; Mohammadi et al., 2022). This method predicts the connectivity for different species by designing movement corridors across the dispersal abilities (Cushman et al., 2013).

Identifying influential environmental variables for habitat suitability, core habitats and connectivity paths is a primary step for the conservation of mammal species (Eslamlou et al., 2022). However, there is not enough data on the ecology and habitat distribution of most mammal species (Zeller et al., 2011; Lham et al., 2021). Therefore, data deficiency regarding species distribution is a major drawback to the conservation of species (Almasieh et al., 2016; Salas et al., 2018). Species distribution models (SDMs) (Guisan and Zimmermann, 2000) apply occurrence points of the species and related environmental variables to predict suitable habitats as core habitats. Identifying the most important environmental variables for the habitat suitability of the species is also an issue that can be predicted by SDMs (Hirzel and Le Lay, 2008). The SDMs also could be promising as an input layer to predict connectivity among core habitats (Farhadinia et al., 2015; Almasieh et al., 2019a).

In western Asia, Iran has an essential role for the conservation of threatened mammal herbivores (Malakoutikhah et al., 2020). Populations of many herbivore species in Iran have declined severely in non-conservation areas (Karami et al., 2016; Farashi et al., 2017); consequently, CAs have an important role in protecting herbivores (Soofi et al., 2022). Mouflon or Armenian wild sheep (*Ovis gmelini* Blyth, 1841) is a large herbivore (Bleyhl et al., 2019; Malakoutikhah et al., 2020; Khosravi et al., 2022) that is distributed in six countries of Iran, Iraq, Turkey, Armenia, Azerbaijan and Cyprus (Michel and Ghoddousi, 2020). IUCN Red List declared mouflon as near threatened (NT) because the population of the species has decreased during the last two decades, resulting from poaching, competition with livestock and habitat degradation (Michel and Ghoddousi, 2020). Mouflon inhabits mountains and hills from the northwest to the south of Iran along the Zagros Mountains (Karami et al., 2016; Yusefi et al., 2019). The highest habitat suitability for mouflon in the Caucasus biodiversity hotspot was located in Iran (Bleyhl et al., 2019). In addition, the south of Iran was introduced as an important area for the conservation of this charismatic species (Eslamlou et al., 2022). Topographic, land-cover and water availability variables, and prevention from human disturbance (e.g., human settlements and roads) partially determine the habitat suitability of mouflon (Eslamlou et al., 2022). Mouflon with extensive habitat distribution serves as an umbrella species, which is similar to another wild sheep species in Iran (i.e., urial *Ovis vignei*) (Hosseini et al., 2019), and conservation of this species could protect other taxa, i.e., other herbivores, mammals, vertebrates, invertebrates and plants (Beier et al., 2008; Almasieh et al., 2019b).

Distribution of mouflon rarely occurs outside the CAs and most of its population in Iran is restricted to CAs in which there is a sort of uncertainty about the connectivity of populations among the CAs (Bashari and Hemami, 2013; Momeni Dehaghi et al., 2018; Eslamlou et al., 2022). Some previous studies evaluated habitat suitability and connectivity of mouflon in the northwest, center and south of Iran (Momeni Dehaghi et al., 2018; Bleyhl et al., 2019; Eslamlou et al., 2022). However, the distribution and connectivity status of the

