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Modeling the Habitat Suitability of Persian Leopard (*Panthera Pardus Saxicolor*) in the Conservation Areas of Kohgiluyeh and Boyer-Ahmad Province, Iran

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ABSTRACT

Aims: The study of the habitat of Persian leopard (*Panthera pardus*) as a keystone effective species in the ecosystem services is significantly essential in terms of protection. Habitat modeling and preparing the suitability map of that habitat is one of the ways of obtaining information and identifying the activity and behavior of species.

Materials and Methods: MaxEnt method was used in the presence data of the leopard and contributing factors in species distribution. Ultimately, habitat suitability modeling (HSM) maps obtained from this method were validated by using ground monitoring and the area under the curve (AUC) of the receiver operating characteristic (ROC) plot. The most suitable habitat for this species was introduced.

Findings: Results showed that distance from the range of the wild goat (*Capra aegagrus*) and the slope are the most critical factor in the distribution of Persian leopard in this province. Several factors, including distance from the conservation areas (CAs), distance from ranger posts, distance from rivers, distance from mines, geographic aspects, distance from water resources, elevation, distance from roads, and distance from villages, were the other important factors affecting the species HSM. Also, the most favorable habitat in Kohgiluyeh and Boyer-Ahmad Province is in cold regions at an altitude of 3300-3700 m, in tropical regions of 2000 to 2500, and on slopes more than 30% and in the west-northwest and the north directions.

Conclusion: based on the hidden correlations between the variables used in modeling habitat desirability of the leopard, the model with high performance and accuracy (AUC=0.927) predicts desirable and undesirable areas for the habitat of this species.

Keywords: *Capra aegagrus*, Distribution, Persian Leopard, *Panthera Pardus*, Habitat suitability.

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Introduction

The International Union for Conservation of Nature (IUCN) has listed the Persian leopard (Panthera pardus saxicolor) as a subspecies of endangered leopard on the Red List [1]. The leopard is a carnivore with unparalleled flexibility in its diet and opportunistically feeds on animals as small as insects to large venomous species such as boars [2]. A sharp decline in the population of this valuable species distributed in Western Asia and Central Asia was due to the destruction of habitat, conflict with humans, hunting by humans for their skins, and preventing their attacks on domestic animals [3]. The lack of suitable prey for the leopards (large and medium-sized wild ungulates) has caused them to inevitably provide their food needs by attacking domestic animals and even cattle dogs. On the other hand, the reduction of the population of the leopard's prey in some parts of Iran has threatened the leopard's survival in the long run [4].

Given that currently, the most significant threat of wildlife is the destruction of the habitats, and according to the estimation of IUCN until 1980, 30% of extinctions are only due to the destruction of wildlife habitats. The habitats are considered the most important factors for protecting species, especially endangered ones. Therefore, methods need to assess the habitats and identify the negative changes in these habitats over time[5]. Habitat conversion, fragmentation, and degradation have somehow endangered the stable life of species. Wildlife management is often based on the conservation, reproduction, and breeding of wildlife populations and the provision of suitable habitats for them[6]. To reduce human and wildlife over-lapping activities, by preparing HSM maps, areas essential for the conservation and management of the ecosystem must be preserved. On the other hand, a suitable habitat can significantly impact survival and reproduction, and thus more attention should be paid to the management and protection of wildlife. Habitat modeling can provide essential applications in identifying and introducing potential habitats to introduce species and indicates promising achievements in deciding management options for threatened species[7]. The suitable habitat can significantly impact survival and reproduction and, therefore, in management and wildlife protection [8].

