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ZOOLOGY

Modeling the Distribution and Habitat Suitability of Persian Leopard *Panthera pardus saxicolor* in Southwestern Iran

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Abstract—Awareness of the habitat needs of top predators is vital for viability of wildlife populations. During 2017–2018, 32 points of presence signs of the Persian leopard (*Panthera pardus saxicolor*) were spotted and they were associated to 6 environmental variables. The maximum entropy (Maxent) model was used to predict the distribution of Persian leopards in the Gisakan, south-western Iran. The validity of habitat suitability model (Training data = 0.844) confirmed the reliability of method. On the basis of Jackknife test, distance from the villages (less presence far from the villages), distance from water resources (the farther from the water resource, the less presence), elevation and slope (most presence in elevations 600–1400 m a. s. l. and slopes 30–70%), distance from the roads (the farther from roads, the more presence) and land cover (more presence in woodlands) variables, respectively, were the most important variables. The results indicate that 25.19% of area (115.13 km^2) contains suitable habitat. We suggest that conservation and management plans for leopards be conducted on areas such as studied area that are not formally protected. The results of this study can also help us to identify and protect suitable habitats for conservation and management as well as decrease wildlife—human conflicts.

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INTRODUCTION

Mammalian predators are desperately threatened in destructed habitats due to their low densities, extensive spatial requirements and conflict with people (Purvis et al., 2000; Cardillo et al., 2005). Awareness of their distribution is important in conservation biology (Hirzel et al., 2001; Engler et al., 2004). Conservationists are looking for the best way to save top predators or flagship species as keystone species in the ecosystems (Berger et al., 2001; Hebblewhite et al., 2005; Soulé et al., 2005). Though they have been playing an ecologically vital role, their distribution has shrunk during the recent century (Swanepoel et al., 2013). Hence, gaining knowledge about them along with the habitat characteristics are important for the viability of the wildlife populations (Ray et al., 2005; Gavashelishvili and Lukarevskiy, 2008; Rabinowitz and Zeller, 2010). It can lend a hand to follow the species dispersal, population viability and conservation of biodiversity (McRae and Beier, 2007; Rabinowitz and Zeller, 2010).

Researchers have identified some specific feature for the leopard *Panthera pardus*. Nowell and Jackson (1996) stated that the leopard *Panthera pardus* is a generalist; Breitenmoser et al. (2010) expressed it a top predator, Nowell and Jackson (1996) considered it the species with the most widespread distribution of Felidae family.

On the basis of literatures, leopards have received less conservation attention than other big cats, mainly due to their widespread distribution and ecological flexibility (Nowell and Jackson, 1996; Nowak, 1999; Erfanian et al., 2013).

The largest leopard subspecies is the Persian leopard (*P. p. saxicolor*) and Iran has the maximum number of population (550–850 individuals) around the span of approximately 885.300 km^2 in the Middle East (Kiabi et al., 2002; Khorozyan, 2008; Youssefi et al., 2010; Khoshnegah et al., 2012).

However, high population and adaptability do not mean that this species condition is suitable in spite of all threats. Being listed as a vulnerable species in the world (IUCN red list, 2016), Persian leopard is endangered in Iran too (Karami et al., 2015).

The most important threats for this species are habitat destruction and fragmentation (Ray et al., 2005), prey decline (Henschel et al., 2011), conflicts with people over livestock predation (Nowak, 1999; Balme et al., 2010), the fur trade (Gavashelishvili and Lukarevsky, 2008), killing (Packer et al., 2011; Athreya et al., 2011; Raza et al., 2012; Farhadinia et al., 2014), hunting (Kissui, 2008) with poisoned carcasses (Croes et al., 2007; Balme et al., 2009) and different traps (Martins and Martins, 2006; Loveridge et al., 2010). Carnivore decline is a global concern especially since leopards are exposed to many anthropogenic threats (Balme et al., 2010).

Different studies have been carried out on the ecological and biological aspects of this species in Iran (Kiabi et al., 2002; Ghoddousi et al., 2008; Omidi, 2008; Farhadinia et al., 2009; Sanei and Zakaria, 2011; Erfanian et al., 2013; Farhadinia et al., 2015; Sadeghinezhad et al., 2017), studies, however, on its conservation and management in Iran is not comprehensive enough (Farashi and Shariati, 2018). Therefore, prediction and mapping of leopards' habitat characteristics and suitability can be important because it can shed light on for persistence and monitoring programs of carnivore populations (Balme et al., 2010), successful conservation and sustainable management (Engler et al., 2004; Guisan and Thuiller, 2005; Rooper et al., 2016).

