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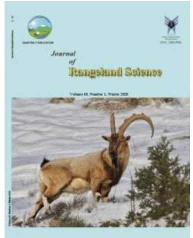

Research and Full Length Article:

Determination of Potential Habitat of Range Plant Species Using Maximum Entropy Method

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Abstract. This study aimed to identify the most important physical variables affecting the distribution of four range plant species (*Tamarix aphylla*, *Calligonum comosum*, *Prosopis spicigera* and *Salsola rigida*) habitats and to prepare potential habitat map of the species using Maximum Entropy (MaxEnt) method in rangelands of Jiroft city, Kerman province, Iran. To this end, sampling of vegetation including species type and percent cover was conducted with a randomized-systematic method in 2015. Sample size was determined as 60 plots with a quadrat size of 25-100 m^2. For soil sampling, eight profiles were dug in each habitat and samples were taken at two depths, i.e., 0–30 and 30–60 cm. Results indicated that the classification accuracy of the model was acceptable and soil variables including EC, percentage of lime, organic matter, moisture content and texture had the greatest effect on the distribution of the studied plant species habitats. Correlations between the actual and predicted maps for *Tamarix aphylla* and *Calligonum comosum* habitats were at a very good level, Kappa= 0.81 and 0.79, respectively; for *Prosopis spicigera* habitat, it was at a good level, Kappa= 0.75, and finally for *Salsola rigida*, it was at a moderate level, Kappa = 0.53. These results indicate that the MaxEnt method can provide valuable information about the physical conditions of plant habitats in arid rangeland. Knowledge on physical characteristics of plant habitats can be useful in determination of potential habitats and rangeland improvement projects.

Key words: Plant distribution, Potential habitat**,** MaxEnt, Kappa index, Jiroft rangelands

Introduction

Predictive modeling of the range plant species distribution can play a key role in studies on conservational biology, determination of habitat suitability for plant species, changes in rangeland vegetation and diversity through quantitative assessment of habitat conditions (Guisan and Thuiller, 2005; Piri Sahragard and Zare Chahouki, 2015; Zare Chahouki and Piri Sahragard, 2016). Prediction models using a set of physical variables in a specific area predict the distribution of the indicator species as a function of physical variables and determine the suitability of that area for the species under consideration (Hirzel and Guisan, 2002). In other words, these models formulate the relationship between plant species and environmental conditions using GIS facilities and multivariate statistical tools to quantify the impact of important physical variables on habitat desirability (Yalpanian *et al*., 2015).

Several methods are used in predictive modeling of range plant species distribution. Machine learning methods are one of the non-parametric methods used in prediction modeling of plant species distribution. Methods such as MaxEnt, inductive classification, decision tree, genetic algorithms and artificial neural networks are included in this group. These methods usually predict the probability of membership of each class to each category related to the response variables based on the frequency distribution in the data used to train the model (Piri Sahragard and Zare Chahouki, 2016). Each of these modeling methods has certain preconditions that should be considered in selecting the method. For example, some methods such as MaxEnt only use presence data for modeling and hence, it has not got complexities of methods that use both presence and absence data (Phillips *et al*., 2006). The MaxEnt method is a multi-purpose method for predicting or deducing incomplete data. This method aims to estimate the probability of distribution of a species by finding a probabilistic distribution with MaxEnt (Phillips *et al*., 2004). In this method, in the first step, the model of the layers related to the environmental variables is evaluated based on the data of the trainer related to the study area and then, the probability of occurrence of any species in the entire study area is estimated (Piri Sahragard and Zare Chahouki, 2016).