The statistical methods are essential in choosing the most appropriate model, and conceptual decisions are important when selecting environmental variables for the model selection process [9]. Watts [10] conducted a study in India to model habitat suitability for the snow leopard *Panthera uncia*. Mukherjee et al. [11] examined the wild cat's condition in India, using the maximum entropy (MaxEnt) method, and considered large biogeographic areas. Ebrahimi et al. [12] implemented the MaxEnt method to model future HSM of the Persian leopard and found the prey availability as a key variable. Moreover, they found *Capra aegagrus* the most important prey for *Panthera pardus* in Iran. Farashi and Shariati [13]employed binary logistic regression to predict the habitat selection of the Persian leopard. The presence of prey and their distribution in leopard habitat has an effective role in the distribution and presence of this species in different areas of its habitat. According to studies, the main prey species include *Capra aegagrus, Ovis vignei, wild boar (Sus scrofa),* and *porcupines*. Hosseini et al. [14] implemented a multispecies approach by combining the species distribution models (SDMs) and circuit theory to model suitable habitats for Persian leopards. They achieved an empirical framework in this regard. Madadi and Varaste Moradi [15] investigated the HSM of the leopard (*Panthera pardus* saxicolar) using the maximum entropy method in Golestan National Park. The results based on the Jackknife Test showed that the distribution of leopard is primarily affected by the distribution of the prey, including *Capra aegagrus*, porcupines, rams, ewes, and ibexes, then depends on other environmental variables, including height of 500-1000 m, distance from water resources and roads. Rouhi et al. [16] investigated the probable corridor of the Persian leopard between two habitats, namely Khoshyeylaq Wildlife Refuge and Golestan National Park. They found that the most important factor in choosing the route and movement of the Persian leopard is to find paths that have enough security and do not interfere with residential areas. Ahmadi et al. [17]utilized SDMs to map potentially suitable habitats in Iran. Shams et al. [18] studied the most common causes of change in the southern habitats of the Asian cheetah habitats and non-climatic factors that directly and indirectly influenced these changes. In general, research indicates the high efficiency of the approach of MaxEnt to predict HSM of various species [19, 20, 21]. For example, Mahdavi et al. [22] used the MaxEnt approach to predict HSM for Eurasian Lynx in Iran for both now and the future.

In this study, factors influencing Persian leopard distribution were investigated, and the most important factors were discussed by modeling HSM and preparing its map by a high-performing machine learning called MaxEnt method in CAs of Kohgiluyeh and Boyer-Ahmad Province.

Materials & Methods

Study Area

This study was conducted in Kohgiluyeh and Boyer-Ahmad Province. The province covers an area of about 15702 square kilometers. It is located in the Zagros Mountains, between 29 degrees and 56 minutes to 31 degrees and 29 minutes north latitude and 49 degrees and 53 minutes to 51 degrees and 53 minutes of east longitude. The province is limited from the north to Charmahal and Bakhtiari Province, from the south to Fars and Bushehr Provinces, from the east to Fars and Isfahan Provinces, and from the west to Khuzestan Province [23]. Kohgiluyeh and Boyer-Ahmad Province have a national park, seven CAs, and five hunting prohibited zones (Figure 1).