A systemic but time-consuming method of spotting the species was collection of presence/absence locations trend which was conducted by using presence-only data based on signs of species and communication with local people and guards (Robertson et al., 2001; Hirzel et al., 2001).

Maximum entropy, as a technique, has the potential of controlling the interactions among the predators (Elith et al., 2011; Merow et al., 2013). Maxent is less sensitive to small sample size (Bean et al., 2012; Proosdij et al., 2016) and the calibration area for pseudo-absences (Giovanelli et al., 2010). It can also be applicable for leopards which are range-limited and unique species (Elith et al., 2006; Phillips et al., 2006).

Similar studies were carried out applying Maxent to determine Persian leopard habitat suitability in the different areas in Iran (e.g. see Ebrahimi et al., 2017; Jafari et al., 2018; Naderi et al., 2018) and other species of leopards in different countries (e.g. see Swanepoel et al., 2013; Karnaukhov et al., 2018; Kalashnikova et al., 2019; Rozhnov et al., 2019, 2020). However, the present study is the first report of Persian leopard habitat suitability in Bushehr province, southwestern Iran. To date, no field study has been carried out in this region. Hence, we used Maxent to: (1) develop predictive habitat suitability maps for Persian leopards, (2) identify the environmental and human important variables for this subspecies distribution and (3) quantify the suitable habitat of Persian leopard for conservation plan.

MATERIALS AND METHODS

Study Area and Population

The Gisakan area covers a 45696-hectare and is located in 51°12′ and 29°16′ in the province of Bushehr, in south-western Iran (Fig. 1). This is mostly a mountainous landscape and elevations ranges from 210 to 1791 m a. s. l. This area has an average annual precipitation 250 mm and annual temperature is varied between 0–50°C.

The most common vegetation is represented shrubs of the genera *Alhagi mannifera*, *Amygdalus lycioides*, *Astragalus* spp., *Thymus* sp., *Juncus* sp., *Capparis spinosa* as well as various species of small trees and trees including *Nerium oleander*, *Tamarix* sp., *Pistacia atlantica*, *Amygdalus scoparia*, *Acer mospessulanum*, *Ficus johanis*, *Populus eupharatica*, *Ziziphus spina-christii*, *Prosopis* sp., *Punica gramatum*.

There are other mammals in this area such as: Wild goat (*Capra aegagrus*), Wild sheep (*Ovis orientalis*), Indian Crested Porcupine (*Hystrix indica*), Wild boar (*Sus scrofa*), Mongoose (Herpestidae), Martens and Rabbits.

Falcons, Owls, Eagles, Partridges, See-see partridge, Pigeons and Doves are the most important birds in the area (provincial DoE of Bushehr province, unpublished reports).

Sampling

Data collection was conducted over a 2-year field study in 2017–2018. A total number of 32 points of presence signs of the Persian leopard were recorded (Fig. 1) based on field surveys using global positioning system, species' signs including tracks, scrapes, feces, scats, camera trap records, observation reports by rangers and staff from the environmental office, interviews with local people, and studying relative annual and daily wildlife reports obtained from provincial DoE of Bushehr province.

Predictor Variables Selection and Data Sources

Using expert knowledge, extensive studies of Persian leopards (Kiabi et al., 2002; Ghoddousi et al., 2008; Omidi, 2008; Gavashelishvili and Lukarevskiy, 2008; Khorozyan, 2008; Farhadinia et al., 2009; Sanei and Zakaria, 2011; Erfanian et al., 2013; Farhadinia et al., 2015; Abdollahi, 2015; Sadeghinezhad et al., 2017) and based on data availability as well as the most important significance to leopard biology (Austin, 2002), 6 predictive variables including topographical factors (elevation, slope), ecological data (land cover, distance from water resources), and human infrastructures (distance from roads, distance from villages) were selected for distribution modeling of Persian leopards.

