

Evaluation of factors affecting predator-prey distribution for grey wolves, wild sheep, and wild goats in Haftad-Gholleh National Park, Iran

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Abstract

Haftad-Gholleh National Park located in central Iran is inhabited by two prey species: the wild sheep (*Ovis orientalis*) and the wild goat (*Capra aegagrus*). Their main predator in the park area is the grey wolf (*Canis lupus*). We applied a maximum-entropy presence-only approach to model habitat suitability for these three species in the Haftad-Gholleh National Park. Moreover, we studied their niche breadth using ENMTools. Altogether seven environmental variables were incorporated into the final models including the percentage of vegetation cover, slope, aspect, elevation, distance from human activities, distance from water, and distance from the road. Results indicated that habitat variables such as slope, aspect, and distance from water were the most important variables affecting the predictive power of the prey and predator species models. The Grey wolf has a distribution larger than that of the wild goat, but smaller than that of the wild sheep. Interestingly, niche-breadth analysis indicates that the grey wolf has a niche breadth half that of the wild sheep and twice that of the wild goat. Wild sheep have a relatively wide geographical extent and show a tendency to marginal and strictly protected habitats; the grey wolf chooses moderate areas fit for its moderate mobility of habitat variability and dependency to restricted natural habitats, and the wild goat has a relatively narrow geographical extent and shows a tendency to specific restricted natural habitats in the Haftad-Gholleh National Park.

Keywords: Habitat suitability modeling, Environmental niche model, MaxEnt

Introduction

Environmental niche models (ENMs) are used to describe the ecological tolerances of populations or species. A range of methods generates ENMs from georeferenced occurrence data (i.e. sample localities associated with latitude and longitude coordinates) and environmental data in the form of geographic information system (GIS) data layers (Warren et al., 2010). The MaxEnt modeling approach is one of the most common algorithms in machine-based learning investigations. It is based on maximum entropy theory (Phillips et al., 2006). ENMTools interacts with the maximum entropy niche modeling program MaxEnt (Phillips et al., 2006; Phillips & Dudík, 2008). Several factors like the physiological tolerance of the species and the interactions with other species define the presence and habitat use of a species in an ecological niche (Warren et al., 2010). Interspecific competition and predation risk are the two most important variables related to a species's habitat use and survival (Kearny et al., 2004). Previous studies investigating the influence of predation on an animal's distribution (e.g., Peers et al., 2014; Esfandabad et al., 2010; Hosseini-Zavarei et al., 2013) emphasize that including prey-predator relationships in habitat models improves diagnosis and prediction of a species's habitat use, and thereby reduces uncertainty.

Observed population declines of the wild goats (*Capra aegagrus*) and wild sheep (*Ovis orientalis*) at national and global levels are caused by several factors, including poaching, habitat degradation (due to land change and road development), and competition with livestock (Ziaie, 2008; Weinberg, 2008). The grey wolf (*Canis lupus*) is the most abundant large carnivore in Iran. It is still found in different natural habitats and protected areas (Safavian, 2018).

The present study aims to develop habitat suitability models for a scenario of two prey and one predator species (wild sheep, wild goat, and grey wolf). Using a presence-only method, maximum entropy (MaxEnt), we hope to model the predation of wild sheep and wild goats (the two prey) by the grey wolf (the single predator) in the Haftad-Gholleh National Park located in Markazi province in the center of Iran.

Material and methods

Study Area

With an area of 97437 ha, Haftad-Gholleh National Park is situated 25 km east of the city of Arak and 15 km to the southwest of Mahallat. It fits within the latitudinal and longitudinal bounds of 37° to 38° N and 40° to 44° 20' E, respectively. The mean annual precipitation is 349 mm and temperature fluctuations range from -30 °C to 38 °C. The park was designated as a hunting-prohibited area in 1974 under the protection of the Department of Environment. The most important mountain range of the area is the Haftad-Gholleh Mountains. Barfshah Mountain with a height of 2993m is the highest summit (Fig.1). Chekab and Sibak are among the most important valleys having springs used as water sources by wild animals. Haftad-Gholleh National Park is the only main protected territory in Markazi Province, which has been declared as a conservation area for the protection of wild goats and wild sheep. The most important wildlife species in this area include wild goats (*Capra aegagrus*), wild sheep (*Ovis orientalis*), the Persian leopard (*Panthera pardus*), the grey wolf (*Canis lupus*), a wild cat (*Felis lybica*), Caracal (*Caracal caracal*), Badgers (*Meles canescens*), and Hedgehogs (*Erinaceus concolor*) (Ansari, 2020). In Haftad-Gholleh

National Park, the wild goat is one of the species with considerable conservation importance. Currently, the wild goat of Haftad-Gholleh is known as a symbol of the biodiversity of Markazi Province (DOE Markazi, 2010). Based on the 2020 census, there are 1300 wild goats and 3200 wild sheep living in the area with a confidence interval of 95% (DOE Markazi, 2020).