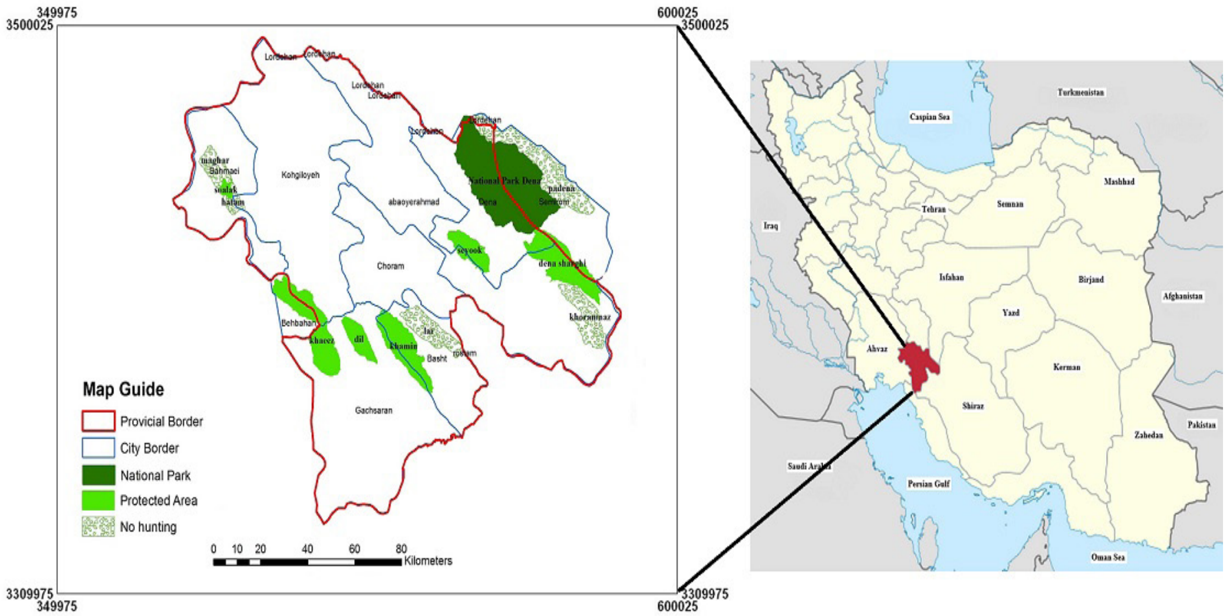

Figure 1) Study area and locations of conservation areas of Kohgiluyeh and Boyer-Ahmad Province in Iran.

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Determining the presence points of the species

Previous studies have shown that the number of samples should be more than 30 in the MaxEnt method to increase the model's accuracy [24]. For this purpose, a list of statistics and observations of the Persian leopard recorded in 12 years was recorded in free areas, and the CAs of Kohgiluyeh and Boyer-Ahmad Province since 2006 were investigated. These points were determined based on direct observation of the rangers and visitors of the regions, images received from camera-trap photographs, and the points in which scat and tracks were observed. The addresses and accurate observation points of the animals or their signs were determined. More geographical coordinates of species presence points were recorded through multiple trips to CAs and field surveys in all seasons in 2019. Finally, a collection of 70 observation points was gathered. At the same time as recording these points in the areas, field information related to elevation and topographic roughness, water resources, and existing wildlife in the presence points were also recorded.

Global Moran's I test was implemented to analyze the spatial autocorrelation of the occurrence points. Seventy occurrence points of the Persian leopard were retained for Species distribution models (SDMs) modeling. A long-term monitoring program was utilized to determine Presence locations for all potential habitats.

Habitat modeling using MaxEnt software

Modeling of suitable habitats of species was performed using MaxEnt software. In this study, 70% of the presence points were randomly assigned to the model training and the remaining 30% as test points for evaluating the model's results [25]. The ROC-AUC analyses were implemented to assess the results of discrimination capacity [26, 17].

The ROC chart shows the accuracy of the predicted presence in contrast to the accuracy of the predicted absence. The AUC is equal to 0.5, indicating that the model's randomization and performance are not better than random. The closer the value to 1 illustrates perfect discrimination. A good model is assumed if the AUC is between 0.7-0.8. If it is between 0.8-0.9, it indicates an excellent model, and more than 0.9 indicates a more excellent prediction [27]. Finally, the leopard's HSM was prepared in Kohgiluyeh and Boyer-Ahmad Province. In the map, the value of the points is between zero to one. The habitat is more suitable for the species as the points approach one [4]. Karami et al. [5] was the main source of obtaining prey distribution data. To calculate the distance to areas known, shape-files of prey species were overlaid, and a composite map was earned.

Findings

Maxent model development and performance assessment

After preparing the layers of the presence points and environmental variables and entering them into MaxEnt software, the HSM map was determined for species, which darker color represents the more suitable areas of leopard habitat in the studied area. The slope of HSM is toward hot colors, which means that however it goes toward the dark color (red = number 1), the habitat for the leopard is more suitable, and so on as it goes to the brighter color (blue = zero number), the desirability of the habitat reduce (Figure 2).

Table 1 shows the percent contributions of environmental variables and the importance of factors used in the Maxent model based on 2019 data. According to Table 1 obtained from MaxEnt software, the most important factors in choosing the species' habitat are the distance from the range of *Capra aegagrus* and the slope, representing 39.8% and 38.5% of the model's explanatory power, respectively. Moreover, the slope was the most