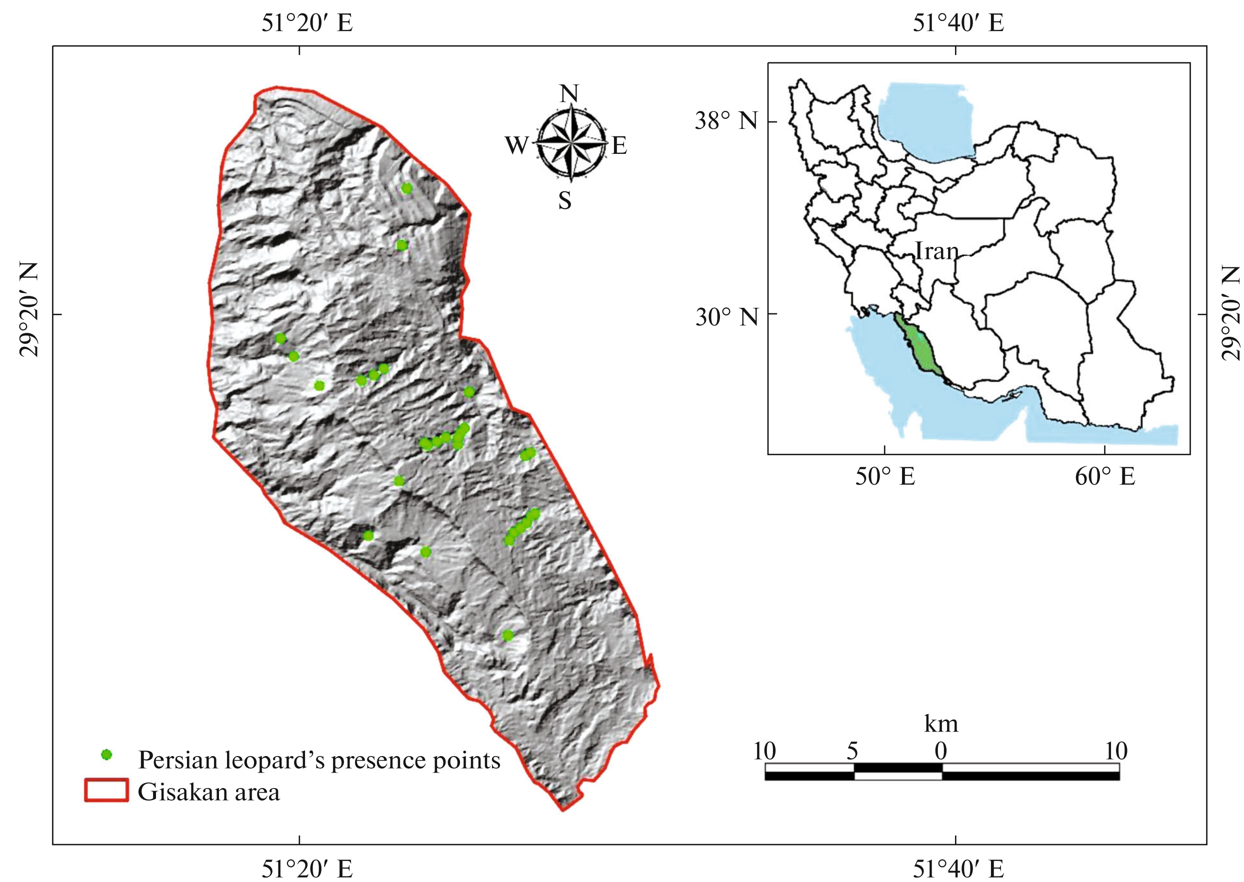

Fig. 1. Gisakan area in Bushehr provinces (green) in south-western Iran with 32 points of presence signs of Persian leopard *Panthera pardus saxicolor.*

Maxent Model Development

The maximum entropy technique and Maxent software (version 3.3.3k) were used for modeling the habitat suitability and Arc GIS software (version 10.3) was applied to figure out the correlations and the layers for Maxent. This model combines predictive environmental variables and Persian leopard presence points and produces random points, and then presents a species distribution model with statistics and diagrams.

Persian leopard presence spots with GPS were used as dependent variables. Predictive environmental variables (the six above-mentioned independent habitat variables) that affect Persian leopard presence were used. Raster maps were made in ASCII format in Arc GIS.

The Digital Elevation Model (DEM) was used to make the elevation and slope layers.

Maxent layers for elevation, slope, distance from water resources, distance from villages, distance from roads are ongoing predictive variables and the layers on land cover are categorical predictive variables. All predictor variables were resampled to a 30 × 30 m spatial resolution and clipped to the study area boundaries. A digital elevation map was used as a reference for overlapping the maps to make the layers' isometric. For preparing the Raster maps for successive analyses and overlapping, the following processes were conducted (e.g. Phillips and Dudík, 2008; Baldwin, 2009; Morovati et al., 2014):

(a) Normality of data: the normality was tested to produce reliable outputs. Thus, by the spatial analyst tool multivariate command, all plans were equalized into one form in Arc GIS.

(b) Data correlation: the multicollinearity test was conducted using the Pearson correlation coefficient to examine cross-correlation. Variables with correlation coefficients ≥0.8 were excluded. The spatial analyst tool multivariate command was used in Arc GIS and since the correlation between all environmental variables in this study was <0.8, no one was eliminated.

(c) For water resources, villages and roads, the distance command in Arc GIS was used to enter those maps into analysis.