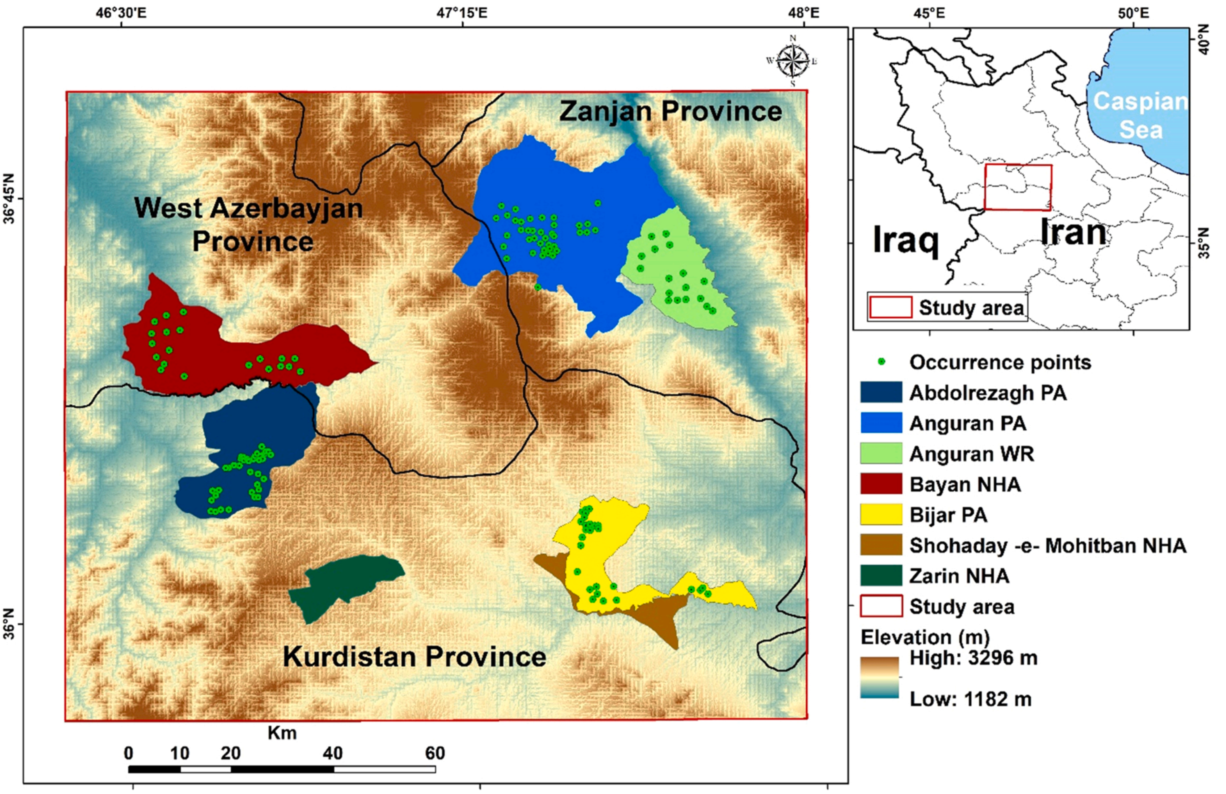


Fig. 1. Study area, conservation areas and occurrence points (collected during the field survey and from game wardens of Iran's Department of Environments) of mouflon in the west of Iran. PA stands for protected area, W*R* for wildlife refuge and NHA for no-hunting area.

species in the west of Iran is unknown. Therefore, the present research was carried out on mouflon in the west of Iran with three aims: (1) detecting important environmental factors for habitat suitability, (2) identifying core habitats resulting from habitat suitability and potential connectivity among core habitats, and (3) evaluating the connectivity of core habitats for conservation priority.

2. Materials and methods

2.1. Study area

The study area (area: 17,800 km^2) covers three provinces of Kurdistan, West Azerbaijan and Zanjan in the west of Iran (Fig. 1). Grasslands and agricultural lands encompass 56.5% and 41.5% of the study area, respectively. Rocks, human settlements and water bodies cover 2% of the study area. Road and river densities in the study area are 36.9 and 55.8 m/km^2, respectively. Mouflon, bezoar goat (*Capra aegagrus*), gray wolf (*Canis lupus*) and striped hyaena (*Hyaena hyaena*) are important mammals in the study area (Karami et al., 2016; Yusefi et al., 2019).

Iranian CAs include national parks (NPs), protected areas (PAs), wildlife refuges (WRs) and no-hunting areas (NHAs). NPs, WRs, PAs and NHAs are comparable to the II, III, IV and IV-VI of the IUCN categories, respectively (Ahmadi et al., 2020). The study area includes seven CAs (15.7% of the study area): one W*R* (Anguran W*R*), three PAs (Bijar PA, Abdolrezagh PA and Anguran PA) and three NHAs (Shohaday -e- Mohitban NHA, Zarin NHA and Bayan NHA), all under the provincial management of Iran's Department of Environment (DoE) (Fig. 1).

2.2. Occurrence points and environmental variables

In the present study, an occurrence point was a location (longitude and latitude) with the observation of mouflon. Occurrence points were collected during field surveys in CAs of Kurdistan Province during four seasons of 2018–2021. Totally, forty-eight efforts within 16 months were carried out within CAs of Kurdistan Province to collect occurrence points. In each effort, mountains of a part of one CA were monitored by the second and third authors of this study using binoculars model Steiner Al-Saghar II 8 * 30 and the location of mouflon observation was recorded using the global positioning system (GPS) model Garmin Map 62 S. In each effort, about 40 km^2 was monitored to collect occurrence points. All parts of CAs within Kurdistan Province were monitored during the field survey at least two times. Occurrence points in the other two provinces (West Azerbaijan and Zanjan) were collected from game wardens and officers of DoE during 2015–2021. They monitored different areas, especially CAs frequently, and these occurrence points were recorded by GPS during daily field surveys and direct observations of mouflon by binoculars during four seasons of the mentioned years. The number of 64 and 77 occurrence points for mouflon were obtained during the field survey and from DoE, respectively (a total of 141 occurrence points). To minimize spatial-autocorrelation, we considered a radius of 1 km (twice the radius considered by Bleyhl et al., 2019 for mouflon in the Caucasus biodiversity hotspot) around each occurrence point to spatially filter occurrence records using the Spatially Rarify Occurrence Data tool in SDMtoolbox (Brown, 2014). Finally, we retained 119 occurrence points for habitat suitability modeling of mouflon in the study area (Fig. 1).