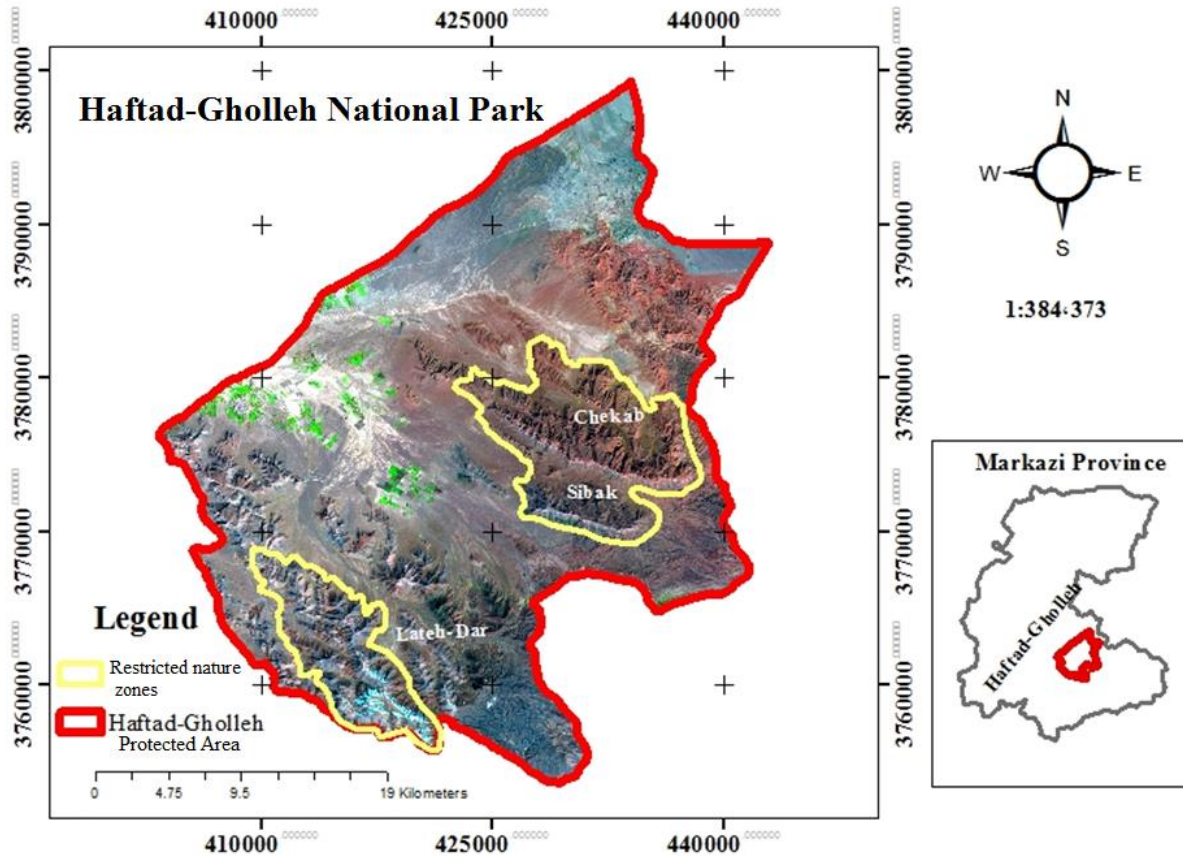


Figure 1. Map of Haftad-Gholleh National Park and its location in Markazi Province

Species Presence Data, Environmental Variables, and Analysis

The study region was modeled in the form of a raster map with a 30×30 pixel size and a 1:50000 scale. During the field phase of the study, a total of 90 direct observations were recorded by GPS for three species in four seasons from April 2018 to March 2019. We also acquired other evidence such as tracks, camera trap images, scats, horns, bones, and feeding remains. At the same time, wardens were asked to report observed presence signs during their daily surveys. A total of 111 presence locations were collected (33 for wolves, 43 for wild sheep, and 36 for wild goats). To validate models, we randomly selected 80% of these as a training set and used the remaining 20% as a test set (Table 1).

Table 1. Species Presence Data

Species	footprint	camera trap images	Scats	horns	bones and feeding remains	Direct observation	Total
Wild sheep	8	10	1	1	0	16	36
Wild goat	10	10	0	1	2	20	43
Wolf	15	10	0	0	0	8	33

Predictive environmental variables were determined by reviewing the literature and matching the species' presence points with the environmental characteristics of the area. A set of independent ecological variables was created that included: topographic features (e.g., distance from water, percentage of vegetation cover, slope, aspect, and elevation); and impacts of human-based activities variables (e.g., distance from human activities such as roadways, agriculture, settlements, and livestock). These are typical variables used in similar studies (Safavian et al., 2018; Farrashi et al., 2011; Ansari et al., 2014). The correlation among variables was examined. We applied the maximum entropy (Maxent) approach to develop habitat suitability models for three species. The Maxent method is based on the comparison of the ecological features of the species presence points with the ecological features of the region. The area under the curve (AUC) for the receiver operating characteristic (ROC) curve was used as a measurement of model accuracy (Phillips et al., 2006). Maps obtained for each species were overlapped using MaxEnt in ArcGIS 10.3 and IDRISI TerrSet 18.31 and were used for data analysis (Ronald Eastman, 2015). To calculate the area of suitable habitats for each species, we classified the continuous suitable habitat map for each species based on the suitability threshold, which maximizes the specificity plus sensitivity for the test data. For each species, areas with suitability higher than the threshold were classified as suitable and their area was calculated. Then, we used ENMTools v1.3, which interacts with MaxEnt (Phillips et al., 2006; Phillips et al., 2008), to measure niche overlap among potential distributions of the wolf, wild sheep, and wild goat. ENMTools allows researchers to automate the generation of ENMs, calculate similarity measures, and implement various statistical comparisons of ENMs. ENMTools implements two quantitative tests of niche similarity introduced by Warren & colleagues (2008) and Legault et al. (2013). In addition, three metrics were produced:

- (1) "I", which treats the two environmental niche models as probability distributions;
- (2) "Schoener's D", which assumes that the MaxEnt score is proportional to abundance (Vanderwal et al., 2009); and,
- (3) "relative rank" which estimates the probability that the relative ranking of any two distributions is the same for the two species being compared irrespective of the quantitative difference in suitability estimates (Warren et al., 2008; Warren et al., 2011).