Two groups of test and training data were included in the random sampling to consider 25 and 75% of presence data, respectively. 75% of species presence

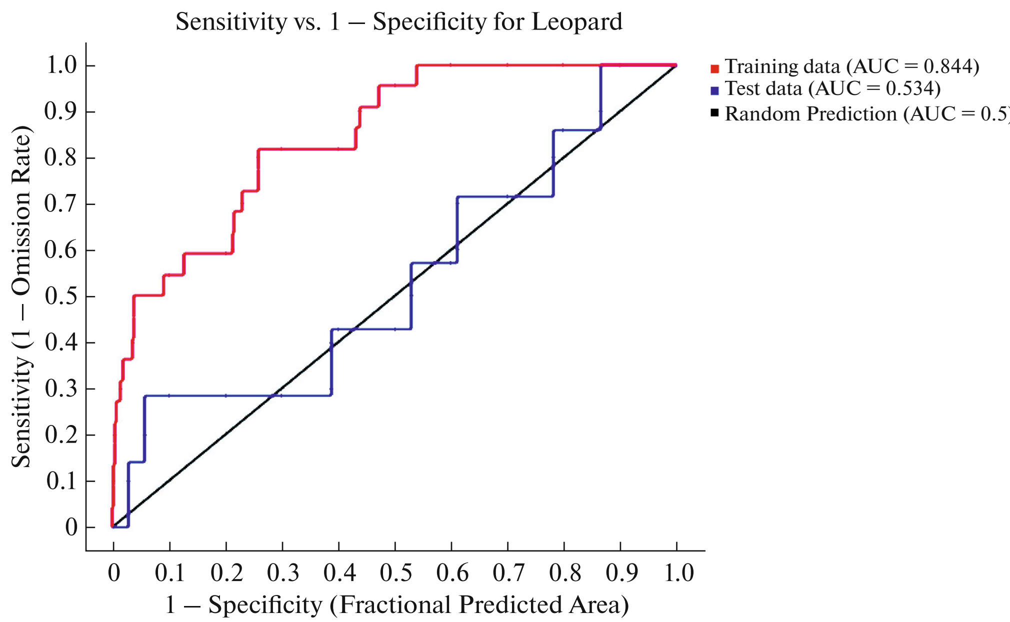

Fig. 2. ROC (Receiver Operating Characteristic) validity of Persian leopard's habitat suitability model based on Maxent method in Gisakan area.

points were randomly used as training data, and the remaining 25% as test data.

Model Evaluation

Either the area under the ROC (receiver operating characteristic) curve, or AUC (The area under curve), will be used to evaluate the model performance.

This curve is represented as a graph with vertical axis as a representative of sensitivity (true positive) and the horizontal axis as a representative of specificity (false positives). AUC is a measure of model performance that varies from 0 to 1. An AUC closer to 1 indicates perfect distinction in the model evaluation (Phillips et al., 2006; Elith et al., 2006).

The importance of environmental variables is evaluated using Jackknife test. This test was used to determine variables that reduce the model reliability when deleted.

RESULTS

Validity of Maxent Model

AUC indicated that the validity of Maxent model is 0.844 (training data), in other words the Maxent model has a better predictability value for the presence points with the probability of 0.844 that proves the high validity of the model (Fig. 2).

Jackknife Test

Jackknife test results (Fig. 3) indicated that among the used predictive environmental variables, distance from the villages and then distance from water resources, elevation and slope, and finally distance from the roads are the most significant variables regarding the Persian leopard's habitat suitability model while the smallest impact is related to the land cover variable.

Response Curves of Persian Leopard's Presence to Environmental Variables

Response curves of Persian leopard's presence to the most important environmental variables are shown in Fig. 4.

The probability of the presence of Persian leopard decreases as distance from villages increases (Fig. 4a). The water resources are located in the valleys whereas Persian leopards observe in high elevations and slopes. As a result, with increasing of distance from river and climbing to the high elevation mountains, habitat suitability increases. Then, the presence of Persian leopard decreases as distance from water sources increases (Fig. 4b). Based on Fig. 4c, Persian leopards mostly observed in elevations 600–1400 m a. s. l. and rarely observed in the elevations <200 and >1800 m a. s. l. Figure 4d indicated that Persian leopards mostly observed in slopes 30–70% and avoid from presence in plains and areas with slope <30%. The probability of the presence of Persian leopard increases as distance from roads increases (Fig. 4e). Among the different land covers, the presence of Persian leopards in woodlands was very high (Fig. 4f) which indicates their highly dependent to vegetation for food and cover.