Topographic, land-cover, water and human disturbance variables were used for habitat suitability modeling of mouflon in the study area (Table 1). Digital Elevation Model (DEM) with a resolution of 250 m was downloaded from http://srtm.csi.cgiar.org (Jarvis et al., 2008) as the elevation variable. This data was derived from the 90 m Shuttle Radar Topography Mission (SRTM, http://earthexplorer.usgs.gov). DEM was used to calculate the slope by using the Surface tool.

Grassland and agricultural land cover-types were derived from the land-cover map of Iran (FRWMO, 2010). A circle-moving window with a 5 km radius was used to create density maps of these two cover-types by using the Focal Statistics tool. Normalized Difference Vegetation Index (NDVI) was created by the 16-day composite MODIS data (MODIS MYD 13Q1 V6 map at 250 m cell size; http://earthexplorer.usgs.gov) considering the mean values for the year 2021 by using the Raster Calculator tool. Given the importance of water resources for herbivores, distance to rivers (DoE, 2018) was considered using the Euclidean Distance tool. Distance to roads (DoE, 2018) was considered as a human disturbance variable. Furthermore, another human disturbance variable, distance to villages (DoE, 2018) was taken into account. All variables were created with a resolution of 250 m and a coordinate system of WGS 1984 UTM zone 38. All tools used to create variables are available in ArcGIS version 10.3.

Multicollinearity was checked by evaluating the correlation between variables and applying a variance inflation factor (VIF). We

Table 1
Environmental variables used for habitat suitability modeling of mouflon in the study area in four categories of topography, land-cover, water resources and human disturbance before and after checking correlation and variance inflation factor (VIF).

Variables category	Variables	Selected after checking the correlation	VIF
Topography	Elevation	Yes	1.83
	Slope	Yes	1.29
Land-cover	Grassland density	Yes	1.28
	Agricultural land density	No	-
	NDVI	Yes	1.19
Water resources	Distance to rivers	Yes	1.13
Human disturbance	Distance to roads	Yes	1.29
	Distance to villages	Yes	1.24

checked the correlation between variables to exclude variables with a correlation coefficient higher than 0.7. Grassland density and agricultural land density had a correlation higher than 0.7; therefore, grassland density was considered, and agricultural land density was excluded. The usdm package (Naimi et al., 2014) in R 3.6.0 (R Core Team, 2019) was used to exclude the variables with VIF higher than 3 (threshold suggested by Zuur et al., 2010). None of the variable was excluded (Table 1).

2.3. Habitat suitability modeling and core habitats

Habitat suitability modeling for mouflon was performed using an ensemble approach in the biomod2 package in R (Thuiller et al., 2019). Integrating predictions of different models and fitting several suitability models improves the model's accuracy (Araújo and New, 2007; Ashrafzadeh et al., 2018, 2022). Three machine-learning models of random forest (RF), maximum entropy (MaxEnt) and generalized boosting model (GBM) were applied for habitat suitability modeling. The accuracy of the models was checked using the area under the ROC curve (AUC) and true skill statistic (TSS). Eskildsen et al. (2013) reported AUC > 0.9 and TSS > 0.75 as excellent performance. We considered 75% of the occurrence points as the training data set and the other 25% as the testing data set. Five hundred pseudo-absence points were randomly created across the study area and outside a radius of 5 km around each occurrence point. The analyses were carried out by applying 20 replicates for each model to achieve higher reliability (Barbet-Massin et al., 2012). Mean variable contributions in the three models calculated by Biomod2 was presented. In addition, response curves of occurrence points to the variables were illustrated for the model with the highest performance. The continuous map of ensemble habitat suitability was converted to a binary map using the 10th percentile of suitability value at the occurrence points of species (Ahmadi et al., 2020) and patches with occurrence points of mouflon were considered as core habitats. The ratio of CAs area within core habitats to the area of core habitats was calculated as the coverage percentage of core habitats by CAs.

2.4. Connectivity modeling

According to the method of Wan et al. (2019), the resistance map was created from the ensemble suitability map. Then, this map was used to obtain the connectivity among core habitats. First, by using the linear method in the Rescale by Function tool in ArcGIS, the ensemble map was rescaled to a map of values between 0 and 1. Then, a negative exponential function was used to create the resistance map using the following formula: $R = 1000^{(-1\times \text{Ensemble Suitability Map})}$, where R represents the cost resistance value assigned to each pixel (Mateo-Sánchez et al., 2015). Finally, the resistance values were rescaled using linear interpolation to yield values ranging from 1 to 10, where 1 and 10 represent the minimum and maximum resistance, respectively (Wan et al., 2019).

Connectivity modeling (i.e., structural corridors) was conducted by using Universal Corridor (UNICOR) software (Landguth et al., 2012). Connectivity prediction was implemented among occurrence points over the resistance map for the species in UNICOR to find the single-source shortest path from the species occurrence point in the landscape to every other occurrence point (Landguth et al., 2012; Cushman et al., 2013). The analysis predicted the least-cost paths from each source point to each destination point regardless of the dispersal threshold to assess all potential corridors, including long-distance dispersal corridors (Cushman et al., 2013; Mohammadi et al., 2021b). Furthermore, the continuous factorial least-cost path map was converted to a categorical map based on $> 10\%$ of the most highly connected areas of the contiguous connectivity map outside core habitats (Cushman et al., 2013; Ashrafzadeh et al., 2020; Almasieh and Cheraghi, 2022).

