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Original Research

Identification of Climatic Refuges of Mouflon Under Future Climate in Central Iranian Protected Areas

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ABSTRACT

Habitat destruction is one of the biggest threats to wildlife populations. Climate change may exacerbate the impacts of habitat destruction and alter the distribution of species. We projected the impact of climate change on the distribution of mouflon (*Ovis gmelini*) in central Iran in 2055 and 2085, evaluated the efficiency of protected areas for protecting this species, and identified potential climatic refugia for this species. We analyzed presence data of mouflon according to climate and topographic factors and generated an ensemble model of habitat suitability based on nine species distribution models. In the modeling process, the most important uncorrelated variables were chosen. Using circuit theory, potential connectivity between habitat patches was estimated. To assess the impact of climate change on the study area in 2055 and 2085, two shared socioeconomic pathways (SSPs), SSP 2.6 and SSP 8.5, were used based on the global circulation models. Based on the climatic suitability model, approximately 34.11% of protected areas were recognized as suitable habitats for mouflon. In the forecasted climate conditions, approximately 3.30% of suitable habitats would become unsuitable and approximately 9.36% of the current protected areas will lose their efficiency in supporting this species. In addition, climate change may reduce habitat connectivity for mouflon in the future. We conclude that the development of the network of protected areas and attention to habitat connectivity are necessary for the future migration and survival of this species; therefore, conservation planning should consider the future potential of protected/unprotected areas in supporting mouflon populations.

Introduction

Global warming plays a dominant role in population decline and local extinction of species (Araújo et al. 2006; Pounds et al. 2006). Owing to the increase in greenhouse gases, followed by changes in climate components such as temperature and precipitation, it is expected that climate change makes alterations to the distribution range of species (Parmesan and Yohe 2003; Root et al. 2003; Lemieux and Scott 2005; Urban 2015). Climate change can also lead to the destruction of natural resources, habitats, and living organisms; species with limited dispersal ability and/or limited geographic ranges are most affected (Levins 1969, 1970; Mestre 2017; Ashrafzadeh et al. 2019; Kusza et al. 2019). Studies show that the severity of these changes increases with increasing altitude, so mountain species are more at risk of these changes (Root et al. 2003).

In addition to changing the distribution range of species, climate change can reduce the abundance of mammal species vulnerable to temperature changes (Thomas et al. 2004; Aryal et al. 2014; Tamburello et al. 2015), e.g., species may be forced to leave protected areas to obtain suitable habitats under climate changes (Araújo et al. 2004; Maiorano et al. 2006; Lisón et al. 2013). The ability of species to reach suitable areas has a significant effect on their survival during climate change (Pitelka 1997). Therefore, increasing habitat connectivity has been proposed as the most common approach to biodiversity management in the face of climate change (Heller and Zavaleta 2009). Landscapes with good habitat connectivity allow species to track their suitable habitat and climate conditions over time, thus preserving ecological and evolutionary processes (Kang et al. 2016).

Compared with small mammals, large mammals have high mobility, so they are more capable of tracking climate change and finding suitable habitats. Provided that the new habitats are suitable under climate conditions, dispersal is the first reaction of big mammals; therefore, identification of habitat corridors can play

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an important role in the conservation of species against climate change.

Over the past few decades, species distribution models (SDMs) have been used as an effective tool for estimating the impact of climate change on the distribution of species (Bakkenes et al. 2002). Modeling strategies to predict future distribution of species under climate change have often focused on the characterization of a species' bioclimate envelope. This approach does not account for some factors limiting species' ranges, such as competition, dispersal, and hunting (Pearson and Dawson 2004). However, they are still the most widely used and efficient tools for this purpose.

To predict climatically suitable habitats, SDMs examine the statistical relationships between climate variables and species occurrence data and then project to the future climate using scenarios of greenhouse gas emission (Pacifici et al. 2015). SDMs are also one of the most useful tools for assessing landscape connectivity and identifying corridors (Littlefield et al. 2019).

Iran is located in one of the most arid regions of the world, which is strongly affected by climate change, and is considered one of the most important habitats for the conservation of *Ovis* and *Capra* spp. (Abassi et al. 2010; Malakoutikhah et al. 2020). Its average temperature will increase by 3.4–3.5° by 2100 (Abassi et al. 2010); the amount of rainfall in Iran is only one-third of the global average, and evaporation is 20% greater than the global average. Significant changes in precipitation patterns and groundwater and surface water depletion have already led to habitat changes in the central part of the country. Mountains seem to be one of the severely affected ecosystems by land use and climate changes globally; hence, biodiversity in mountainous areas is highly vulnerable (Price and Butt 2000; Root and Schneider 2006).