Eventually, we estimated the niche breadth of each species using Levin's inverse concentration metric (Nakazato et al., 2010), implemented in ENMTools (Safavian et al., 2018).

Results

Species Presence Data

Figure 2 shows recorded observations for the three species (the wild sheep, the wild goat and the grey wolf) near a water source in the study area. Most of the observations of wolves were during the night and they were rarely seen in the day. However, wild sheep and wild goats were only observed in daylight hours.

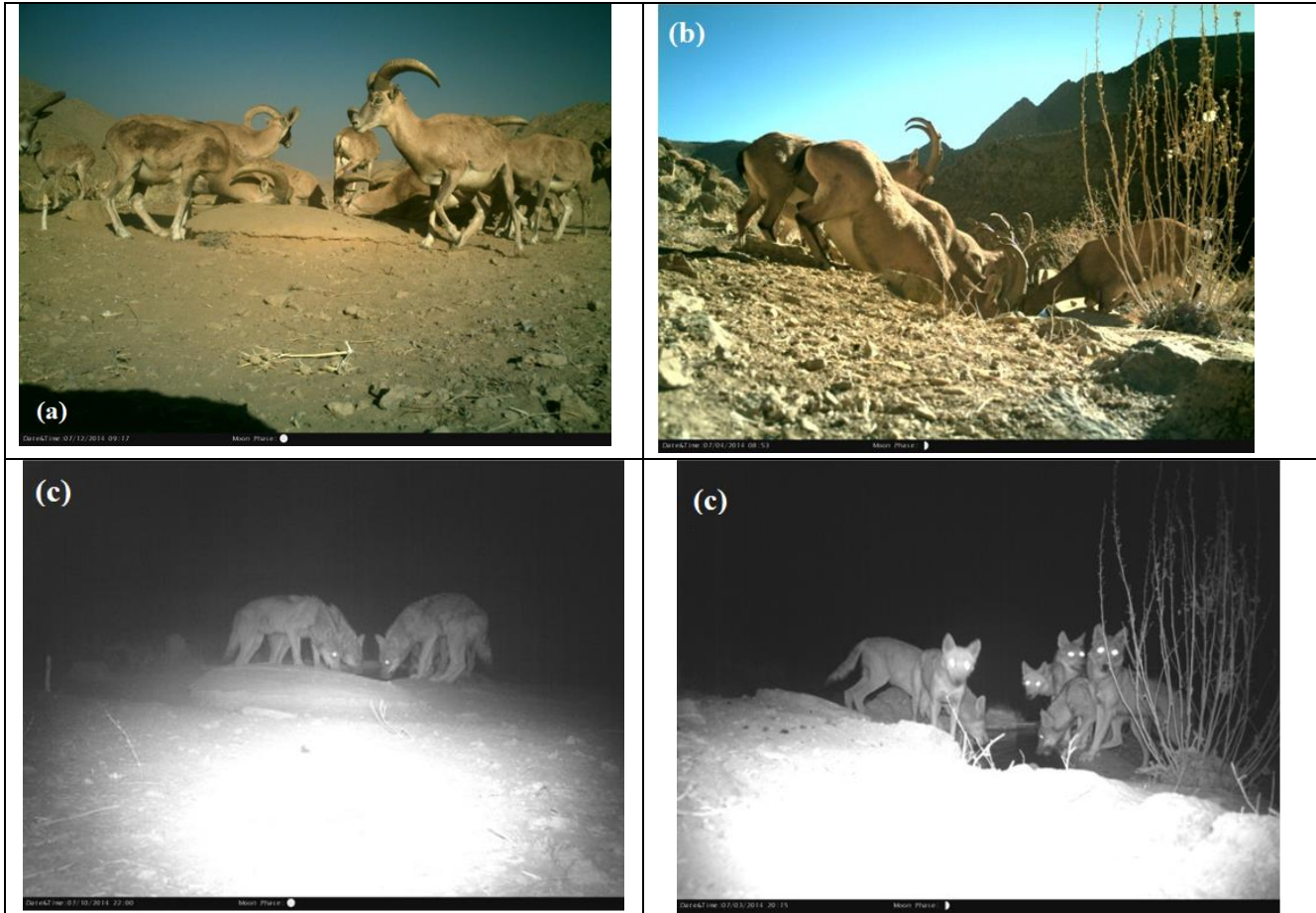


Figure 2. The presence of three species of wild sheep (a), wild goat (b) and grey wolf (c) at a water source captured by a camera trap in Haftad-Gholleh National Park.

Model Evaluation

The results of the model evaluation with AUC showed high discriminative power for all three models for both training and test data (Table 2).

Table 2. The measured AUC for habitat suitability models for Wolf, Wild sheep and wild goat

Species	AUC	
	Training data	Test data
Wild sheep	0.824	0.977
Wild goat	0.960	0.990
Wolf	0.918	0.965

Slope, distance from water, distance from the road, and aspect are the top four predictors in the distribution of Wolf with percent contributions of 30.1, 23.4, 17.7, and 17.5 respectively. Wild sheep distribution was strongly predicted by the distance from human activities, slope, and aspect with contributions of 32.8, 31.8, and 15.3, respectively. Whereas, wild goat distribution was strongly predicted by the slope, distance from human activities, and distance from the road with contributions of 35, 22.9, and 18.2, respectively (Table 3). Figures 3, 4, and 5 show the response curves of different environmental variables for the three species listed.