2.5. Connectivity prioritization for core habitats

Core habitat prioritization for connectivity was performed using measures of the probability of connectivity (dPC; Saura and Pascual-Hortal, 2007), including dPCintra, dPCflux and dPCconnector in Conefor version 2.6 (Saura and Pascual-Hortal, 2007; Saura and Torné, 2009). dPCintra measures intrapatch connectivity, and dPCflux measures dispersal flux and depends on a patch's area and its position within the landscape. dPCconnector depends on the position of a patch within the landscape (Saura and Rubio, 2010), and determines the stepping stone patch/patches based on dispersal between patches (Avon and Bergès, 2016; Saura and Rubio, 2010). To prepare the data for Conefor, the categorical core habitats created in the Section 2.3 was used (Almasieh et al., 2022). According to information provided by DoE game wardens regarding the dispersal ability and movement of mouflon between Bijar PA and Abdolrezagh PA, a maximum dispersal distance of 70 km was considered for the species to calculate dPC index in Conefor software. Moreover, the Conefor Input ArcGIS extension (http://www.jennessent.com/arcgis/conefor_inputs.htm) was applied to prepare Conefor software inputs (node and distance files). The nodes included the area (km) of each core habitat and the distance files included the distance (m) between each pair of core habitats for species. The highest value for dPC and its derivatives (i.e., dPCintra, dPCflux, and dPCconnector) represented the highest probability of connectivity, and the highest intrapatch connectivity, dispersal flux, and

Table 2
AUC and TSS of three habitat suitability models for mouflon in the study area.

Models	AUC	TSS
RF	0.933	0.85
MaxEnt	0.924	0.81
GBM	0.911	0.76

stepping stone patches, respectively.

3. Results

3.1. Habitat suitability and variable contributions

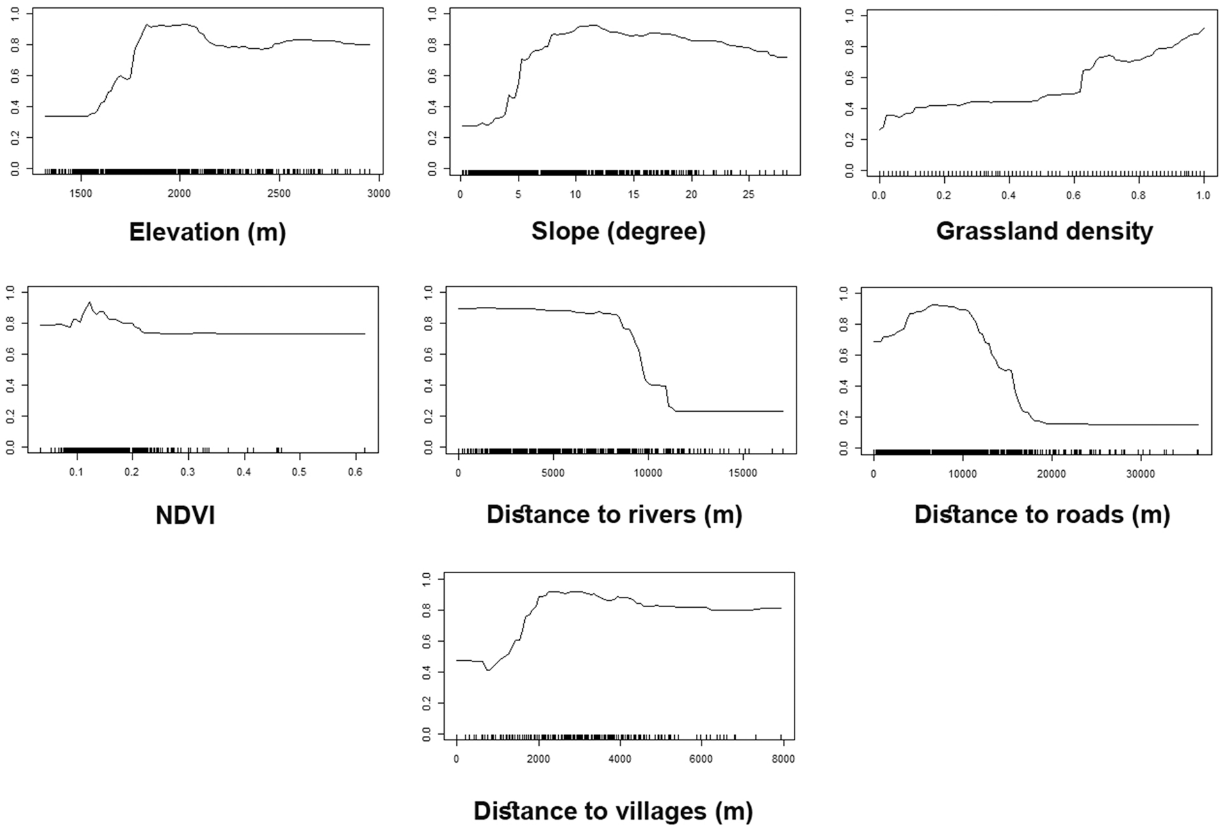
AUC and TSS values for all three models were higher than 0.9 and 0.75, respectively, implying excellent performance (Table 2). The RF model had the highest performance among the three models (i.e., highest values of AUC and TSS). Based on the average of the three models, grassland density, elevation, slope and distance to roads were the most influential variables for predicting the occurrence of mouflon in the study area (Supplementary Materials, Table S1).