Iran is located in the central part of the mouflon (*Ovis gmelini*) distribution range and is of great importance in terms of abundance and genetic diversity (Valdez et al. 1978; Rezaei et al. 2010). In the last half-century, the species has declined dramatically in abundance and geographic range and is listed as Near Threatened in the IUCN Red List (www.iucnredlist.org), implying that more conservation effort should be put into this valuable ungulate. There is a paucity of data on the impact of climate change on the distribution of *Ovis* species. A study by Salas et al. (2018) on Marco Polo argali (*Ovis ammon polii*) indicated that climate change will cause significant habitat losses at elevations less than 4300 m in eastern Tajikistan, whereas habitat gains will occur at elevations higher than 4500 m, implying that elevational range shifts may happen in the future. A similar study by Malakoutikhah et al. (2020) on three ungulate species revealed that climate change affects more severely the ungulates in mountainous regions, i.e., mouflon and wild goat (*Capra aegagrus*), compared with goitered gazelle (*Gazella subgutturosa*), which is distributed in low-relief plains. They also estimated that more than 40% of the movement corridors of mouflon will be lost as a consequence of climate warming.

In this study, we evaluated the impact of future climate change on the distribution and connectivity of mouflon in central Iran with the following objectives: 1) understanding the current and expected future distribution of mouflon under different climatic scenarios, 2) identifying potential climatic refugia for the species, and 3) assessing the efficiency of protected areas for protecting this species in the future.

Materials and Methods

Study area

Mouflon in Iran are distributed from cold highlands of the Alborz and Zagros mountains to dry and semiarid steppes of the central regions and the hot and humid coastline of the Persian Gulf (Ziaie 2008). The average annual rainfall is approximately 100 mm in the central parts and up to more than 400 mm in the northern and northwestern parts of Iran (Darvishsefat 2006). *Artemisia* spp. and *Astragalus* spp. are among the predominant plant species in most mouflon habitats in central Iran. The study area is approximately 40476 km^2 including Isfahan, Markazi, and Chaharmahal-and-Bakhtiari provinces (lat 32°30´–34°30Ń, long 50°–51°30É). The Zagros Mountains are one of the main mountain ecosystems in the region, with an elevation of 767–4409 m above sea level. The study areas include Mooteh wildlife refuge, Ghamishloo national park, Haftad Gholeh protected area, Dalan kooh protected area, Sheida protected area, and Palang Galoon no-hunting area, which are the main habitats for mouflon in Iran (Fig. 1). Seasonal migration occurs in many mouflon populations in Iran (Esfahani and Karami 2005; Ziaei 2008).

Mouflon locations

Initially, we obtained occurrence data resulting from field observations during the annual total census from the Department of Environment (N=84). We then assessed this data set to identify data gaps and then recorded additional occurrence locations (N= 87) by conducting fieldwork during 2015–2018. To check for spatial autocorrelation of presence points, the Moran index in ArcGIS software was used (Naimi et al. 2011). We then reduced occurrence data by setting a minimum interval distance of 5 km among them, which resulted in 164 points.

Climate change and habitat modeling approach

To investigate the impact of climate change on the mouflon distribution, climate parameters at 1-km resolution were obtained from the Chelsa database (https://chelsa-climate.org; Karger et al. 2017). To assess climatic suitability changes and avoid circular reasoning, we used climate variables as a surrogate measure of vegetation variation because of the dependence of vegetation suitability on climate. Also, the slope and terrain roughness layers were used as topographic parameters. Terrain roughness or ruggedness is defined as the variability or irregularity in elevation (highs and lows) within a sampled terrain unit. We calculated average surface roughness using the method specified by Hobson (1972). To provide background contrast, 4000 pseudoabsence points were used randomly using R software. Climate variables (n=19) were extracted for presence and pseudoabsence points, and their collinearity was investigated based on variance inflation factor (VIF) using "usdm" package (Naimi 2015). As a result, seven climate variables (VIF<10) including annual mean temperature (bio1), mean diurnal range (bio2), isothermality (bio3), temperature annual range (bio7), precipitation of wettest month (bio13), precipitation of driest month (bio14), and precipitation of warmest quarter (bio18) were used for suitability modeling of the mouflon habitat. All these variables were ecologically relevant and have been widely used in similar studies (Salas et al. 2018; Malakoutikhah et al. 2020; Rather et al. 2020).

Because of the variability between the predictions of SDMs, the simultaneous use of several methods in the framework of consensus modeling is desirable. The ensemble model can create a stronger model and overcome the uncertainties caused by the interpretation of individual model results (Araújo and New 2007). Nine SDMs with high predictive performance, including generalized additive models, maximum entropy, generalized linear models, generalized boosting models, surface range envelop, classification tree analysis, random forest, multivariate adaptive regression splines, and flexible discriminant analysis, were used to assess the habitat suitability of the species. These methods included regression methods, machine learning methods, and classification methods. All the different models are among the most common SDMs.