Modeling the distribution of the potential habitat of plant species using MaxEnt method has shown that this method can be useful for prediction of plant species with low amount of available data and the results can be used in rangelands monitoring and conservation programs (Kumar and Stohlgren, 2009; Tarkesh and Jetshcke, 2012). Comparison of the predictive function of the MaxEnt with Bioclimatic Prediction and Modeling System (BIOCLIM) and Genetic Algorithm for Rule Set Production (GARP) methods also suggests that the predictive function of the MaxEnt method is better than other methods (Tarkesh and Jetshcke, 2012). Moreover, the use of MaxEnt method in the modeling of the potential distribution of a medicinal plant, i.e., *Justicia adhatoda* in Himalayan Mountains suggested that the produced models had high accuracy so that the method can be effectively used to predict the distribution of the species and its conservation (Yang et al., 2013). In addition, modeling the distribution of three species including *Tamarix ramosissima*, *Seidlitzia rosmarinus* and *Cornulaca monacantha* using the MaxEnt method in Poshtkouh rangelands of Yazd province, Central Iran showed that distribution of these species was mainly affected by soil properties such as EC, available moisture and the amount of lime. The accuracy of the MaxEnt method was acceptable in estimating the potential distribution of these species in Poshtkouh rangelands (Zare Chahouki and Piri Sahragard, 2016). On the other hand, the repeated use of these predictive models in new regions to evaluate their predictability is one of the important points in predicting the distribution of plant species (Termansen et al., 2006). Considering the various methods used in prediction modeling of the distribution of plant species, identifying more user-friendly, more accurate and less costly methods is one of the research priorities in this field. Therefore, considering the necessity of repetition of models in different climate zones to evaluate their predictive performance with the aim of public models development with a specific confidence interval and usable in rangeland improvement practices, the present study was carried out in Jiroft, Southeastern Iran. The objectives of this study were to determine the capability of the MaxEnt method in identifying effective variables in the separation of range plant habitats, the ecological analysis of the relationship between these variables and the distribution of species, and preparation of predicted map for these habitats in rangelands.

Materials and Methods

Study Area

The study site with an area of 11,717 ha is located in Kerman province, southern part of Jiroft city and north of the Jiroft - Faryab road. The area lies within 56° 17′ E longitude and 26° 43′ N latitude (Fig. 1). The highest and lowest elevation of this area is 527 and 805 m above sea level (msl), respectively. The maximum and minimum rainfall occurs in February and September, 41.2 and 2.8 mm, respectively. The average annual rainfall is about 183.1 mm. The climate of the area is classified as dry and desert by Emberger`s climate classification. Major plants of the study area belong to Chenopodiaceae and Polygonaceae families. Vegetation types change clearly with topography, soil and altitude variations (Maddahi Nezhad, 2015).