Mouflon preferred 1500–2500 m elevation above sea level and 10–25 degrees of slope. As the density of grasslands increased, the probability of mouflon occurrence increased continually. In addition, NDVI initially increased habitat suitability for the species, but further, the impact waned as NDVI increased. Habitat suitability was constant, as distance to rivers increased and subsequently decreased sharply at about 8 km. Distance to roads seems to have a positive effect on habitat suitability since the probability of occurrence increased and then decreased at about 20 km. As distance to villages increased, the probability of species occurrence increased sharply before flattening at about 2 km (Fig. 2).

Ensemble suitability maps showed that the north and northeast of the study area had the highest suitability for species. However, some suitable habitats were found in the south of the study area (Fig. 3). Habitat suitability maps generated by the RF, MaxEnt, and GBM models for the species are shown in Supplementary Materials (Fig. S1).

3.2. Core habitats and corridors

Five core habitats for mouflon were identified in the study area, with a total area of about 1350 km^2 (8% of the study area); about 90% of which was covered by CAs (Fig. 4A and Table 3). The largest core habitat was Core1, located in the northeastern part of the study area (about 770 km^2, 87% CAs coverage). The second-largest core habitat was Core2, located in the west of the study area (about 220 km^2, 98% CAs coverage). The third-largest core habitat was Core4 located in the southeast of the study area (about 210 km^2, 95% CAs coverage). Total road density within core habitats was about 8 m/km^2; Core 4 was the only core habitat crossed by the road



Elevation (m)

Slope (degree)

Grassland density

NDVI

Distance to rivers (m)

Distance to roads (m)

Distance to villages (m)

Fig. 2. Response curves of occurrence points of mouflon to the environmental variables in the study area (RF model as the best performance was considered) (Y-axis represents the mouflon's probability of occurrence).