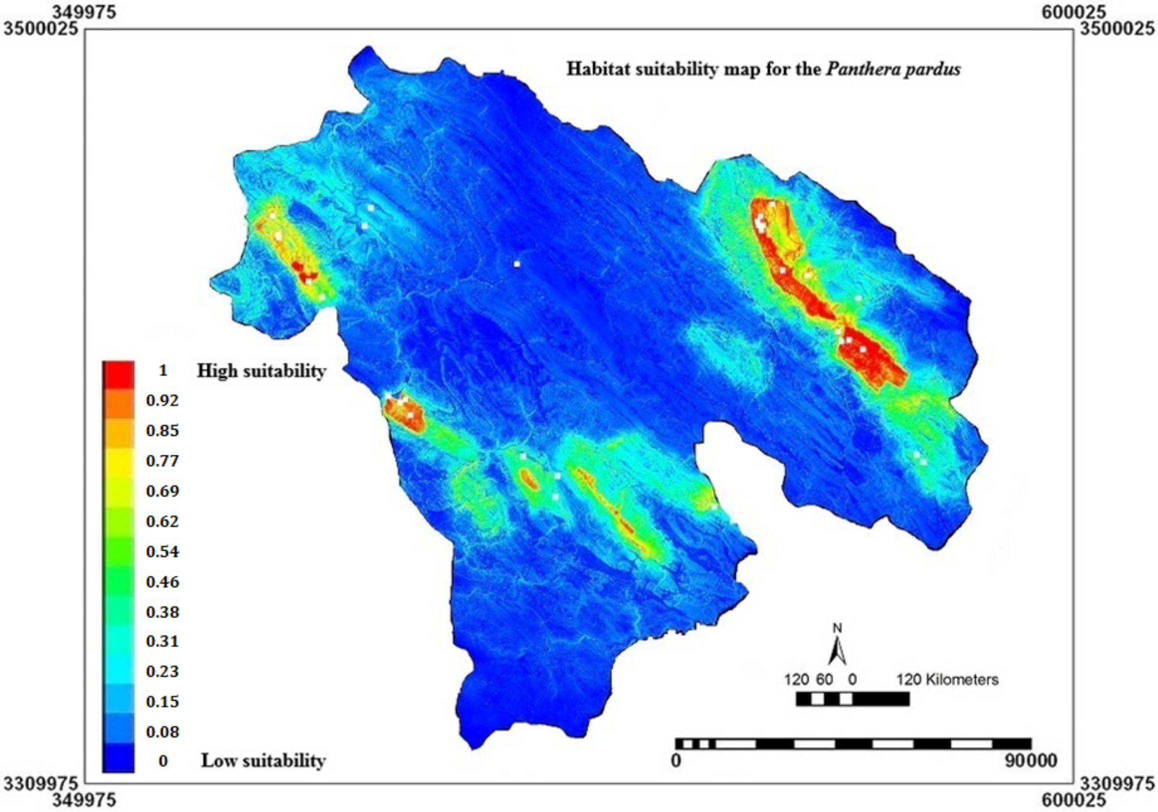

Figure 2) MaxEnt predicted habitat suitability within the study area for *Panthera pardus*.

Table 1) Percent contributions of environmental variables and the order of importance of factors used in the Maxent model based on 2019 data for the study area.

Variables	Average percent contribution (%)	The order of importance of factors (%)
Distance from the range of *Capra aegagrus*	39.8	3.2
Slopes	38.5	26.9
Distance from CAs	6.9	15.5
Distance from ranger posts	3.8	24
Distance from rivers	3.2	6.8
Distance from mines	2.2	11.4
Direction	1.5	1
Distance from water resources (springs)	1.4	4.3
Height	1.1	0.6
Distance from roads	1	4
Distance from villages	0.7	2.4

important environmental variable that affected the habitat suitability of this species. Similarly, the distance from CAs, the distance from ranger posts, the distance from the rivers, the distance from mines, the direction, the distance from the springs, the height, and the distance from roads are factors that participate in the model. In this study, the distance from villages' factor can be ignored because it is less than 1.

AUC index was implemented to assess model performance, and variable percent contribution was utilized for power. The accuracy of the model by the AUC index was assessed. According to the obtained AUC values and AUC classification, the model predictive accuracy of the Persian leopard habitat was assessed as an acceptable level (AUC = 0.927). If the average AUC score obtained from the graph was more than 0.9, it indicated a highly excellent prediction of the model for species habitat. Therefore the MaxEnt model has high performance and accuracy for predicting Persian leopard habitat.