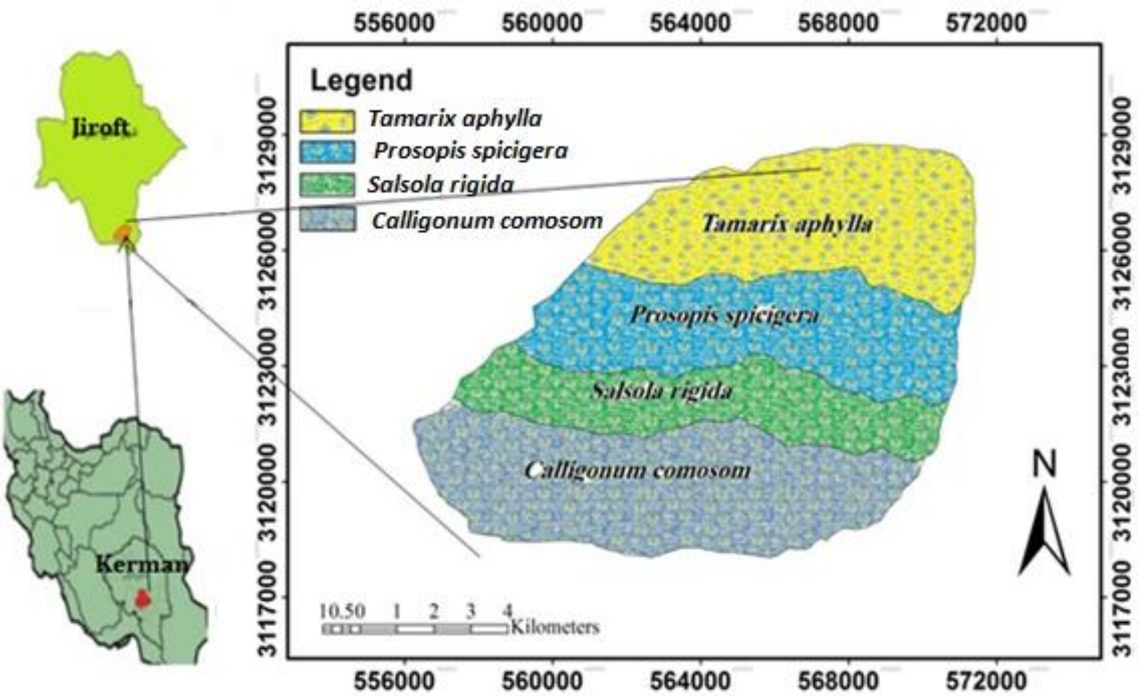

Fig. 1. Location of the study site in Kerman Province, Iran

Data Collection

Sampling units were identified by mapping the slope, elevation and geology of the study area in the scale of 1:25000. Homogeneous sampling units were selected by intersecting slope, elevation and geology maps in GIS environment. Four homogeneous sampling units were selected for vegetation and soil sampling according to percent slope, elevation and geological characteristics of the habitats. The randomized-systematic sampling method was used for vegetation sampling through establishment of quadrats along the four transects with 200-300m length. The length of transects and space between them was determined according to vegetation type, plant distribution pattern, topography and other physical conditions of habitat. In each habitat, four transects were established parallel and perpendicular to slope. The distance between transects was determined based on the number of samples and the area of habitat. Quadrat size ranged from 25 to 100 m^2 according to the existing species type, percent canopy cover, plant density and the variables under consideration (Table 1). The sample size was determined in each sampling unit with regard to vegetation changes and Cochran statistical method (Piri Sahragard et al., 2018). Some of the information about the vegetation types and soil characteristics are presented in Tables 2 and 3. In addition to recording vegetation characteristics (species type and percentage of canopy) in each habitat, information on elevation, slope, aspect, latitude and longitude of sampling points as well as geographical coordinates related to the boundaries of each habitat was recorded in order to provide a real map of the vegetation.

Table 1. Length of sampling line, distance between quadrats, number of quadrats and quadrat size in studied habitats of rangelands in Jiroft, Kerman Province, Iran

S/n	Habitat	Sampling line length (m)	Distance between quadrats (m)	Number of quadrats	Quadrat size (m^2)
1	*Tamarix aphylla*	300	30	40	100
2	*Prosopis spicigera*	300	30	40	100
3	*Salsola rigida*	200	15	60	25
4	*Calligonum comosum*	200	15	60	25

Table 2. Characteristics of plant habitats in arid climate rangelands in Jiroft, Kerman Province, Iran

S/n	Habitat	Symbol	Cover (%)	Slope (%)	Aspect	Area (ha)	Rainfall* (mm)	Altitude (m)
1	*Tamarix aphylla*	Ta. ap	35-40	1-5	Southern	3,061	100–190	500-600
2	*Prosopis spicigera*	Pr. sp	35-40	1-5	Southern–northern	2,856	100–190	600-650
3	*Salsola rigida*	Sa. ri	40-50	5-10	Southern	2,037	100–200	650-700
4	*Calligonum comosum*	Ca. co	45-50	5-10	southern	3,763	100–200	700-800

* Rainfall is the mean of 20-year data (1995-2015)

Preparation of Soil Properties Map Using Geostatistics Methods

To prepare the predicted map of a habitat, it is necessary to map the environmental factors using Geostatistics methods. In this study, the relationship and spatial structure of the variables were investigated using the Kriging method and the GS^+ version 5. The Kriging method is one of the high-precision interpolation methods, which provides the best unbiased estimation with the least variance. In this way, error reduction can be achieved by measuring more data (Wu *et al*., 2008; Zare Chahouki *et al*., 2010). To create the MaxEnt model, layers related to environmental variables and information about the presence points of the species are required. After generating maps of the environmental variables, the layers of the environment variables were prepared in ASCII format and the layers of the presence of the species were prepared in CSV format. After preparing the layers and performing the desired settings in the software configuration, the MaxEnt software Version 3.3.3e was used for modeling. It should be noted that in this method, 25% of the data was used to test the model and the rest was used for training. The maximum number of times of the model running was also considered 1000 repetitions. Jackknife test was used to determine the importance of environmental variables. This test has been accepted as an assessment method with an acceptable accuracy (Phillips *et al.*, 2004; Hosseni *et al.*, 2013).