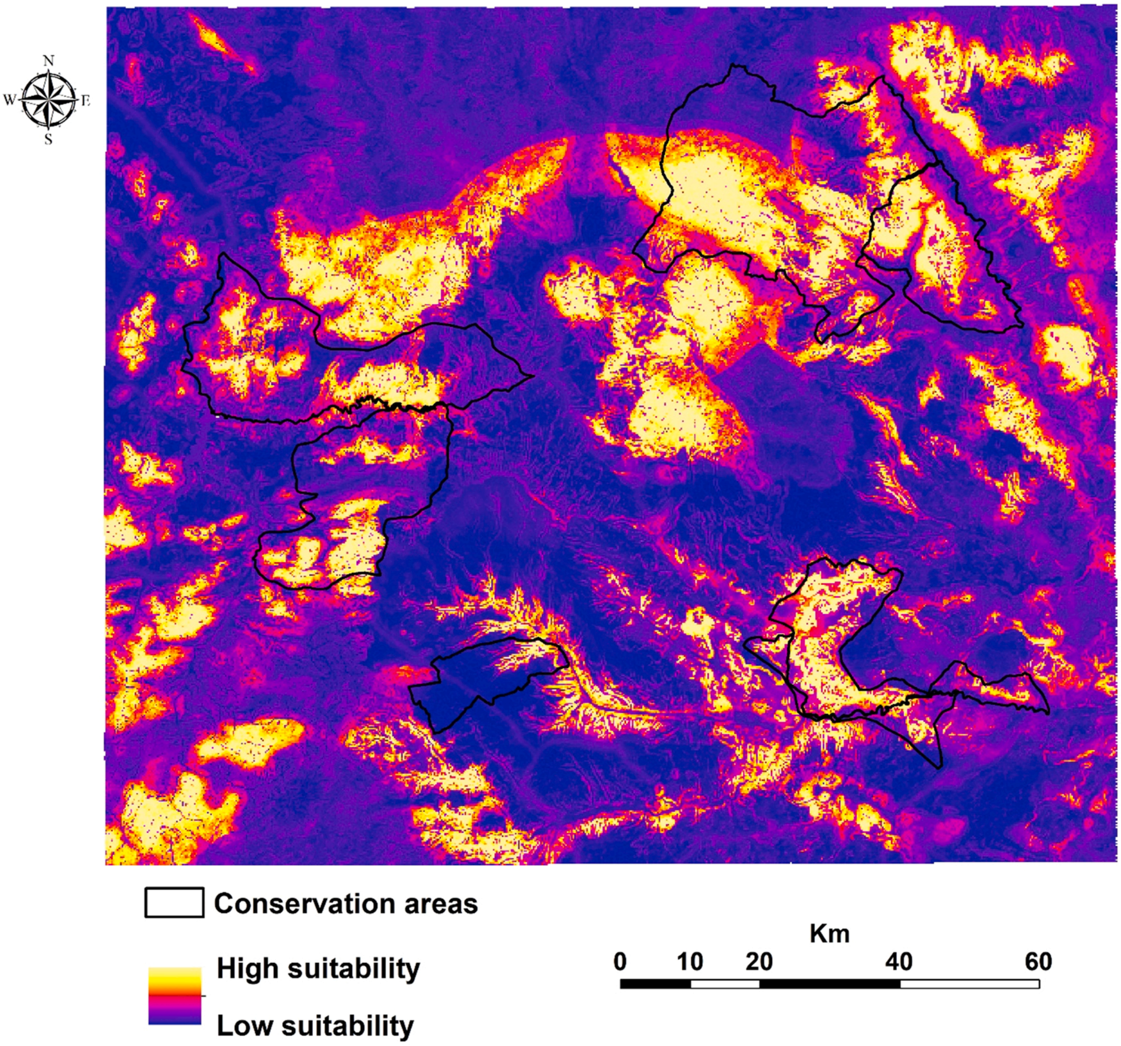


Fig. 3. Ensemble habitat suitability for mouflon in the study area based on MaxEnt, RF and GBM models.

network. Total river density within core habitats was about 66 m/km^2 with the highest river density for Core5 and the lowest for Core2 (Table 3).

There was a robust connectivity between mouflon's core habitat in the northern and western parts of the study area (Fig. 4B). The highest connectivity was predicted to be among Core1, Core2, and Core3. Moderate connectivity was found between Core3 and Core4. The low connectivity was found between Core1 and Core4 and between Core4 and core5 (Fig. 4B). The area of categorical corridors was about 1200 km^2 (6.5% of the study area), about 23% of which was covered by CAs. The largest corridor was the corridor between Core1 and Core2 (about 388 km^2, 11% coverage by CAs), and the second-largest corridor was the corridor between Core3 and Core4 (about 306 km^2, 10% coverage by CAs) (Fig. 4A and Table 3). Road density within corridors was about 15 m/km^2, with the highest density for the corridor between Core1 and Core2 and the lowest density (zero) for corridors between Core2 and Core3, Core3 and Core4, and Core4 and Core5 (Table 3). River density within corridors was about 102 m/km^2; the highest density for the corridor between Core4 and Core5 and the lowest density for the corridor between Core2 and Core3 was found (Table 3).

3.3. Connectivity prioritization of core habitats

Based on dPC, Core1 had the highest contribution to habitat connectivity for mouflon in the study area, followed by Core2 and Core4 (Table S2). According to dPCintra and dPCflux, Core1 showed the highest intrapatch connectivity and the highest flux due to its area and position within the landscape, followed by Core2 and Core4. Core2 and Core4 had the highest contribution as stepping-stones (Table S2).