Table 3. Relative contributions are in percentages of the environmental variables to the MaxEnt model for wild sheep, wild goat, and grey wolf

Environmental variable	Percent contribution		
	(Grey wolf)	(Wild sheep)	(Wild goat)
Slope	30.1	31.8	35
Distance from water	23.4	5.4	15.5
Distance from road	17.7	7.3	18.2
Aspect	17.5	15.3	4.6
Percentage of vegetation cover	5.9	1.7	0.7
Elevation	3.3	6.3	3.1
Distance from human activities	2.1	32.8	22.9

Importance of Environmental Variables

The importance of environmental variables differed among wolves, wild sheep, and wild goats in Haftad-Gholleh National Park. According to a Jackknife test, the two most important variables in wolf distribution were slope and aspect, respectively. The slope is in the first place of the wild sheep's distribution (i.e., it is the most effective variable). In 2nd, 3rd and 4th place, respectively, are the percentage of vegetation cover; height; and distance from human activities. Distance from human activities is the most effective variable for explaining the distribution of the wild goat. Distance from water, slope, and aspect follow distance from human activities in relative importance (Figs. 6, 7, and 8).

By executing the MaxEnt program, habitat suitability maps were created in logistic format for wolves, wild sheep, and wild goats (Fig. 9). The most suitable habitats for all three species in Haftad-Gholleh National Park were located in 'restricted nature' parts of the region (Fig.9). Table 4. Shows the threshold level and area of suitable habitats for each of the three species. Results of suitable habitat overlaying indicated that about 5301.09 hectares (5.44% of the study area of 97,438 ha) are suitable for all three species. Table 5 summarizes the analysis of niche breadth obtained from ENMTools, which yielded values of 0.35, 0.65, and 0.18 for the wolves, wild sheep, and the wild goat, respectively. Table 6 shows the pairwise niche overlap between wolf, wild sheep, and wild goat in Haftad-Gholleh National Park.

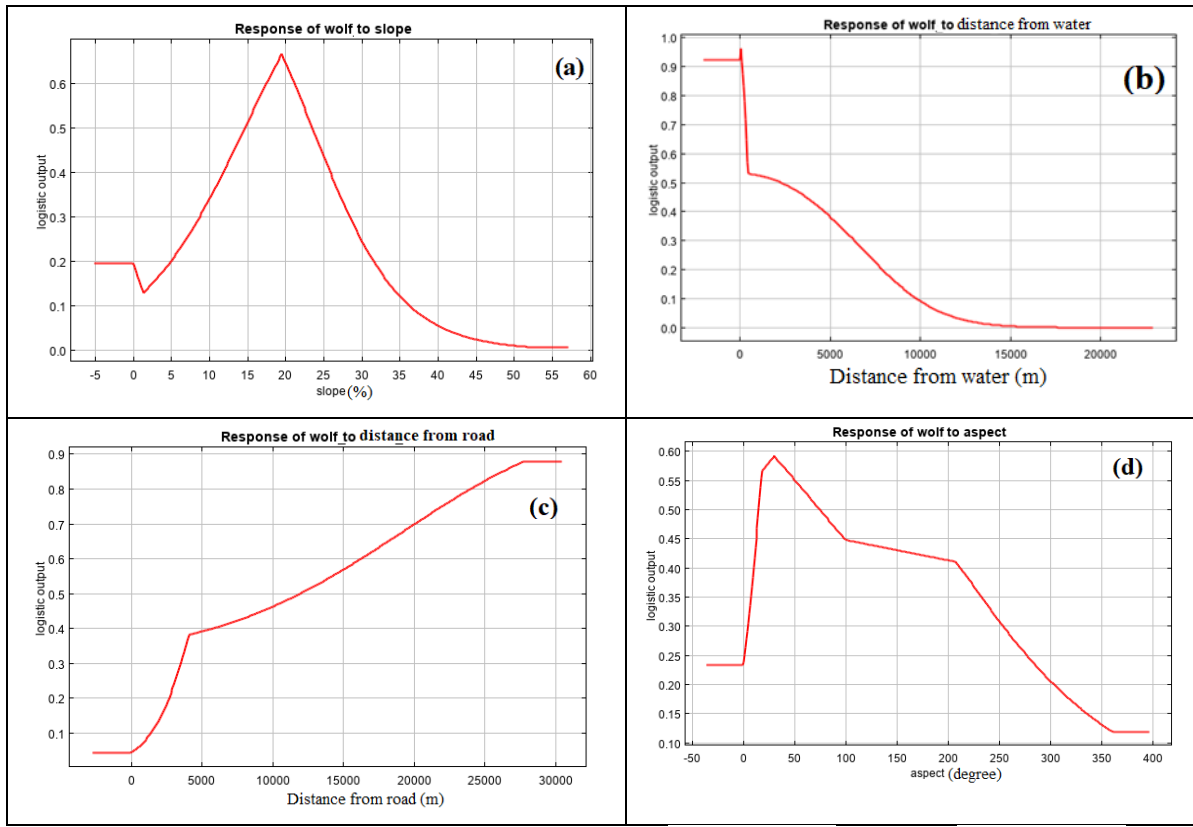
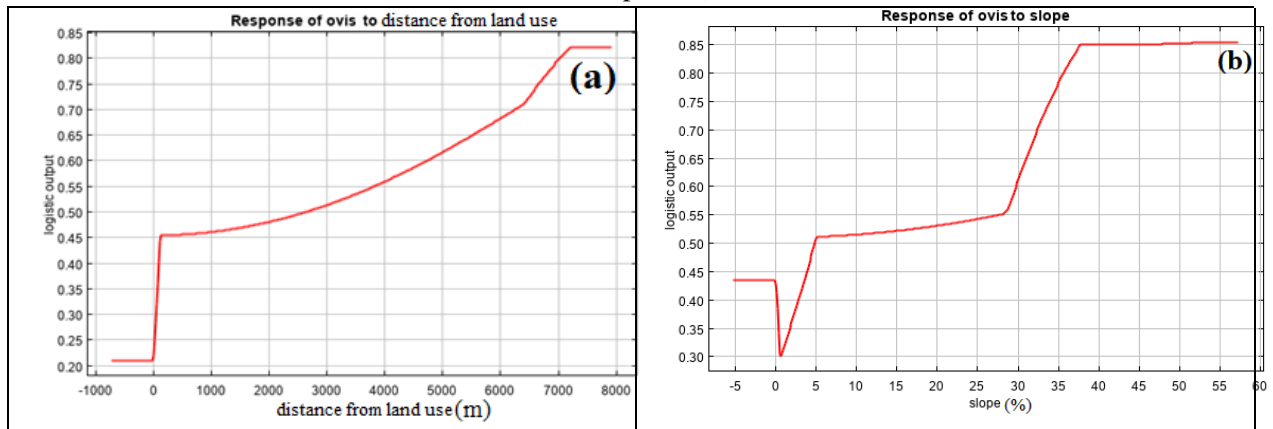