Evaluating the Effectiveness of Prediction Models for Preparing Presence and Absence Maps of Species

In order to evaluate the prediction models generated by the MaxEnt method, analysis of the Area Under Curve (AUC) of the function feature was used (Sweet, 1988). Because MaxEnt model output is a continuous map, it is necessary to determine the optimal threshold for generating presence or absence maps of the species (Phillips et al., 2006; Negga, 2007). In this research, after determining the optimum threshold using the combination of equal sensitivity and specificity, continuous predicted maps were converted into the presence and absence maps of the species. This method is one of the common methods for determining the limit of optimal thresholds in which the sensitivity (the fraction of correctly predicted presence) and the specificity (the fraction of correctly predicted absence) are calculated around the threshold between 0 and 1 (for example, 0, 0.01, 0.02, 0.03 ... 0.99, 1). In the next step, by plotting the changes of these two indicators in front of each other, the intersection of the two charts (the point where the sensitivity and specificity are equal) was considered as the optimal threshold for the presence (Kumar and Stohlgren, 2009). After determining the optimum threshold and producing maps for the presence and absence of species, their agreement with the actual map was evaluated by calculating Kappa index in IDRISI 32 release 2 software. Studies have shown that Kappa is one of the best and most widely used indices for this purpose (Zare Chahouki *et al*., 2010; Mohtashamnia *et al*., 2011).

Results and Discussion

Altitude, soil lime content, EC and organic matter in first depth (0-30 cm) had the greatest effects on the distribution of the habitat of *T. aphylla* (Fig. 2). According to the response curves of *T. aphylla* to the environmental factors, the most probable presence of this species occurred in areas with altitude of 500–550 m above msl, soil lime content of 10-14%, EC of 6-16 dS/m, and organic matter amount of 4-6% in soil’s first depth. The response curve analysis of lime content of soils in first depth indicated that increasing the amount of lime to 10-14% can increase the likelihood of *T. aphylla* presence (Fig. 2).

Soil EC in 0-30 and 30-60 cm depths, saturated moisture and percentage of sand in depth 30–60 cm were the most important factors, respectively in distribution of *P. spicigera* habitat. The highest fitness for the occurrence of *P. spicigera* was in areas where soil EC was 20-30 and 55-60 dS/m in 0-30 and 30-60 cm depths, respectively, and saturated moisture was about 40-45%. Altitude and soil organic matter in 0–30 cm depth were the most effective variables in habitat distribution of *S. rigida*. Areas with altitude of 550–600 m and 1-2.5% organic matter in 0–30 cm soil depth had the highest presence of *S. rigida* habitat. Furthermore, Altitude, soil lime content in 0–30 cm depth, and soil EC in 30–60 cm depth had the greatest effects on the distribution of *C. comosum* habitat. It can be stated that the most probable occurrence of *C. comosum* was in areas with altitude of 630-650 m, 6-8% of lime in 0-30 cm depth and EC of 3-5 dS/m.