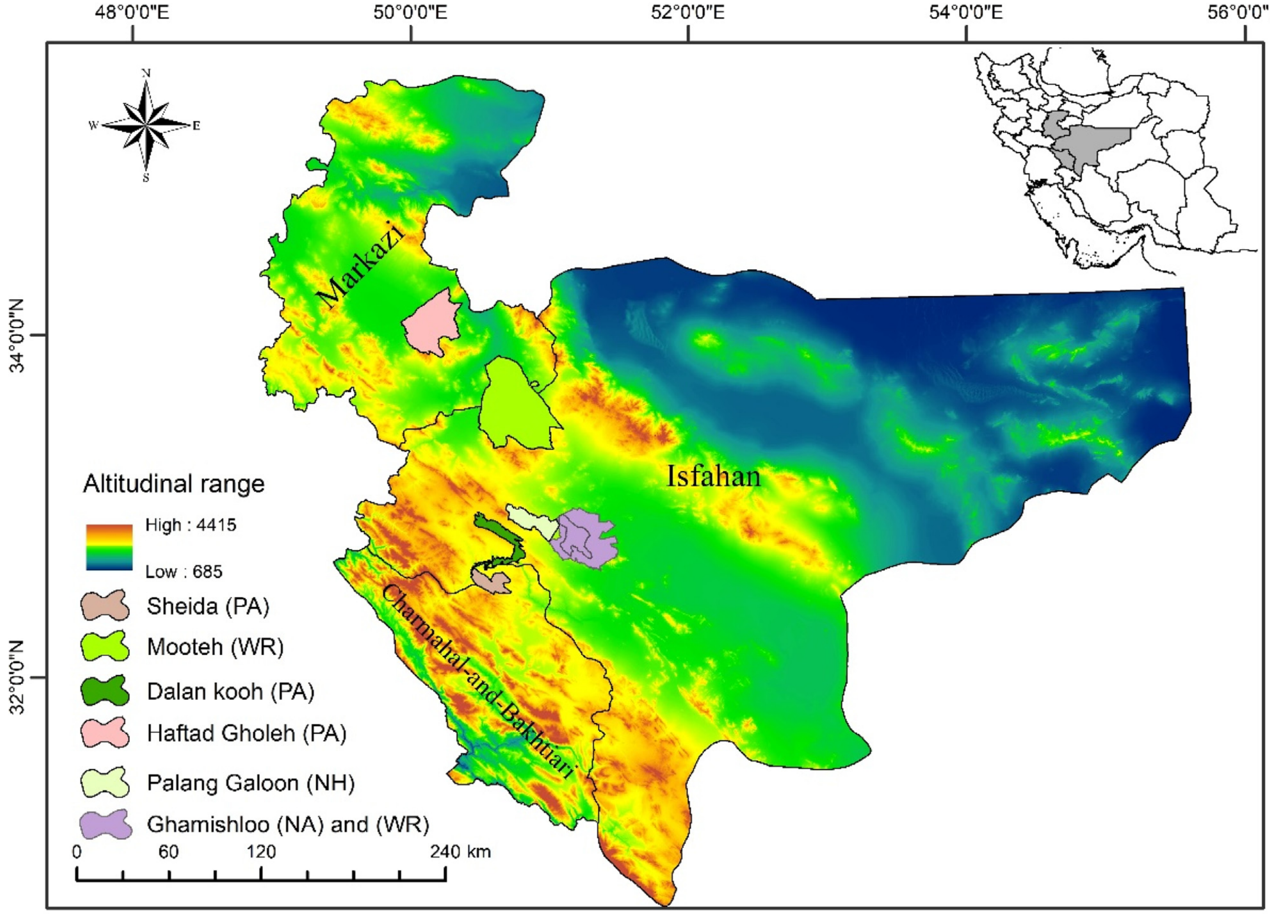

Fig. 1. Location of the study area in central Iran. Solid lines show the border of provinces; their names are depicted on the map.

Finally, all models were combined into one ensemble model using the biomod2 package in R software. We used 75% of the presence data for model training and the remaining 25% for model evaluation; the models were repeated 10 times. To evaluate the implemented models, we used the area under the receiver operating curve (AUC) and true skill statistic (TSS) because of their independence from the prevalence of presence data using the biomod2 package in R software (Allouche et al. 2006).

The future habitat suitability was predicted using four different global circulation models (GCMs) including GFDL-ESM4 and IPSL-CM6A-LR for the years 2055 (average for 2041–2070) and 2085 (average for 2071–2100). The greenhouse gases emission scenarios shared socioeconomic pathway (SSP) 2.6 and (SSP) 8.5 were also included in the analysis. The results of habitat suitability were presented based on average GCMs outputs.

To assess changes in current suitable habitats (loss/gain) by 2055 and 2085, the habitat map was classified into two suitable and unsuitable groups using the minimum suitability score at occurrence data (Malakoutikhah et al. 2020). Using SDM TOOL extension in ArcGIS software, the desired map was then prepared. The output map showed contraction, expansion, and unchanged habitat distribution (Brown 2020).

We used Circuitscape software (www.Circuitscape.org) to prepare habitat connectivity maps (McRae et al. 2008). The software uses the concept of electric circuits and analogs the species movement paths in the landscape to current flow in an electrical circuit board. This method requires a resistance map, which is obtained by inverting the habitat suitability map. The value of each cell in the landscape represents the degree of resistance or permeability of that cell to the species' movement. Where habitat is highly suitable, it is less resistant and the movement is more likely (McRae et al. 2008). In this study, using the ensemble habitat distribution map as a conductivity indicator and protected areas as a source of patches, the intensity of habitat connectivity flow was investigated.