Figure 3. Response curves of Grey wolf to the slope (a), distance from water (b), distance from road (c) and aspect (d)



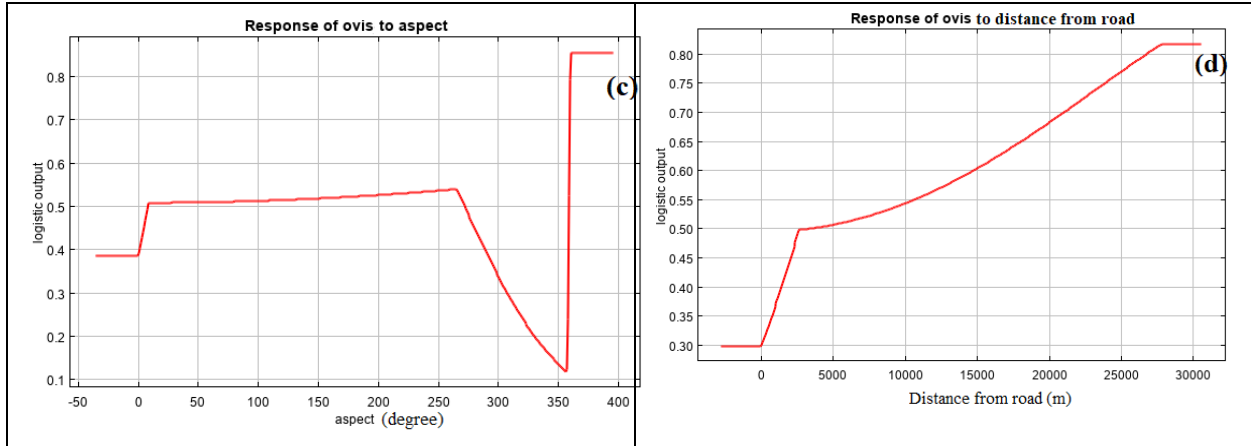


Figure 4. Response curves of Wild sheep to distance from human activities(a), slope(b), aspect(c) and distance from road(d)