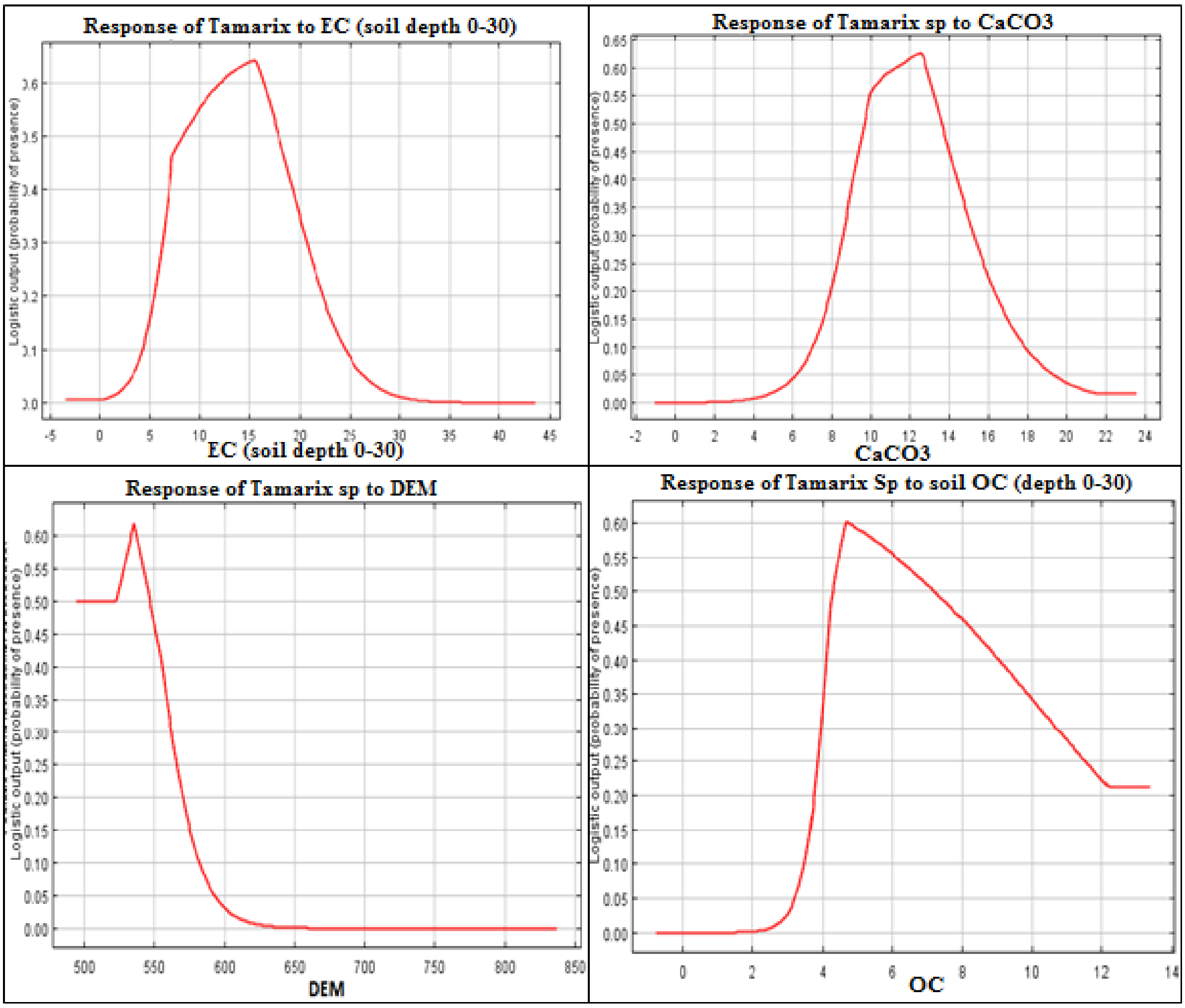

Fig. 2. Response curves of the most important variables in *Tamarix aphylla* habitat

Analysis of the relative importance of physical variables using Jackknife test showed that altitude, soil moisture content, texture, lime content, EC, pH, and organic matter played the most important role in the distribution of the studied plant habitats in rangelands of Jiroft, Kerman province, Southeastern Iran (Fig. 3). Consistently, it has been reported that soil organic matter, EC, pH, nitrogen, phosphorus, potassium, lime, slope and altitude were the most important environmental factors affecting plant habitats in rangelands of Jiroft (Maddahi Nezhad, 2015). These variables provide useful information about the distribution of range plant species. Other variables, when used individually, have less significance in prediction models of the habitats. Variables with less importance can be removed from the prediction model in order to improve its accuracy (Zare Chahouki and Piri Sahragard, 2016; Piri Sahragard and Ajorlo, 2016). Moreover, the results of the importance of variables indicated that the location of each habitat affected the input of the most influential variables in prediction models. Our results clearly demonstrated that the MaxEnt method was suitable for modeling the distribution of plant species in arid rangelands. This method can be easily used by experts and users (Phillips *et al.*, 2006), and it uses small number of variables to generate an accurate prediction model (Piri Sahragard and Ajorlo, 2018).