Response curves

Response curves represent the relationships of environmental variables and suitable habitat distribution of the Persian leopard (Figures 3 to 9). This curve can provide helpful information about the required habitat suitability of the Persian leopard.

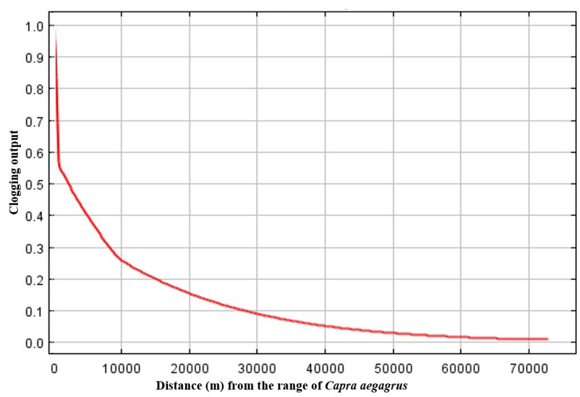

Figure 3) Results of the area under the receiver operating characteristics curve (ROC-AUC) analyses for a MaxEnt model of distance from the range of *Capra aegagrus* (in meters) for *Panthera pardus*.

As shown in Figure 3, the response curve analysis (RCA) of distance from the range of *Capra aegagrus* was shown in which the dependence of the leopard species in the region was evident in the presence of the range of *Capra aegagrus* by moving away from the location of these ranges, the desirability of the habitat for the leopard decreases with a steep slope. Any predator in its habitat uses a different range of prey and species to meet its food needs.

Figure 4 shows the RCA Persian leopard to the slope variable. The slope of each domain could influence the depth of the soil and vegetation on it. In this diagram, with increasing slope, habitat utility increases, which seems to be due to the dependence of this species on the range of *Capra aegagrus* and *Bezoar Ibex*.

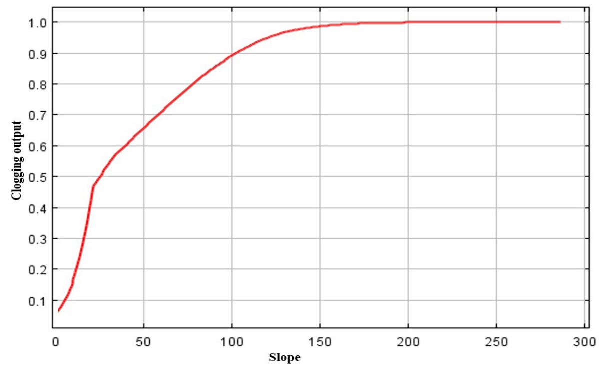

Figure 4) ROC-AUC analyses for a MaxEnt model of the slope variable (in percent) for *Panthera pardus*.

As shown in Figure 5, the RCA of the Persian leopard to distance from the CAs showed that by moving away from the CAs, the habitat desirability of the leopard was reduced. This might be due to the security of the CAs.

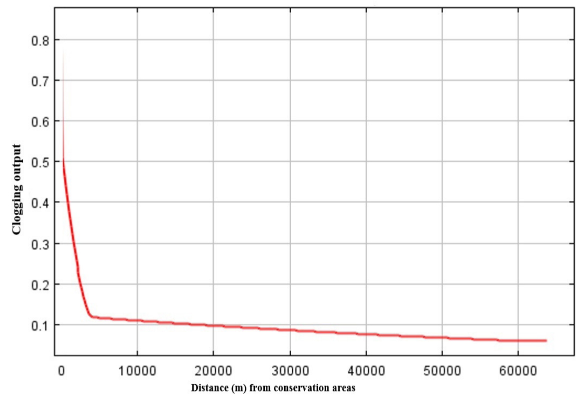

Figure 5) Results of ROC-AUC analyses for a MaxEnt model of distance from CAs for *Panthera pardus*.

As shown in Figure 5, the RCA of the Persian leopard to distance from the CAs showed that by moving away from the CAs, the habitat desirability of the leopard was reduced. This might be due to the security of the CAs.