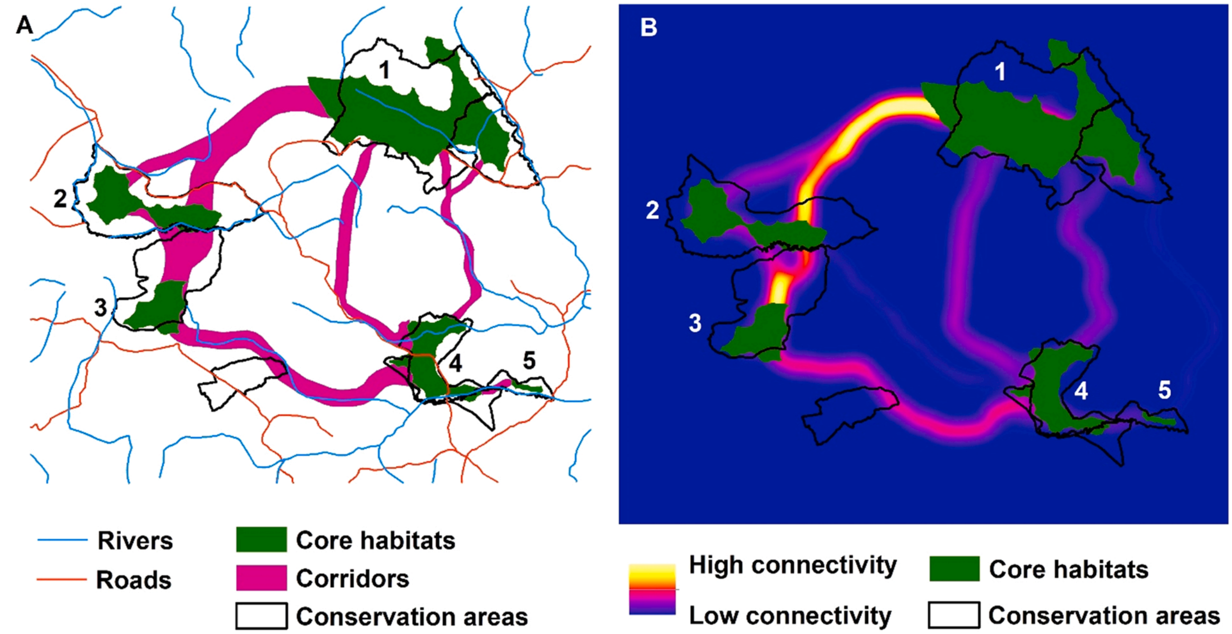


Fig. 4. Core habitats and corridors for mouflon in the study area (A: categorical core habitats and corridors, and B: contiguous corridors).

Table 3
Properties including area, coverage with conservation areas, and river and road densities of the predicted core habitats and corridors for mouflon in the study area.

		Area (km2)	CAs coverage (%)	Density (m/km^2)	
				Roads	Rivers
Cores	Core1 *	770.66	87.08	0	52.19
	Core2	222.58	98.43	0	39.46
	Core3	133.72	88.36	0	64.39
	Core4	207.31	94.96	51.57	127.17
	Core5	18.71	94.60	0	288.22
	Total	1352.98	90.39	8.1	56.9
Corridors	Core1 and Core2	388.1	11.1	26.41	46.46
	Core2 and Core3	153.96	91.15	0	45.93
	Core3 and Core4	306.2	10.26	0	174.1
	Core1 and Core4 (left branch)	194.75	5.32	19.44	104.36
	Core1 and Core4 (right branch)	117.44	20.47	26.63	161.76
	Core4 and Core5	15.66	94	0	382.37
	Total	1176.11	23.48	14.66	102.46

*Number of cores are available in Fig. 4.

4. Discussion

This study was carried out on habitat suitability and connectivity of mouflon in the west of Iran, a less known area for this near threatened species. Our study determined core habitats and the intensity of connectivity among them. The results revealed that grassland density, elevation, slope and distance to roads were the most important variables for predicting habitat suitability for the species. Core habitats for the conservation of mouflon were concentrated in CAs of the study area. There was a high connectivity from the north to the west and a moderate connectivity from the west to the southeast of the study area. CAs covered about one-fourth of corridors. Conservation implications and management of mouflon in the west of Iran could be carried out according to provided information in the present study.

4.1. Environmental variable contributions in habitat modeling

Grassland density appears to be the most important variable for habitat suitability of mouflon across all regions including the Caucasus biodiversity hotspot (Bleyhl et al., 2019), the center (Malakoutikhah et al., 2020), the south (Eslamlou et al., 2022) and the west of Iran (the present study). Roads have adverse impacts on mouflon across all regions (Makki et al., 2013; Yeganeh Keya et al., 2016; Farashi et al., 2017; Mohammadi et al., 2018; Mohammadi and Fatemizadeh, 2021; Eslamlou et al., 2022). Elevation was an important variable for habitat suitability of mouflon in some regions including the central (Momeni Dehaghi et al., 2018) and the west of Iran (the present study). The importance of elevation and slope was also confirmed for urial in Iran (Hosseini et al., 2019). Distance to villages was identified as an important factor for habitat suitability of mouflon in some regions including the Caucasus biodiversity hotspot (Bleyhl et al., 2019) and central Iran (Momeni Dehaghi et al., 2018), which is not an important factor in the west of Iran (the present study). This is why most of the villages in our study area were located outside the CAs and far from occurrence points of mouflon, and this factor was not very important for habitat suitability of mouflon in the west of Iran.

Land-cover and topography are critical parameters for mouflon survival in Iran due to providing food and security. In recent decades, land-use change of grasslands to agricultural lands by humans put pressure on the mouflon populations in Iran (Karami et al., 2016). Mouflon moves across different elevations to find fresh foods (Bleyhl et al., 2019), and development of human settlements at lower elevations increases the humans' risks to mouflons. In addition, movement of mouflon individuals within corridors in the areas crossed by roads should be considered by wildlife managers in Iran. Installing wildlife warning-signs in the areas with a high probability of mouflon accidents by vehicles could reduce mouflon collisions in Iran (Mohammadi et al., 2018).