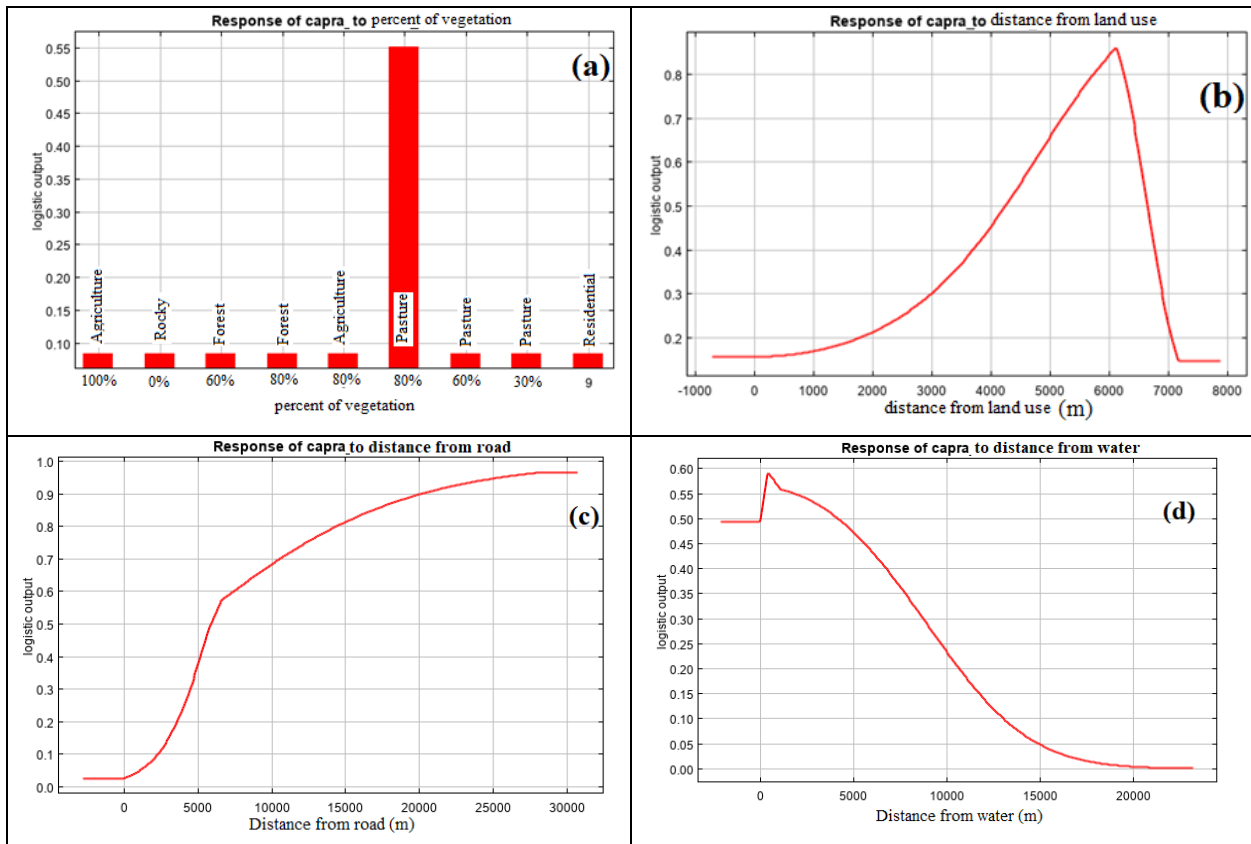


Figure 5. Response curves of Wild goat to percentage of vegetation cover(a), distance from human activities(b), distance from road(c) and distance from water(d)

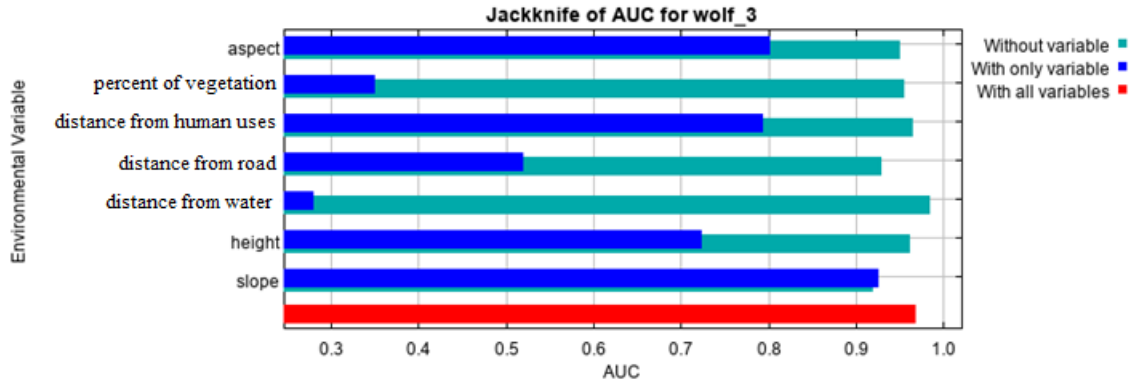


Figure 6. The importance of environmental variables for MaxEnt models for Grey wolf

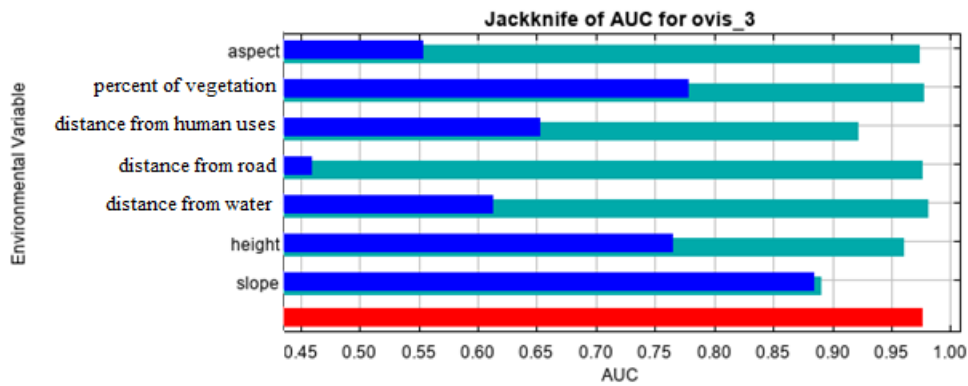


Figure 7. The importance of environmental variables for MaxEnt models for Wild sheep

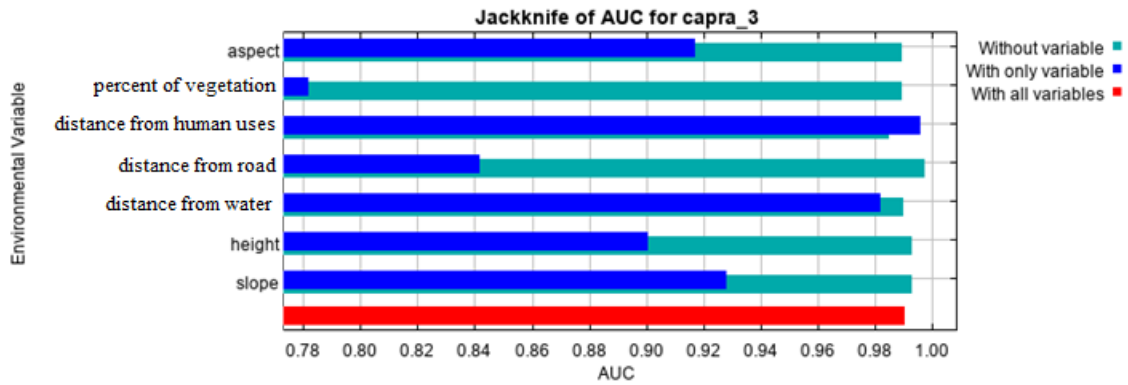


Figure 8. The importance of environmental variables for MaxEnt models of Wild goat