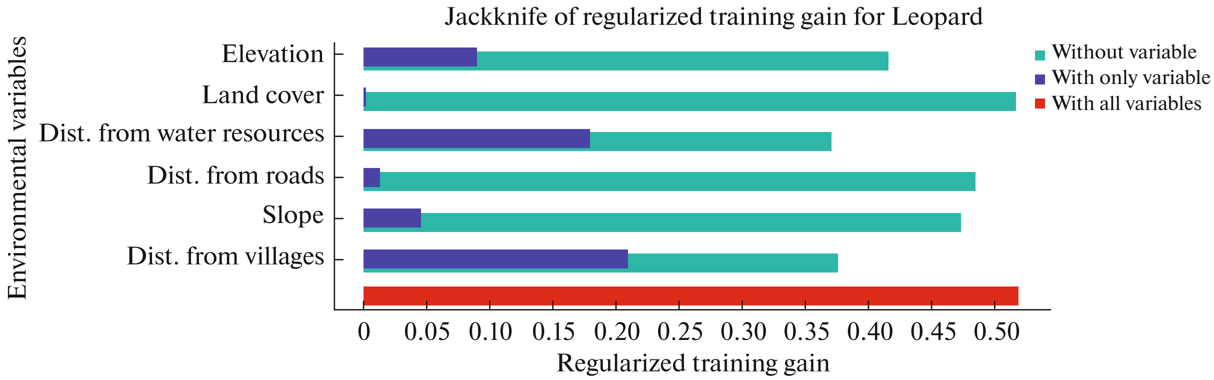

Fig. 3. The jackknife test results for the importance of each variable on the Persian leopard's habitat suitability model in Gisakan area. Green lines represent model performance when the corresponding variables are excluded from the set of variables and blue lines indicate performance of the test when each variable is included separately. Red lines indicate total model gain using all the variables.

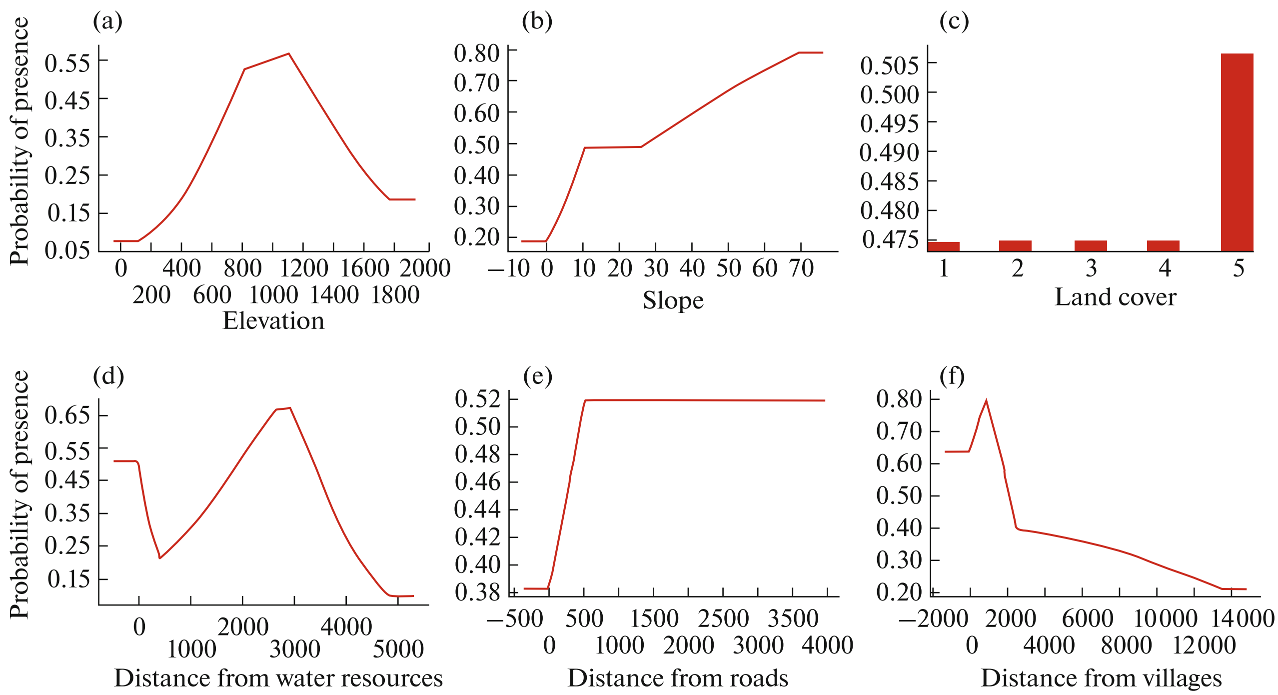

Fig. 4. Response curves of Persian leopard's presence (vertical axis) in Gisakan area to the (a) elevation; (b) slope; (c) land cover (1, medium rangeland, 2, watery farming, 3, dry farming, 4, date lands, 5, woodland); (d) distance from water resources; (e) distance from roads and (f) distance from villages.