4.2. Core areas, connectivity, and CAs

At a large scale (Iran), one large core habitat was identified for mouflon in the west of Iran (our study area) based on the previous study by Farashi et al. (2017). This core habitat is spatially isolated from the southern and northern core habitats of mouflon in Iran (Farashi et al., 2017). At a fine scale, five core habitats were identified in the west of Iran based on the present study. Therefore, connectivity among these core habitats is necessary for the movement of mouflon individuals in the west of Iran. This connectivity among core habitats was confirmed in some cases by the game wardens of DoE (i.e., between Core2 and Core3, and between Core3 and Core4). The corridor between Core2 and Core3 occurred mainly within the CAs, which facilitates the movement of mouflon individuals. Coverage of corridors by CAs mainly occurred at the start and end of corridors, and Zarin PA is the only CA situated in the half of the corridor between Core3 and Core4. However, this CA did not have a population of mouflon, and it could be considered a stepping-stone for mouflon individuals. The corridor between Core2 and Core3 with good river density and zero road length facilitated the movement of mouflon individuals between two CAs (Abdolrezagh PA and Bijar PA). Yeganeh Keya et al. (2016) revealed that there was low connectivity among core habitats of mouflon in Tehran County (the capital of Iran) resulting from highways. In addition, the development of road networks has been reported as the cause of low connectivity of mouflon individuals among the CAs in the south of Iran (Eslamlou et al., 2022). However, there are no highways in our study area, and mouflons can probably move among core habitats more easily. Overall, potential corridors among the CAs with a low density of roads and a high density of rivers provide a suitable situation for the movement of mouflon individuals in the west of Iran.

4.3. Limitations in the habitat suitability modeling and future studies

One of our limitations in habitat suitability modeling was lack of the access to the layer of wildlife water stations. These water stations are located within CAs and mouflon individuals used these water stations in addition to rivers based on personal observation. Even by considering this limitation, the results of the model evaluation were excellent. Moreover, the identified core habitats correspond with occurrence points. In addition, the threshold considering to categorize continuous habitat suitability map (10th percentile of suitability value at the occurrence points of species) was very conservative (Puddu and Maiorano, 2016), and core habitats represent areas with high habitat suitability. The game wardens of DoE confirmed the movement of mouflon individuals within two predicted corridors (mentioned in the Section 4.2). Due to some differences between structural and functional corridors (Momeni Dehaghi et al., 2018), monitoring other predicted corridors to assess the movement of mouflon individuals among the CAs is strongly recommended for future studies.

4.4. Implications for conservation

The distribution of large herbivores including mouflon has decreased drastically in Iran and most of their populations are restricted to CAs (Malakoutikhah et al., 2020). CAs have an important role in protecting mouflon from poaching and habitat loss. Mouflon was the seventh most poached ungulate species in Iran during 2010–2018 (Soofi et al., 2022). Consequently, mouflon population has decreased drastically outside the CAs and CAs are the last habitat of this species in Iran. Several studies were carried out on habitat suitability and connectivity modeling of mouflon in the center, northwest, and south of Iran (e.g., Momeni Dehaghi et al., 2018; Bleyhl et al., 2019; Malakoutikhah et al., 2020; Eslamlou et al., 2022); however, the habitat suitability and connectivity status of this species were unclear in the west of Iran. Therefore, the results of our study were necessary for the conservation of this species in Iran. On the other hand, due to severe habitat loss of mouflon in the future in arid areas (with spars vegetation cover) of central and southern Iran resulting from the climatic change (Malakoutikhah et al., 2020; Eslamlou et al., 2022), west of Iran could play an important role for mouflon conservation in Iran and the entire distribution of the species in the world. The higher value of core habitats coverage by CAs in our study area compared to other studies implied that mouflon is more restricted to CAs in the west of Iran. Corridors among the CAs should be protected from roads collisions and poaching. As in Iran, wildlife management and conservation is carried out provincially by DoE, a strong cooperation should be carried out among provincial DoE in order for the conservation of mouflon corridors. In this regard, despite the low density of roads within corridors, two corridors were crossed by roads and management actions are needed in these parts. In addition, to prevent poaching within corridors, the establishment of new CAs within corridors, such as Zarin PA is strongly needed. Considering the challenges of establishing CAs with more protection (e.g., WRs and PAs), the establishment CAs with less protection (i.e., NHAs) is recommended (Almasieh et al., 2022).

5. Conclusion

The present research aimed to identify suitable habitats, the most important core habitats and the strongest potential corridors that connect the habitats of mouflon in the west of Iran. According to the present results, the species was strongly associated with steep grasslands of low human interference (away from roads and villages). Moreover, our results showed that core habitats were strongly restricted to CAs. Connectivity analyses were carried out in order to determine potential movement of mouflon individuals within corridors. The study area had better conditions than the dry landscape of south and center of Iran regarding the survival of mouflon in the future. The conservation of the species within the CAs in the study area was mainly achieved. However, protection of predicted potential corridors for the movement of mouflon individuals among the CAs was necessary for the survival of this near threatened species. Based on our results, we recommended conservation of corridors among core habitats, particularly between Core1 and Core2, and between Core3 and Core4. Our results paved the way to have strategic action plans for the conservation of mouflon in the west of Iran.

CRediT authorship contribution statement

K.A. and **H.R.** conceptualized and designed the project. **H.R.** and **F.H.** collected the data. **K.A.** analyzed the data and interpreted results. **K.A., H.R.** and **F.H.** wrote the manuscript. **K.A.**, **H.R.** and **F.H.** discussed the results and commented on the manuscript.

Declaration of Competing Interest

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

Data Availability

The authors do not have permission to share data.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2023.e02377.

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