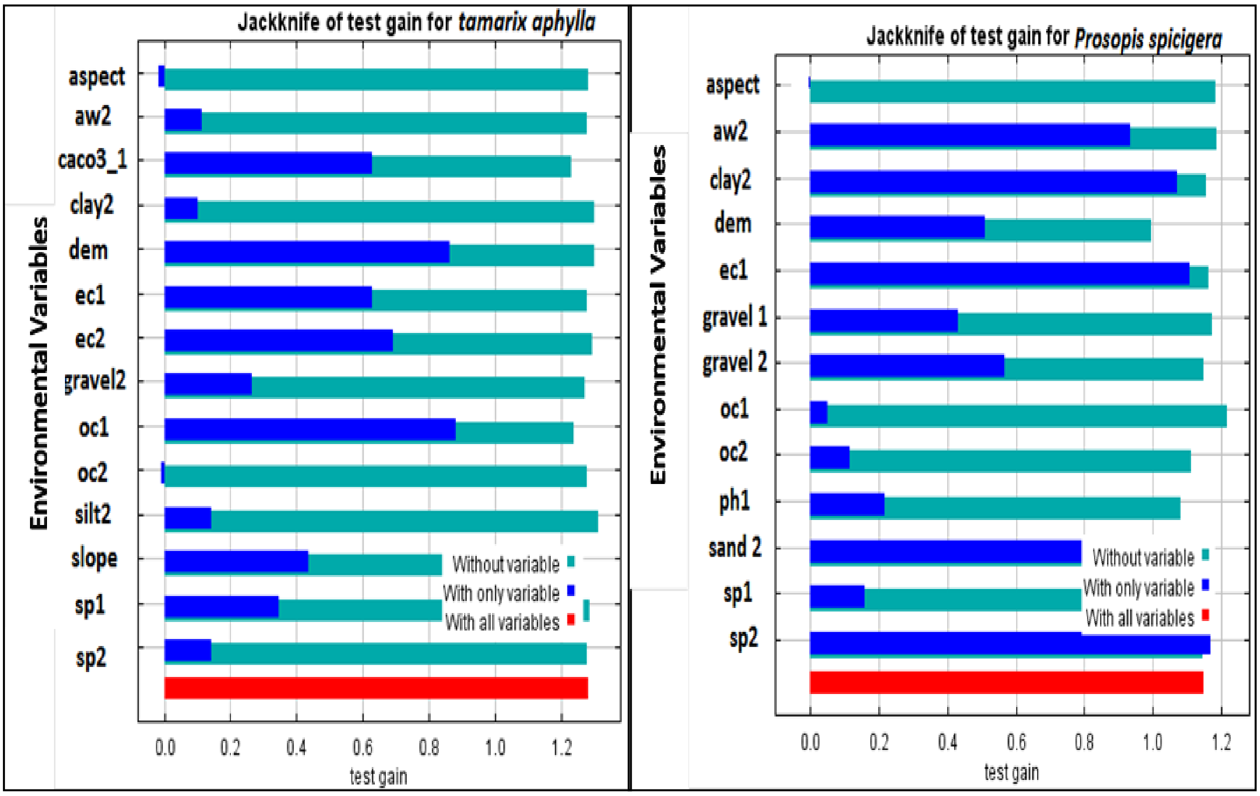

Fig. 3. Results of Jacknife test for determining the relative importance of environmental variables in *Tamarix aphylla* and *Prosopis spicigera* habitats

The effect of soil lime and pH has been reported as one of the factors influencing the distribution of *T. aphylla* (Zare Chahoukiet *et al*., 2010; Zare Chahouki and Piri Sahagard, 2016). Furthermore, several studies have emphasized on the role of altitude as a positive factor on the distribution of *T. aphylla* (Arekhi *et al*., 2010; Maltez; Mouroet *et al*., 2005). Altitude can largely affect the distribution of plant species through affecting air temperature, air pressure, ultraviolet radiation, precipitation, and consequently changing the climatic conditions. Thus, various plant species are located in different altitude levels according to their ecological needs. In addition, it has been reported that there is a strong correlation between the presence of *Tamarix* sp. with high levels of soil EC and saturated moisture content; hence, this species is known as a halophyte species that grows in saline lands with fine-grained texture (Tatian *et al*., 2011; Zare Chahouki *et al*., 2012). Soil texture as one of the effective physical variables in the distribution of *Tamarix* sp. can play important roles in distribution and growth of its communities in arid regions through affecting the water and nutrients availability for the plant (Enright et al., 2005). For example, *Tamarix passerinoides* has been introduced as a species of saline lands with a fine-grained texture in several studies with a high availability of water due to poor drainage and low infiltration (Zare Chahoukiet *et al*., 2010; El-barasi and Barrani, 2012). Furthermore, salinity is directly affected by soil texture as finer soil texture can increase salinity level (Sokoti Oskuei *et al*., 2007). The effect of salinity on increasing the suitability of habitat for *Tamarix* sp. and the presence of this species in plant composition has been emphasized in numerous studies (Azarnivand *et al*., 2010; Khalasi Ahwazi *et al*., 2012; El-Barasi and Barrani, 2012; Zare Chahouki and Piri Sahragard, 2016). High soil saturated moisture content which can be affected by soil texture can also cause soils to retain more moisture (Cohen, 1960).