Persian Leopard's Habitat Suitability

Persian leopard's habitat suitability map based on equal training sensitivity and specificity in Maxent results is shown in continues format (Fig. 5a). Very suitable areas with a high probability of Persian leopard presence are shown in yellow; locations where the probable presence of Persian leopard is zero are shown in violet. Locations with a probability of 0 to 40.9% observation of Persian leopards was classified as unsuitable (mustard color) and the regions with a probability of 40.9. to 100% was suitable (blue) (Fig. 5b). This classification indicated that 11513 ha of Gisakan area is suitable and the remaining 34183 ha was unsuitable.

DISCUSSION

The selection of variables in the modeling of Persian leopard's habitat suitability is different (Merow et al., 2013; Syfert et al., 2013) and is geographic-depended. Patterns of suitable habitat distribution can

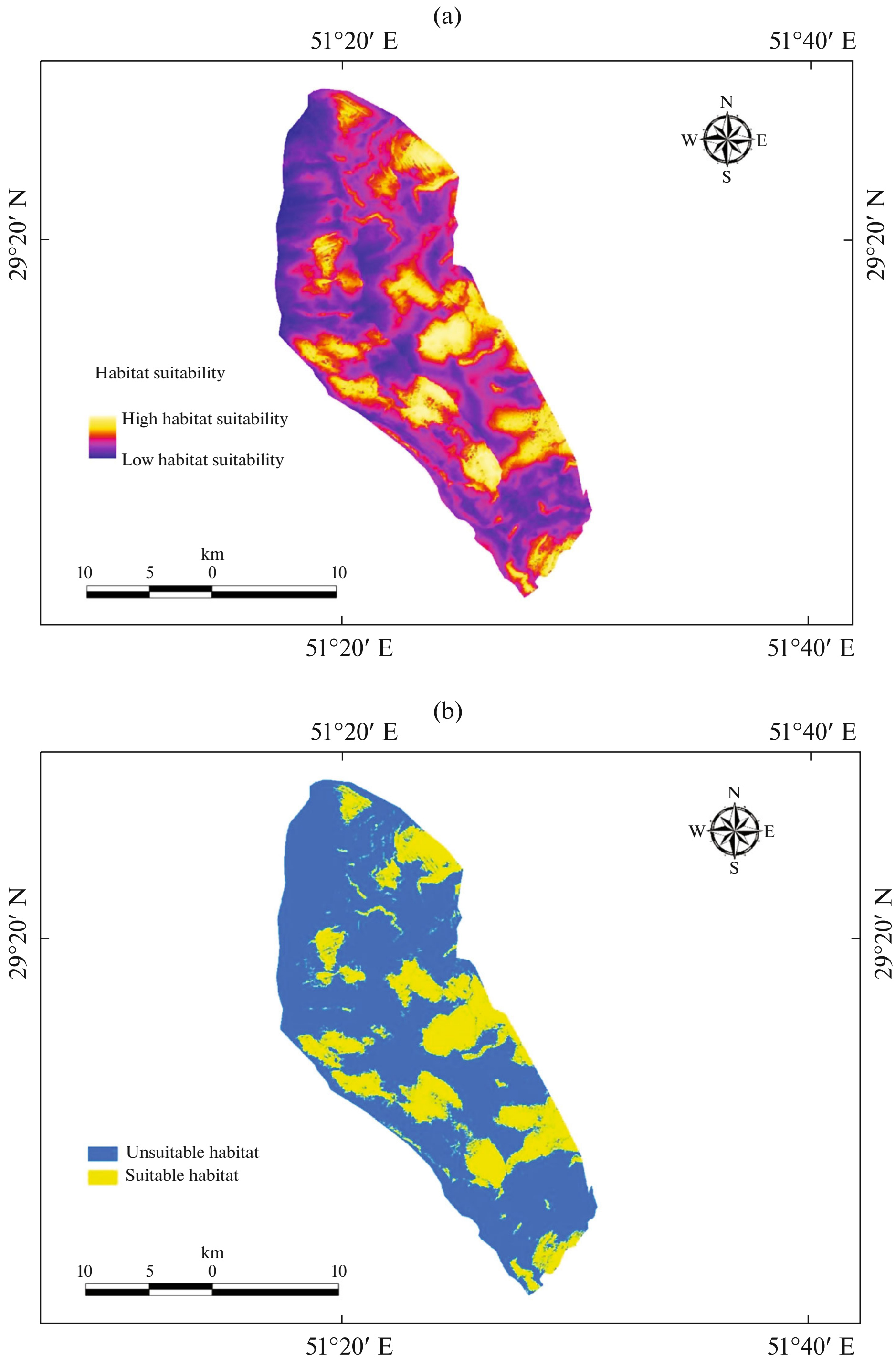

Fig. 5. Persian leopard's habitat suitability modeling in Gisakan area using Maxent ((a) continues map, (b) map with suitable and unsuitable categories).