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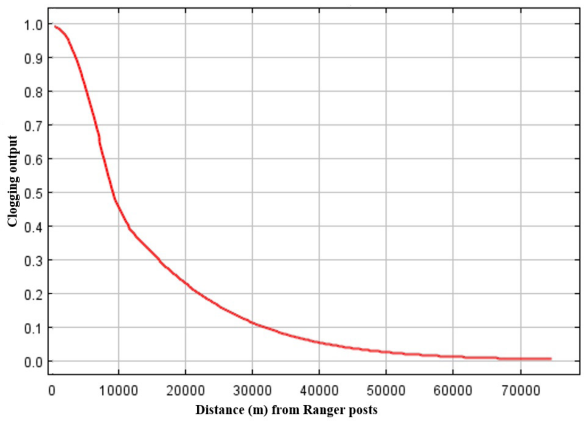

Figure 6) ROC-AUC analyses for a MaxEnt model of distance from ranger posts for *Panthera pardus*.

Figure 6 shows the RCA of the Persian leopard to the variable of distance from ranger posts. In this diagram, the desirability of leopard habitat increases up to a distance of 1 km, and then, by moving away from the ranger posts, the desirability of leopard habitat decreases. This seems to be the security due to the presence of rangers at the checkpoints to prevent wildlife hunting.

Figure 7 shows the RCA of the Persian leopard to distance from rivers. Based on the curve at a distance of 6-10 kilometers from rivers, the HSM of the leopard was high, which had the most suitability at a distance of 10 kilometers from the river, and remained unchanged afterward.

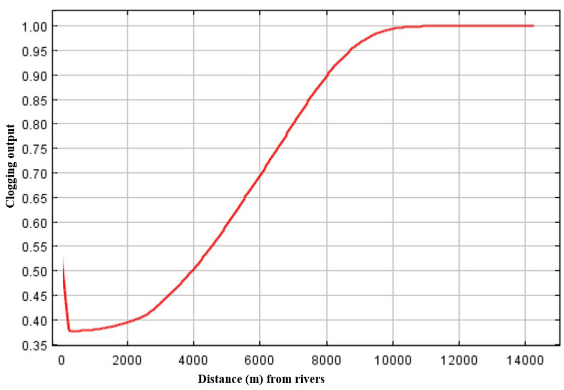

Figure 7) Results of ROC-AUC analyses for a MaxEnt model of distance from rivers for *Panthera pardus*.

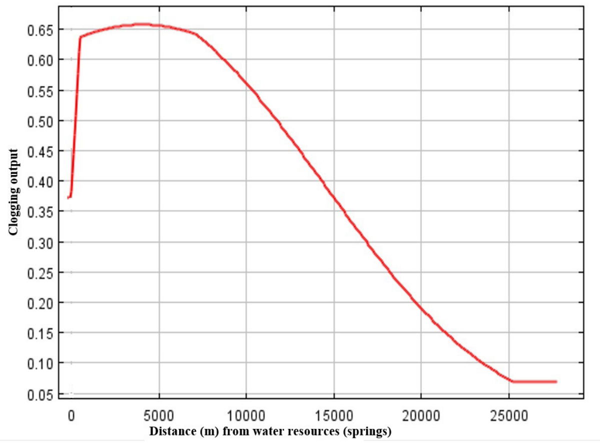

Figure 8) Results of ROC-AUC analyses for a MaxEnt model of distance from water resources (springs) for *Panthera pardus*.

Figure 8 shows the RCA of the Persian leopard to distance from water resources (springs). Water is vital and one of the basic needs of a species. So in habitat assessment, distance from water resources was considered one of the most fundamental factors in predicting the presence of species.

The high dependence of the Persian leopard on water resources like springs is visible to a distance of 5 kilometers. After 5 km, the habitat desirability of the leopard was reduced.