Results

The potential distribution of mouflon

The AUC and TSS values showed excellent or good prediction accuracy (all AUC $>$ 0.75; all TSS $>$ 0.51; Table 1). Our model predicted that approximately 31.5% (1 696.61 km^2) of the mouflon's suitable habitats falls in protected areas, and other areas of protected areas do not have the conditions to support this species (Fig. 2C). As expected, Haftad Gholeh PA in the southern regions of Markazi province, the Mooteh wildlife refuge in the northern regions of Isfahan province, Ghamishloo national park in the central parts of Isfahan province, the Palang Galoon no-hunting area, and Sheida protected area in Chaharmahal-and-Bakhtiari province provide the most suitable habitat for the species. The models have also predicted that southern parts of Haftad Gholeh protected area are highly suitable, which is in fact used for the winter migration. In addition, the scattered and discontinuous patches in the northwest of Isfahan province and in the vicinity of Sheida protected area in Chaharmahal-and-Bakhtiari province have moderate–strong suitability. These suitable habitats cover 8.3% (3 384.5 km^2) of the study area (Fig. 2C). Temperature annual range (23.9%), precipitation of the wettest month (16.8%), slope (13.8%), and annual mean

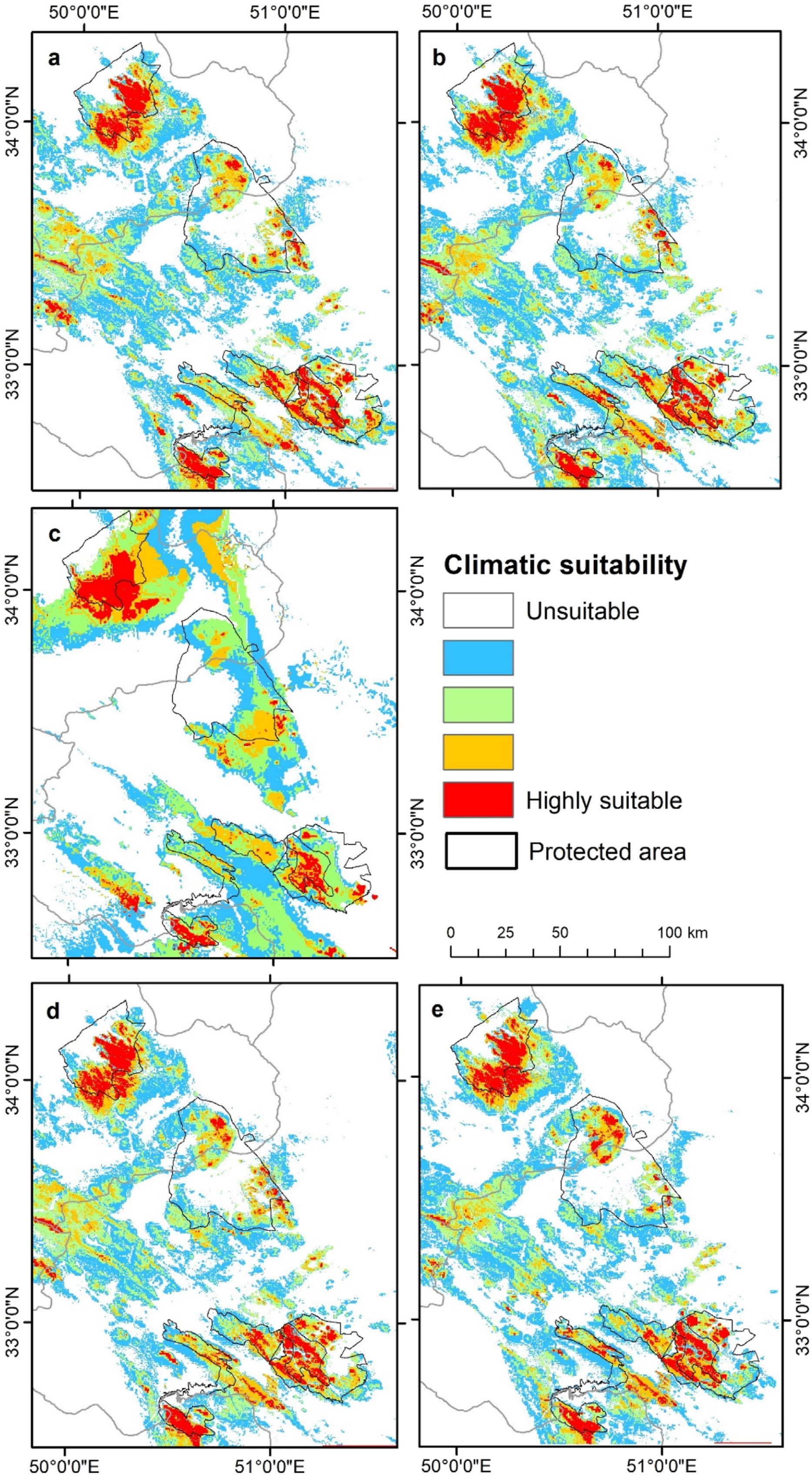

Fig. 2. Predicted current (**C**) and future distribution of mouflon in central Iran based on climate model with SSP 2.6 (**A**) and SSP 8.5 (**B**) scripts for 2055 and SSP 2.6 (**D**) and SSP 8.5 (**E**) for 2085. SSP indicates shared socioeconomic pathway.