be related to both the changes in physiological functions of Persian leopard and changes in environmental conditions of the study area (Shams et al., 2010). Therefore, AUC should be reliable for comparing the models for a species in the similar area and/or with the similar variables (Fourcade et al., 2014). The AUC for training data was 0.844; if the AUC value is between 0.8–0.9, the model will be confirmed as an excellent model (Giovanelli et al., 2010). The results indicate that model is able to separate the presence and non-presence locations of Persian leopards and prove that the reality with habitat is high.

Among different environmental predictors in this study, distance from the villages, distance from water resources, elevation, slope, and distance from the roads are the most significant variables regarding the Persian leopard's habitat suitability while the smallest impact is related to the land cover variable. Although, the importance degree is diverse in different areas. For more details and comparisons, we summarized the effect and direction of different variables on the habitat distribution of leopard in Table 1.

Distance from the villages was the most important environmental predictor for habitat suitability of Persian leopard. The probability of the presence of Persian leopard decreased as distance from villages increased. Habitat selection of the leopard depended on livestock as prey in the villages (Taghdisi et al., 2013). The major prey species for the Persian leopard in Iran are wild goat, wild sheep, goitered gazelle, red deer and wild boar (Farashi and Shariati, 2018) whose distribution plays a major role for habitat suitability of the Persian leopard (Ebrahimi et al., 2017). Decline of wild preys in the natural areas, and leading leopards shift towards human populated centers such as villages and livestock areas (Sanei et al., 2012; Swanepoel et al., 2015) to prey more on them (Odden and Wegge, 2005) will in turn result in killing of leopards by local farmers which will subsequently lead to limitation in carnivore persistence (Lindsey et al., 2004) and this condition has deteriorated the conflict (Khosravi et al., 2012; Babrgir et al., 2015). Hence, careful attention and mitigation in relation to conflict with livestock farmers (Swanepoel et al., 2013) is important (Dickman et al., 2011). These conflicts also take place inside and outside of protected areas (Taghdisi et al., 2013). On that account, studies on the modeling of the trends and severity of human-leopard conflicts are strongly needed for plans to meet viable leopard populations and to compensate leopard-human conflicts.

Distance from water resources was the second important environmental predictor for habitat suitability of Persian leopard. The presence of Persian leopard decreased as distance from water sources increased. Water resources (e.g. rivers) are one of the important habitat parameters for leopards and may limit their presence. It implies that our results coincide with some of previous studies (see Table1).

Elevation and slope were the third and fourth important environmental predictors for distribution of Persian leopard, respectively. Persian leopards were mostly observed in elevations 600–1400 m a. s. l. and rarely in the elevations <200 and >1800 m a. s. l. They also were spotted in slopes of 30–70% and were not tracked in areas with slope <30%. The results indicated that the preferred elevation and slope for Persian leopard in current study coincide with previous studies (see Table 1).

Distance from the roads was the fifth important environmental predictor for distribution of Persian leopard. The probability of the presence of Persian leopard increased as distance from roads increased. The development of the road types for local people and rural and industrial construction projects especially around the protected area pose life risk for wildlife (Arvin et al., 2016). They also cause some fatal accidents and consequently animal loss (Jowkar et al., 2016). Furthermore, the roads make some fragmentation in the habitats (Wingard et al., 2014). Hence, stopping the road development in the natural habitats is important for conservation of species viability (Erfanian et al., 2013). However, we had only some small/local but no developed roads in the study area and due to this reason, the importance degree of roads is lower or different from other studies (see Table 1).

The smallest impact was related to the land cover variable. Presence of vegetation is important for thermal needs, reproduction, escape and ambushing prey. Among the different land covers, the presence of Persian leopards in woodlands was very high. They usually require dense vegetation or topographically diverse habitats (Hayward et al., 2006). Note that the Persian leopard as a generalist cats will be adopted with different types of land covers depending on variation of the areas (Gavashelishvili and Lukarevskiy, 2008). However, our results coincide with different studies (see Table 1).