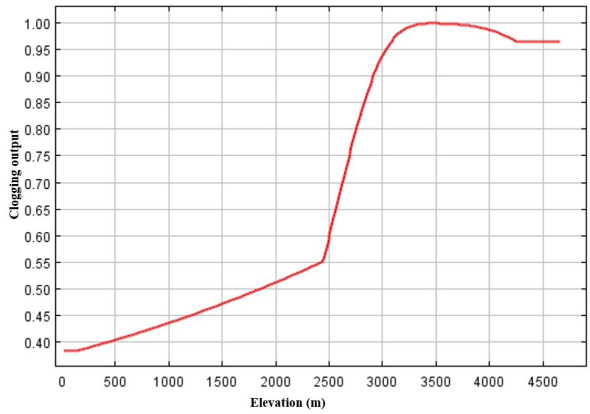

Figure 9) Results of ROC-AUC analyses for a MaxEnt model of the elevation variable for *Panthera pardus*.

Figure 9 shows the RCA of the Persian leopard to the elevation variable. The diversity of elevation and topographic roughness, and difference in the elevation provided a suitable bed

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for the emergence of various plant species and animals. The existence of high and mountainous regions led to the formation of a cold microclimate in warm and dry areas. With increasing height, the temperature could also affect the composition of plants. Hence, the height (altitude) was also entered into the modeling as a factor affecting the presence of the species. Our results demonstrated that the HSM of the leopard was increased with increasing height after 2500 meters, and the most suitable elevation for the leopard is between 3000-4,000 m.

Therefore, it can be concluded that the habitat with a reduction in distance from the range of *Capra aegagrus* (39.8%), increase in the slope (38.5%), reduction in distance from the CAs (6.9%), reduction in distance from ranger posts (3.8%), increase in distance from rivers (3.2%), reduction in distance from water resources (2.2%) and increase in the elevation (1.1%), can provide a suitable habitat for Persian leopard.

Receiver Operating Characteristics (ROC) Curves

According to the obtained AUC values and AUC classification [31], the model predictive accuracy of the Persian leopard habitat was assessed as an acceptable level (AUC=0.927) (Figure 10). Also, the assessment of the accuracy level of model output showed that MaxEnt could successfully predict the HSM of the Persian leopard (AUC= 0.927). According to the diagram, the red line represents the data used in the model, the blue line represents the data used to test the model, and the black line represents the model prediction at random. As shown in the diagram, the AUC is 0.927 for the data used in the model (red line) and 0.881 for the data used to validate the model. In this model, the area below the curve is 0.927, indicating the excellent detection power of the model. This is due to the adaptability of the Persian leopard to diverse habitat conditions.

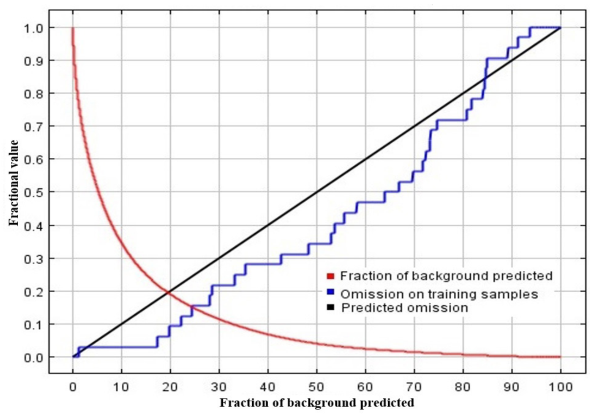

Figure 10) Omission rates versus predicted area for a MaxEnt model of predicted habitat suitability for *Panthera pardus*.

Discussion

MaxEnt model indicated that the most important factors in the habitat distribution of Persian leopard are the distance from the range of *Capra aegagrus* and slope. Other factors, such as distance from CAs, distance from ranger posts, distance from rivers, distance from water resources (springs), elevation, and distance from roads, are in the following priorities. Therefore, our results do not follow those of Vesali et al. [28] and Shoaei et al.[4], suggesting the most important factors influencing the presence and absence of the leopard as surface roughness and distance from roads. These results are in line with the results of Rohi et al. [17] and Omidi et al. [29], demonstrating the most important factor influencing the presence and absence of the Persian leopard in areas as being in the proximity of food sources (*Capra aegagrus*). Therefore, it seems that the Persian leopard in Kohgiluyeh and Boyer-Ahmad Province is still dependent on the initial prey to feed. In this regard, in this study that aimed to protect the species of carnivores located at the head of the food ecological pyramid, the most important factor is the food habits of the species because the life of carnivores depends on their prey and the first step in protecting is determining their primary prey. The Persian Leopard mainly focuses on habitats with the capability to trap the prey; therefore, mountains and the existence of topographical features increase the possibility of trapping [31]. Moreover, studies on the leopard habit indicated that a significant part of the leopard meal consists of ungulates living in the mountains like *Capra aegagrus* [12, 13].