Table 1
Evaluation of nine models used to predict the mouflon climatic distribution using AUC and TSS.[1]

	GAM	GLM	GBM	RF	MAXENT.Phillips	CTA	MARS	FDA	SRE
AUC	0.91	0.87	0.93	0.94	0.90	0.85	0.90	0.85	0.75
TSS	0.76	0.61	0.76	0.79	0.70	0.68	0.68	0.56	0.51

[1] AUC indicates area under the receiver operating curve; CTA, classification tree analysis; FDA, flexible discriminant analysis; GAM, generalized additive model; GBM, generalized boosting model; GLM, generalized linear models; MARS, multivariate adaptive regression splines; MAXENT, maximum entropy; RF, random forest; SRE, surface range envelop; and TSS, true skill statistic.

Table 2
Percentage of relative importance of predictive parameters in ensemble model of mouflon distribution.

Variables	Relative importance (%)
bio7 (temperature annual range)	23.95
bio13 (precipitation of wettest month)	16.82
slope	13.84
bio1 (annual mean temperature)	12.88
bio2 (mean diurnal range)	10.73
Roughness	8.99
bio18 (precipitation of warmest quarter)	5.71
bio3 (isothermality)	5.26
bio14 (precipitation of driest month)	1.72

Table 3
Changes in current suitable habitats (loss/gain) of *Ovis gmelini* by 2055 and 2085 under two SSP scenarios (%).[1]

	2055		2080	
	SSP 2.6	SSP 8.5	SSP 2.6	SSP 8.5
Unchanged unsuitable	92.78	93.04	92.57	92.98
Unchanged suitable	1.92	2.01	2.04	1.96
Expansion	1.94	1.67	1.97	1.74
Contraction	3.36	3.28	3.24	3.32

[1] SSP indicates shared socioeconomic pathway.

temperature (12.8%) had the greatest impact on mouflon distribution (Table 2). After binarizing the suitability habitat maps, it was observed that the areas with the highest suitability in the ensemble model are characterized by temperatures annual range of 40.84–43.03°C and precipitation of the wettest month of 28.12–53.57 mm (Fig. 2C).

Predicted habitat distribution under climate scenarios

Habitat suitability under the climate model for 2055 and 2085 is shown in Figure 2. According to the Figure, all SSPs for 2055 and 2085 habitat suitability will decrease compared with the current status but increase in some scattered patches in the west of Isfahan province (Fig. 2A, B, D, and E). SSPs for 2055 and 2085 predicted a substantial decrease in habitat suitability in Markazi province (Fig. 2A, 2B, 2D, and 2E). Also, patches with moderate–strong suitability in the northwest of Isfahan province and adjacent areas in Chaharmahal-and-Bakhtiari province were detected in the south of the Mooteh wildlife refuge that have retained their suitability, and the extension of the habitats with moderate–strong suitability is predicted in the western part of the province; these patches overlap exactly with the no-hunting area of Satable (Fig. 2A, B, and D).

According to the climatic model, suitable habitats for mouflon will decrease by 3.30% in 2055 and 2085 (Fig. 3; Table 3). In all climate scenarios, the distribution range of the species decreases over time; especially main habitats supporting large populations will be affected (Fig. 3). In the predicted models, new suitable habitats (previously unsuitable) increase by −1.83% in 2055 and 2085 (Fig. 3; Table 3). All climate scenarios indicate changes in the suitable altitude range. Currently, the suitable habitat elevation for mouflon was estimated to be 1 438–3 409 m, but on average, in 2055 and 2085, the suitable altitude range is projected to be 1 587–3 564 m. Our climatic models have predicted that by 2055 and 2085, approximately 12.35% of the current protected areas will be potentially suitable as mouflon habitat (Fig. 3), and therefore, the efficiency of protected areas will decrease under climate change conditions.

Habitat connectivity

The density of current flow in a landscape indicates movement possibility for an animal among habitat patches. Therefore, landscape structures that facilitate gene flow can be identified based on this information. The Circuitscape analysis indicated good habitat connectivity between habitat patches in the present time model, especially in areas where mouflon are present (Fig. 4C). The predicted corridors based on the measured density of current flow between Mooteh wildlife refuge and Haftad Gholeh protected area extend both east and north–south. Also, the current connectivity model shows multiple connectivity routes from the southern parts of Mooteh wildlife refuge to the Ghamishloo national park, among Palang Galoon no-hunting area, and in Dalan Kooh protected area (Fig. 4C). Strong but relatively discontinuous corridors have linked Ghamishloo to Dalan kooh and Ghamishloo to Sheida protected areas. A short strong corridor connecting the Sheida protected area to the Dalan kooh protected area strengthens the habitat connectivity between southern and northern protected areas (Fig. 4C). However, habitat connectivity between these two sets of protected areas is concomitant with the low quality of habitat and increased concentration of human activities. In addition, our results suggest that habitat connectivity will decrease toward 2055 and 2085, especially in the southern parts of the study area. However, intermittent and weak currents have been identified in the western areas of the region (Fig. 4A, B, D, and E).

Discussion

Climate change is predicted to have substantial negative impacts on biodiversity for a wide variety of taxa across many regions of the world. Climatic changes can affect shifting and contracting the range of species, changes in movement patterns, and ecological interactions of species (Van Beest and Milner 2013; Su et al. 2015). These changes can reduce the abundance of species with the deterioration of habitats (Lannoo 2005). In central Iran, wild herbivores are probably sensitive to climate change and can lead to the decline of rare and endangered species such as mouflon.