Although Maxent is an adept technique for predicting suitable habitat, it is less fruitful for evaluating the underlying mechanisms which determine how environmental variables are influencing habitat suitability (Swanepoel et al., 2013). For example, the presence points of a biotic predictor (e.g. preys) accompanying with abiotic factors, increase the predictive power for leopard distribution modeling (Pellissier et al., 2013; Trainor et al., 2014; Jafari et al., 2018). Furthermore, climate factors are not included part of the environmental factors in this study. Therefore, inclusion of the above-mentioned limitations and environmental and anthropogenic factors can increase the predictive ability of habitat suitability and reality of the model (Arvin et al., 2016; Jafari et al., 2018; Kalashnikova et al., 2019).

Awareness of the most important predictors in the preferred habitats is important for developing some conservation strategies and improving viability on umbrella/flagship species such as leopards (Erfanian et al., 2013). They are the most important representative for conservation of mammals (Breitenmoser et al., 2010) and their population is associated with biodiversity and will help along identifying biodiversity hotspots (Gavashelishvili and Lukarevsky, 2008). Gisakan area as an only-Persian leopard habitat in Boushehr province is not a protected area yet. Around one-third of suitable leopard habitats in the world are located in protected areas (Dudley, 2008). Hence, planning the conservation of Persian leopard for all distributed areas (protected and especially non-pro-

Table 1. Summary of important environmental predictors and direction of correlation/relation with habitat suitability of Persian leopard

Variables		Direction of correlation/relation	References
Topographical predictors	Slope	Positive	(Mobargha, 2007; Omidi, 2008; Omidi et al., 2010; Erfanian, 2011; Abdollahi, 2012; Erfanian et al., 2013; Abdollahi, 2015; Farhadinia et al., 2015; Farashi and Shariati, 2018; Jafari, et al., 2018)
	Aspect	No/low correlation	(Erfanian et al., 2013)
	Altitude	Positive	(Mobargha, 2007; Omidi, 2008; Omidi et al., 2010; Erfanian, 2011; Abdollahi, 2012; Erfanian et al., 2013; Abdollahi, 2015; Farhadinia et al., 2015; Farashi and Shariati, 2018; Jafari et al., 2018)
		Negative	(Farashi and Shariati, 2018)
	Rocky mountains	Positive	(Erfanian et al., 2013; Abdollahi, 2015; Farhadinia et al., 2015; Ebrahimi et al., 2017; Farashi and Shariati, 2018)
Water resources		Positive	(Erfanian et al., 2013; Abdollahi, 2015; Farhadinia et al., 2015; Farashi and Shariati, 2018)
Human infrastructures	Roads	Negative	(Kiabi et al., 2002; Erfanian et al., 2013; Abdollahi, 2015; Farhadinia et al., 2015; Farashi and Shariati, 2018)
	Agricultural lands	Negative	(Erfanian et al., 2013; Abdollahi, 2015; Farhadinia et al., 2015; Farashi and Shariati, 2018)
		No/low correlation	(Erfanian et al., 2013)
	Villages	Positive	(Erfanian et al., 2013; Abdollahi, 2015; Farhadinia et al., 2015; Farashi and Shariati, 2018)
Cover/vegetation	Meadows	Positive	(Erfanian et al., 2013; Abdollahi, 2015; Farhadinia et al., 2015; Farashi and Shariati, 2018)
	Mixed forests	Positive	(Erfanian et al., 2013; Abdollahi, 2015; Farhadinia et al., 2015; Farashi and Shariati, 2018)
	NDVI (normalized difference vegetation index)	No/low correlation	(Erfanian et al., 2013)
Prey availability	Wild goat	Positive	(Omidi et al., 2010; Erfanian et al., 2013; Abdollahi, 2015; Farhadinia et al., 2015; Ebrahimi et al., 2017; Farashi and Shariati, 2018; Jafari et al., 2018)
	Wild sheep	Positive	(Erfanian et al., 2013; Abdollahi, 2015; Farhadinia et al., 2015; Farashi and Shariati, 2018)
	Goitered gazelle, red deer, wild boar	Positive	(Erfanian et al., 2013; Abdollahi, 2015)
		No/low correlation	(Erfanian et al., 2013)

tected areas) and new approaches for determining the population density and monitoring are urgent necessities (e.g. see Hernandez-Blanco et al., 2013; Karnaukhov et a., 2017; Rozhnov et al., 2019, 2020). Therefore, with cooperation between people, NGO's and organizations for monitoring the leopards' populations (Rozhnov et al., 2019), the conservation policy and fair management strategies will develop around the human populated centers and the human-carnivore conflicts and further deterioration of habitats (Linnell et al., 2001; Moqanaki et al., 2013) will decrease consequently.

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COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflict of interest.

This article does not contain any studies involving animals or human participants performed by any of the authors.

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