The results of this study showed that the most favorable habitats in Kohgiluyeh and Boyer-Ahmad Province are in cold areas at an altitude of 3300-3700 m, in tropical areas at 2000 to 2500, and on slopes more than 30% and in Western, Northwest to the North directions, that is, rocky and impassable mountainous areas. Our findings are consistent with those of Shoaei et al. [4], Omidi et al. [29], and Vesali et al. [28], demonstrating that the choice of the altitude higher than 2000 meters, the slopes more than 30%, and the northern directions are compatible.

The results also proved that due to the *Panthera pardus* preference to live on steep hillsides, steep slope plays the leading role in defining a suitable habitat for this *species* [13]. Given that the existence of slopes is one of the factors affecting the distribution of wildlife population, whether prey or predators, it is one of the biological factors affecting the presence and distribution of wildlife species. Also, this issue can influence the presence and distribution of the leopard that some parts of its prey and rival predators are distributed on high slopes of the land. Given the importance of slops in the leopard habitat, slopes were entered into the model as one of the habitat variables. Since the *Capra aegagrus*' habitats were located in steep and mountainous slopes and the leopard also depended on this prey, the leopard's habitat desirability increased [13].

After the effect of prey, the most important factors are the effects of CAs and the presence of ranger posts in the regions. The highest presence of Persian leopard prey, like *Capra aegagrus* located in CAs, is seriously protected by the Department of Environment, and the continuous presence of rangers in these areas provides high security for leopard species. Hence, according to protective prioritization based on the distribution of presence points, desirable habitats for the leopard and the prey, *Capra aegagrus*, in Kohgiluyeh and Boyer-Ahmad Province are as follows: Dena National Park, Eastern Dena CA, Kaiez CA and Sorkh, Kamin CA and Soulk CA. The findings from HSM present a substantial change of suitable habitats, which could be the essential parameter in determining the long-term survival of *Panthera pardus* in Iran.

As it noted, five factors such as distance from the range of *Capra aegagrus*, distance from CAs, slopes, distance from ranger posts, and distance from rivers have played more influential roles in increasing the suitability of habitat and predicting desirable areas for the presence of the leopard in Kohgiluyeh and Boyer-Ahmad Province. The leopard is most likely to be present and active at 10 kilometers from the rivers. At a distance of less than one kilometer, the leopard's presence is relatively high, and up to 6 kilometers decreases, then more than 6 kilometers increases again. This subject can be surveyed from two aspects. Whether the water need of the leopard is high and the leopard's dependence on the rivers is due to its need, or primarily to find prey, especially in summer. In Tandoureh, it was found that most prey of the leopards in summer are near water (32).

As stated, the leopard lives in places located at the foot of mountainous areas to heights. Satellite collaring in northeastern Iran showed that leopards could disperse up to 80 km (33). Given that water is one of the primary needs of any living creature, the leopard near the rivers is not due to its need, but because of the presence of prey at the water resources of the rivers.

Conclusion

In this model, the variables of distance from the range of *Capra aegagrus*, distance from CAs, slopes, distance from ranger posts, and distance from rivers had the largest share. Habitat modeling and preparing the suitability map of that habitat is one of the ways of obtaining information, choosing habitat and types of performance of species in the habitat, in fact by specifying the desirable habitats and sources of attraction and rejection of the species and determining favorable and unfavorable factors in presence and distribution of species in the habitat. We can design a special protective and supportive program suitable for the performance of the species in the habitat to protect the species and manage its habitat.

According to the results, with the increase of security near the ranger posts and due to the large area of protected areas in the province and the lack of rangers, the number of rangers should be increased and equipped to work more for more security in the areas. Also, because most locals did not have good information about the characteristics, habits, and behavior of the leopard species, educating and informing the residents of the area about the importance of the protected areas of the province as well as the wildlife in them through mass media, radio, and public and institutional organizations and government.

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