Climate change and future distribution of the mouflon in central Iran

We examined the mouflon suitable habitats under current and future climates using two data sets including climatic and topographic variables. The modeling results identified the negative impact of climate change on the mouflon habitat in central Iran. Despite differences in results among individual models, all models including the ensemble model represented similar spatial patterns of significant mouflon habitat losses in 2055 and 2085; other studies also show that the habitat suitability of herbivores will decrease

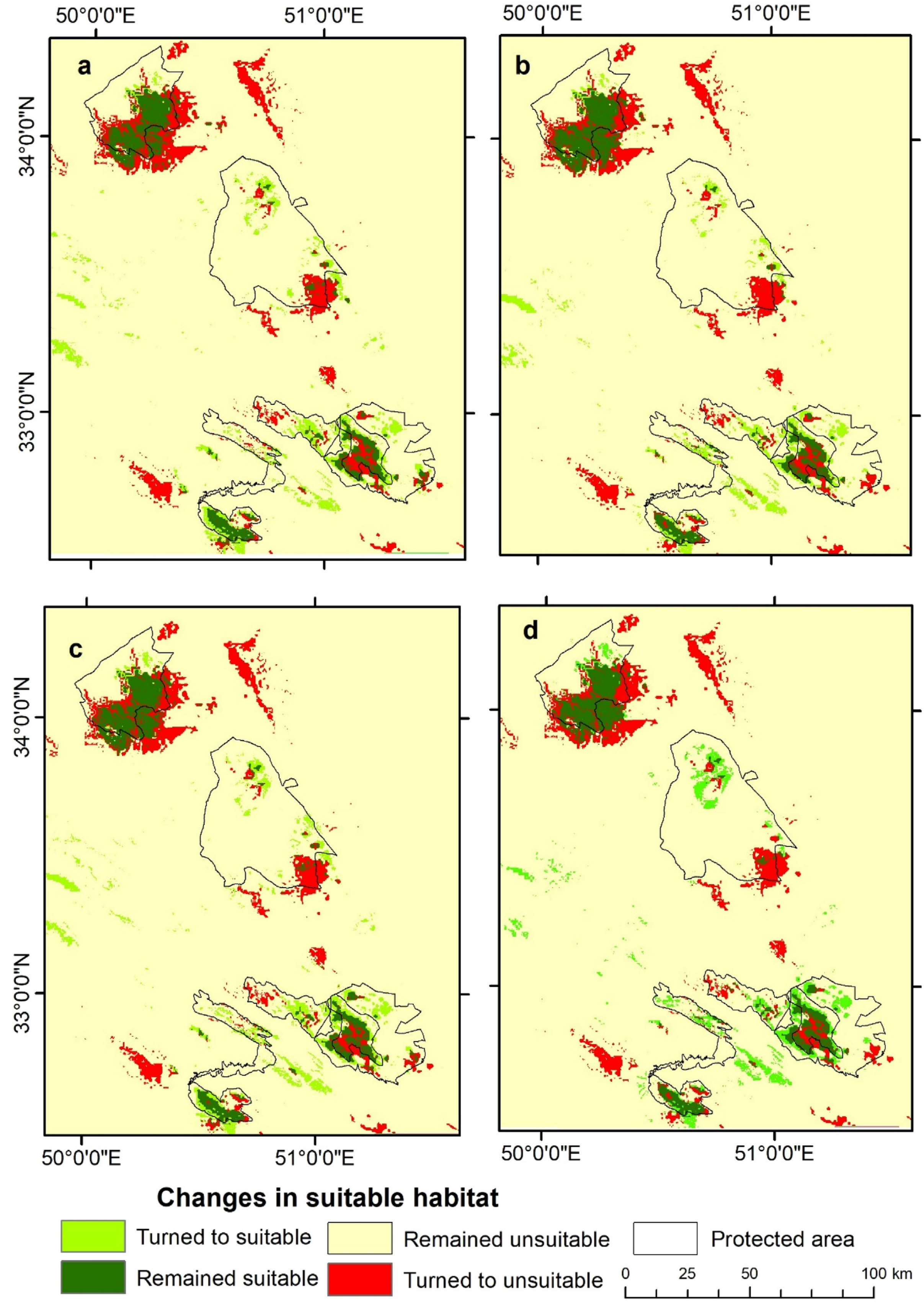

Fig. 3. Changes in current suitable habitats (loss/gain) of *Ovis gmelini* by 2055: **A,** SSP 2.6, **B,** SSP 8.5; and by 2085: **C,** SSP 2.6, **D,** SSP 8.5; under two SSP scenarios. SSP indicates shared socioeconomic pathway.