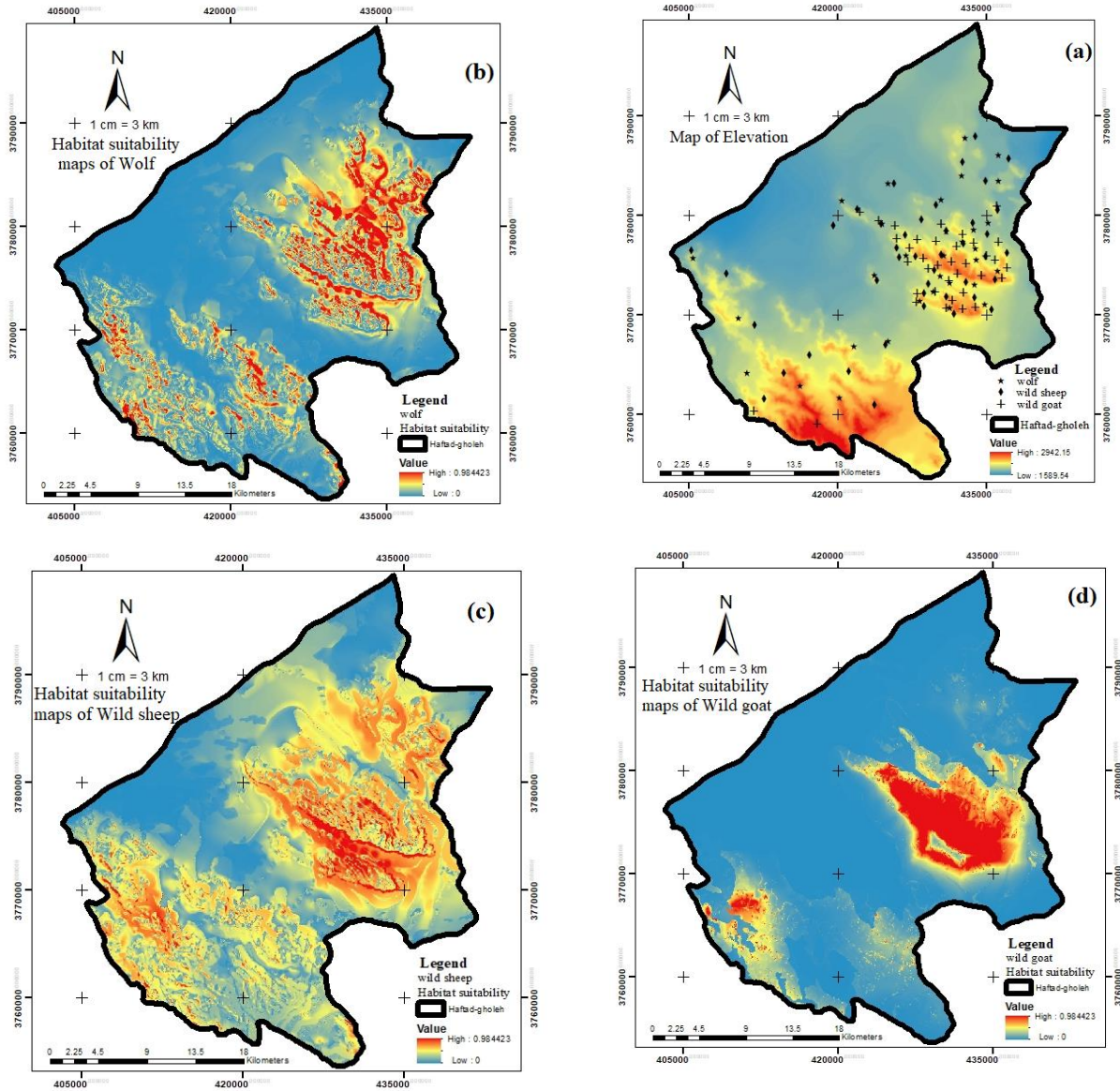


Figure 9. Map of elevation classes, distribution of species' presence points(a) and Predicted potential habitat suitability maps for Grey wolf(b), Wild sheep(c), and Wild goat (d).

Table 4. Threshold level and area of suitable habitats for three species

Species	Grey wolf	Wild sheep	Wild goat
Threshold level	0.168	0.229	0.121
Habitat suitability (ha)	24826.32	13207.68	11213.55
Habitat suitability (%)	25.47	13.55	11.5

Table 5. Suitable habitat overlap of Grey wolf, Wild sheep and Wild goat

Species	Wild goat & Grey wolf	Wild goat & Wild sheep	Grey wolf & Wild sheep	Grey wolf & Wild sheep & Wild goat
Habitat overlap (ha)	6905.43	6469.20	9797.22	5301.09
Habitat overlap (%)	7.08	6.64	10.05	5.44

Table 6. Ecological overlap (D and I) of potentially suitable habitats for Grey wolf, Wild sheep, and Wild goat.