Topographic features such as elevation, slope and aspect can be very influential in some soil characteristics such as depth, moisture content and organic matter; thereby, they can control the distribution of plant species such as *S. rigida* (Mohtashamnia *et al*., 2011; Piri Sahragard and Zare Chahouki, 2015). The role of altitude as a positive factor in the distribution of plant species has also been reported in many studies (Arekhi et al., 2010; Zare Chahouki *et al*., 2012; Piri Sahragard *et al*., 2018). Increase in altitude, lime content of soils in 0–30 cm depth and EC 30-60 cm soil depth can provide the conditions for the establishment of *C. comosum*. In consistent, it was reported that *C. comosum* mostly grows on sandy soils of watercourses and light soils such as loamy-sand with relatively high loam (Ahqaqiet *et al*., 2011).

Based on the categorization of the AUC values (Table 3), accuracy of prediction models for *T. aphylla* habitat was at a good level and for *P. spicigera*, *S. rigida* and *C. comosum* was at an acceptable level (Table 4). The predicted maps of presence and absence of species for each habitat showed that their agreement with actual maps was different (Fig. 4). In consistent with the findings of this study, it has been reported that the values of the AUC are affected by the ecological niches of species, and its value tends to be lower for species with a wide range of distribution than for species with limited ecological niche (Evangelista et al., 2008; Yang et al., 2013; Ardestani *et al*., 2015; Piri Sahragard and Ajorlo, 2017). Based on the classification of Kappa index values (Cohen, 1960), actual and predicted maps of *T. aphylla* and *C. comosum* habitats had a very good agreement, in *P. spicigera* habitat they had a good agreement and finally in *S. rigida* habitat, they had a moderate agreement (Table 5). In fact, the lowest and highest agreement levels were allocated to *T. aphylla* (as a species with limited distribution range) and *S. rigida*, respectively. In contrast to the findings of this study, it has been reported that the MaxEnt method is able to estimate species with broad ecological niches more accurately (Piri sahragard and Zare Chahouki, 2015). In addition to the nature and algorithm used in modeling, model prediction function also depends on species characteristics, response form of species to environmental conditions and the range of geographical distribution of species (Luoto and Hjort, 2005; Zare Chahouki and Piri Sahragard, 2016).

Table 3. Classification of area under curve (AUC) (Sweet, 1988)

Range	Accuracy level
0.5–0.7	Weak
0.7–0.9	Acceptable
0.9–1.0	Good

Table 4. Area under curve (AUC) and classification accuracy of the prediction models in the studied habitats, Jiroft rangelands, Kerman Province, Iran

Habitat	AUC value	Classification accuracy
Tamarix aphylla	0.93	Good
Prosopis spicigera	0.89	Acceptable
Salsola rigida	0.73	Acceptable
Calligonum comosum	0.75	Acceptable

Table 5. Presence optimal threshold and agreement level of predicted and actual maps in the studied habitats, Jiroft rangelands, Kerman Province, Iran

Habitat	Presence optimal threshold	Kappa value	Agreement level
Tamarix aphylla	0.30	0.81	Very good
Prosopis spicigera	0.20	0.75	Good
Salsola rigida	0.20	0.53	Moderate
Calligonum comosum	0.50	0.79	Very good