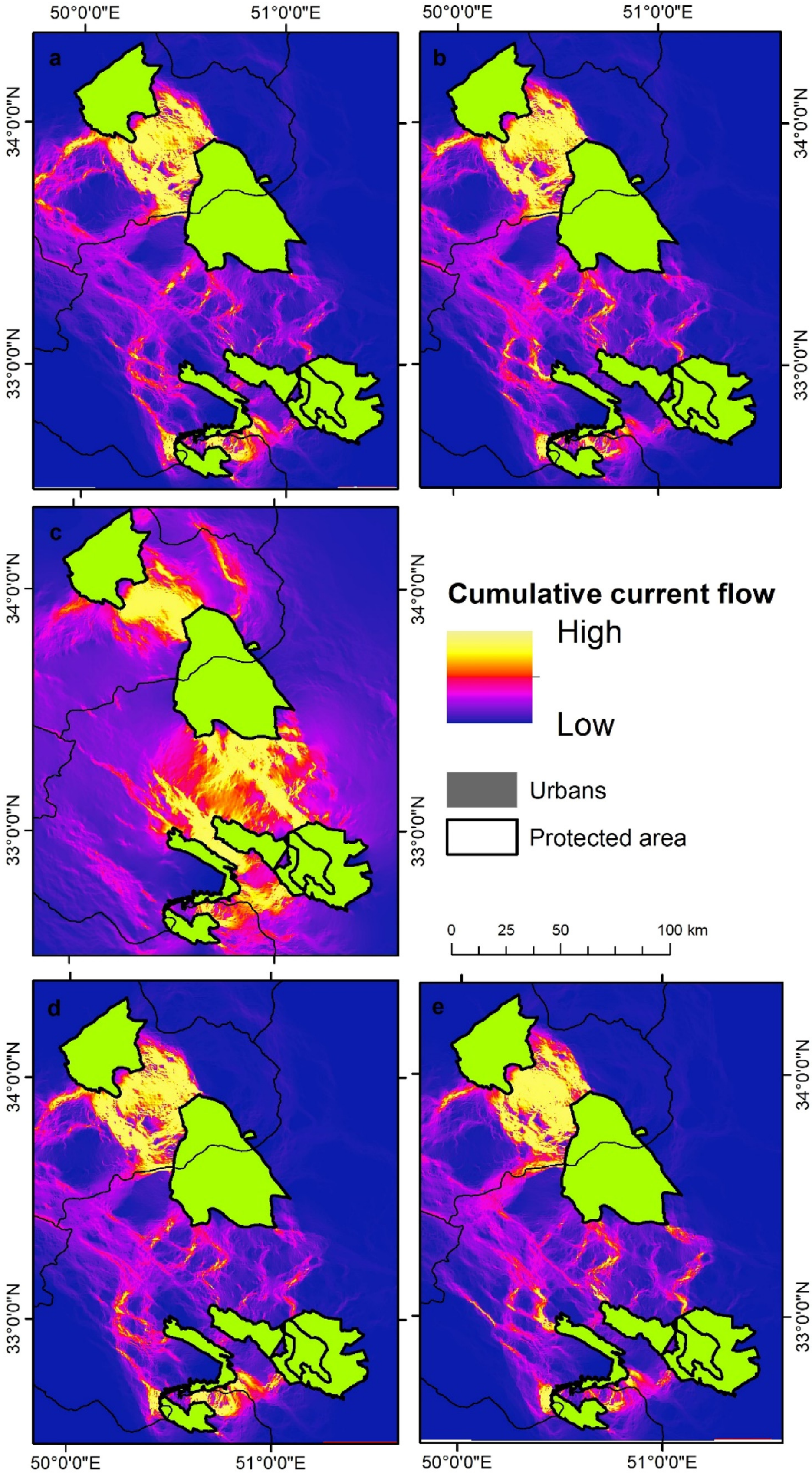

Fig. 4. Habitat connectivity among protected areas based on circuit theory in central Iran, predicted current (**C**) and future distribution of mouflon with SSP 2.6 (**A**) and SSP 8.5 (**B**) scripts for 2055 and SSP 2.6 (**D**) and SSP 8.5 (**E**) for 2085. SSP indicates shared socioeconomic pathway.

under climate change conditions (Raxworthy et al. 2008; Sexton et al. 2009; Salas et al. 2018; Karami et al. 2020; Malakoutikhah et al. 2020). Both SSP scenarios (SSP 2.6 and SSP 8.5) predicted that the current habitats of mouflon in northern and central parts of the study area may become unsuitable in the future. However, the majority of the southern region may remain intact. These results were also evident in the study of Malakoutikhah et al. (2020) for three ungulates including mouflon. We estimated, on average, a reduction of mouflon suitable habitats by 0.6–7% in 2050 and by 1–8% in 2070 (Singh et al. 2020), which is lower than the estimated reduction of habitat for mouflon in a previous study in central Iran (Malakoutikhah et al. 2020), for Marco Polo sheep in Tajikistan (Salas et al. 2018), and for Marco Polo argali in Tibetan Plateau (Luo et al. 2015). One reason for these differences in projected estimates could be related to different habitat requirements of these ungulates, which have occupied different regions and variations in sensitivity to climate change (Chen et al. 2011). According to a study by Ebrahimi et al. (2019), the distribution of the Bovidae family in Iran will be decreased by 2070 owing to climate change, and parts of the suitable habitats will be located outside the current protected areas. According to the all SSP scenario, habitats in the protected areas will have moderate–strong suitability; however, under the climatic scenarios of the western regions of the study area, where it is outside the current protected areas, these regions overlap with the no-hunting area of Satable, which is currently not a mouflon habitat (Singh et al. 2020).