	Grey wolf			Wild sheep			Wild goat		
	D	I	relative rank	D	I	relative rank	D	I	relative rank
Grey wolf	1	1	1	0.64	0.89	0.78	0.44	0.72	0.73
Wild sheep				1	1	1	0.44	0.74	0.75
Wild goat							1	1	1

Discussion

Our findings indicate with high accuracy that the AUC for ROC curves point to the superior performance of the Maxent method (Giovanelli et al., 2010). Overall, our model found that the most suitable areas for wolves are located in mountainous regions where human disturbance is limited. Yet, it was also clear that wolves are relatively flexible in their use of habitat at the landscape scale. Wolf presence was recorded along all the northeast altitudinal gradients in Haftad-Gholleh National Park. In general, wolves could potentially live in any area where human tolerance and prey populations are adequate to support viable numbers. Wolves show different patterns of habitat selection based on time (year, season, time of day) and area. They are more present in winter on the southern altitudinal gradients and in summer on the northern altitudinal gradients. Our data support previous observations that wolves occur in various types of habitat and show low habitat specificity and high levels of ecological resilience compared with other large carnivores (Kabir et al., 2017; Mech & colleagues, 2003; Mohammadi et al., 2018; Farhadinia et al., 2017). The response curves for different environmental variables indicated that for wolf the most suitable slope is at or below 20 degrees. Adjacency to water resources is an important factor for wolf habitat suitability. It is due to the accumulation of wild sheep and wild goats around the springs. Wolves prefer slopes facing east and southeast because those areas have fewer rocks and precipices. These preferences suggest the importance of high mobility for wolves and are in concordance with findings of (Kabir et al., 2017; Mech & colleagues, 2003; Mohammadi et al., 2018) and (Ahmadi et al., 2014). Previous investigations showed that wolves were attracted to multiple-use agroecosystems rather than intact areas and deserts because they tended to use marginal habitats and anthropogenic features (Treves et al., 2011; Tourani et al., 2014; Mohammadi et al., 2019). Models indicate wolves' dependency on water resources and special topography selection is a function of

prey habitat-selection behavior, except regarding constructed items such as water troughs. We found that the distribution of wild goats in the study area is not so much affected by human-induced disturbances such as roadways, agriculture, settlements and livestock as by other factors such as their predators' habitat selection. Wild goats prefer higher-than-medium altitude rocky areas at all seasons in Haftad-Gholleh National Park; and its habitat suitability increases with increasing altitude. Wild goat response curve results show that as the distance from human and road activities increases, the habitat becomes more suitable. Areas adjacent to water resources are more suitable than areas that are far from water (Ansari et al., 2014; Hosseini et al., 2019). Totally we found that wild sheep in the study area are not affected by human induced disturbances; whereas this factor does affect their predators' habitat selection behavior, as reported in other investigations (Mech et al., 2003; Rich et al., 2012). According to our results, wild sheep prefer low-altitude areas in autumn and winter. Also, by increasing altitude, its habitat suitability decreases in Haftad-Gholleh National Park (Ziaie, 2008). On the other hand, the distance from water resources (up to 1000 meters) at first increases the habitat suitability for wild sheep presence. This is followed by a strong habitat suitability decrease with distance; and at distances over 6000 meters, water sources have no effect on wild sheep's habitat suitability (Safavian et al., 2018). The wild sheep's response curves show that their habitat becomes more suitable (in the north direction) with increasing distance from human and road activities because such areas are desirable in terms of habitat variables. Wild sheep prefer low altitude areas in Haftad-Gholleh National Park and by increasing elevation, its habitat suitability decreases (Safavian et al., 2018; Hosseini et al., 2019). Therefore, wolves, wild sheep, and wild goats prefer medium elevations and aspect of southerly areas in winter; and in summer, prefer close proximity to water resources and aspect of northwardly areas. These two preferred areas of the winter and summer have more niche overlap for three species in Haftad-Gholleh National Park. The range size of the habitat of the wolf, wild goat and wild sheep is better explained through incorporating the species-environment relationships. Niche breadth (assessed by ENMTools) for the wolf was estimated to be half that of the wild sheep, and twice that of wild goat. This demonstrates that wolves moderate ability and specialization in Haftad-Gholleh National Park. Population size, suitable habitat, and niche breadth for wild sheep are greater than that of both the wild goat and wolves. During the study period, images of wild sheep, wild goats or grey wolves were obtained by the camera trap more than twenty times with a presence-interval average of 10 hours in the overlapped water resource in the Haftad-Gholleh National Park. The minimum interval was three hours and the maximum interval was forty-eight hours. This is indicative of the overlapped niche of these three species. Due to the large population of wolves in the Haftad-Gholleh and the decrease of reports of the presence of leopards in the area, it seems that there is intense competition between wolves and leopards in the area (Farhadinia et al., 2018).

In general, according to habitat suitability maps, habitats suitable for Grey wolves, Wild sheep, and Wild goats covered 5.44% of the study area. More effective wildlife conservation efforts should be focused on in this area. In the Varjin Protected Area, suitable habitats for Grey wolf and Wild sheep cover 4.32% of the study area (Safavian et al., 2018; Ahmadi et al., 2013). Whereas

wild sheep in Haftad-Gholleh National Park has a relatively narrow geographical extent and show a tendency to marginal habitats, wolves cover more areas, denoting their high mobility and low dependency to specific habitats (Safavian et al., 2018; Hosseini et al., 2019). Assessments of the area of habitat suitability, niche breadth, habitat overlay, niche overlap, and Camera trap images for Grey wolf, Wild sheep, and Wild goat, respectively, are mutually supportive and tell the same story regarding the distribution of these three species in Haftad-Gholleh National Park (Kabir et al., 2017).

Conclusion

Wild sheep have a relatively wide geographical extent and show a tendency to marginal and restricted nature. Wolves cover moderate areas which denote their moderate mobility and dependency on restricted-nature habitats. The wild goat has a relatively narrow geographical extent and shows a tendency to specific restricted-nature habitats in Haftad-Gholleh National Park.

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