Our results also projected a future altitudinal change of suitable areas from lower to higher elevations in the southern parts of the studied landscape. Other studies have also suggested that shifting of species range northward and upward in response to climate changes (Root et al. 2003; Salas et al. 2018). The topographic variables were among the most important parameters of mouflon habitat selection. Topographic variables also affect other predictive factors such as precipitation, temperature, and humidity (Funnell and Parish 2005). In addition, the role of elevation in providing adequate forage cover should not be underestimated; high-altitude regions offer more abundant forage cover for grazing throughout an extended period compared with low-altitude areas (Wehausen 1992). Our model, like previous studies, emphasizes the importance of slope and elevation in determining habitat suitability for mouflon (Ranjbar et al. 2016; Rezvani et al. 2020). This highlights the significance of habitat security in the selection process for mouflon. Slope plays a crucial role in minimizing the risk of predation (Bashari and Hamami 2013; Rezvani et al. 2020) and providing escape routes from potential threats, including illegal hunting.

Among climatic variables, our models were controlled by annual temperature range, precipitation of the wettest month, and annual mean temperature. The temperature annual range can affect the overall climatic conditions that mouflon experience throughout the year. Extreme temperature fluctuations can affect their behavior, reproduction, and overall survival. The amount of precipitation of the wettest month and the annual mean temperature during a year can affect the availability of water and food resources for the mouflon. It can also affect vegetation growth, which in turn affects the quality of mouflon habitat (Khan et al. 2016). St-Louis and Côté (2014) found that forage quality can be a key factor in determining habitat selection patterns for large herbivores (Forrest et al. 2012; Aryal et al. 2014; Khan et al. 2016; Salas et al. 2018).

The ability of species to adapt to climate change is influenced by the rate of climate change and the species' range, as highlighted in studies by Moritz et al. (2008) and Schloss et al. (2012). Many studies have documented the important impact of climate change on the habitat suitability of species (Araújo et al. 2004, 2011; Alagador et al. 2014). It has been suggested that if current climate change trends persist, existing protected areas may not be sufficient to ensure the survival of species, as indicated in studies survival (Araújo 2002; Hannah et al. 2002; Scott et al. 2002; Araújo et al. 2004). Nonetheless, this study suggested the effectiveness of protected areas in serving as climate refugia for species.

Climate change and future habitat connectivity of the mouflon in central Iran

Species' ability to leave unsuitable habitats and reach suitable areas is largely related to habitat connectivity. Currently, seasonal migrations of mouflon in our study area occur among the protected areas (Rezvani et al. 2020). However, the prediction of the climate models suggests that the connectivity between habitat patches may significantly decrease by 2055 and 2085. Such loss of connectivity leads to a decrease in gene flow among the populations, resulting in reduced genetic diversity and adaptation to climate change (Hermes et al. 2018). Nevertheless, the exact corridor that a species use to move between areas is not always predictable through distribution modeling (Sharifi et al. 2013; Keeley et al. 2017). For instance, plain areas between Mooteh wildlife refuge and Haftad Gholeh protected area are not suitable habitats for mouflon; however, seasonal migration between these two areas occurs.

Conclusion

In this study, we demonstrated the potential for mouflon population distribution in central Iran under future climate change. Our research on the impact of climate change on mouflon distribution in the region showed that current suitable habitats have the capacity to support the species in the long term and act as important climatic refugia. Haftad Gholeh protected area and Ghamishloo national park are among the habitats that have the ability to support mouflon as climate refugia in the future. Also, Dalan kooh and Sheida protected areas in Chaharmahal-and-Bakhtiari province are also high and suitable habitats under climate change conditions. According to the habitat suitability under the climatic conditions, the Palang Galoon no-hunting area has the necessary conditions to improve the protection level. In addition, owing to the proximity of this area to Ghamishloo national park, it has made it possible to move the species. The connectivity routes between Haftad Gholeh protected area and Mooteh wildlife refuge, which are currently used by the species, should be taken into consideration. Likewise, the pinch points between Mooteh wildlife refuge and Ghamishloo national park and between Sheida and Dalan kooh protected areas are also hotspots of connectivity, which will be cut off if the connection between the habitats is removed. Most of the connectivity corridors are cut off by the road network, so it is necessary to pay attention to the practical routes for the movement of wildlife and how to arrange them for human development. By identifying suitable habitats inside and outside protected areas, it is possible to ensure the survival of the mouflon by expanding existing reserves and creating new habitats in areas of high suitability. It is important to consider the seasonal migration patterns of species and maintain connectivity between habitats to facilitate movement and expansion. Inclusion of habitat corridors in conservation strategies along with resistance units is essential for sustainable management and conservation efforts aimed at maintaining the mouflon population in central Iran.

Declaration of competing interest

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers· bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

CRediT authorship contribution statement

Azita Rezvani: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. **Sima Fakheran:** Conceptualization, Writing – original draft, Writing – review & editing. **Mahmoud-Reza Hemami:** Conceptualization, Writing – original draft, Writing – review & editing, Formal analysis.

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