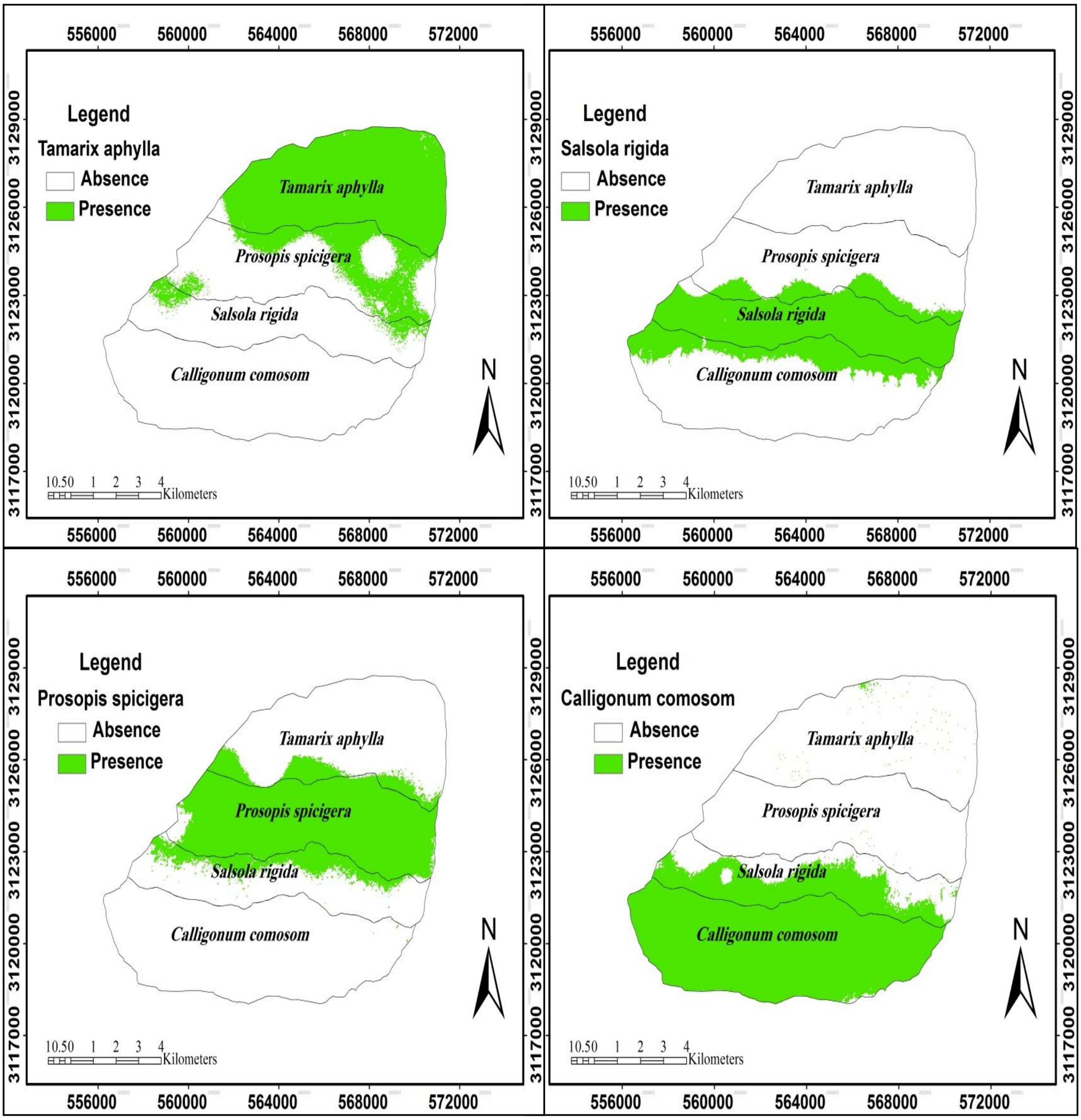

Fig. 4. Predicted and actual maps of the studied habitats generated by using MaxEnt method (color parts are predicted maps)

Conclusion

The results of this study showed that the MaxEnt is a suitable method for identifying the ecological needs of plant species and predicting the distribution of species in the study area. The special features of this method is providing great amount of information about the ecological needs of plant species and the ease of understanding of the outputs. In this study, due to the fact that most of the studied species had a limited distribution range, the MaxEnt method was able to estimate the range of geographical distribution of these species accurately. The most accurate estimate of the distribution range was related to *T. aphylla*. This indicates that in comparison with other species, this species has more limited ecological niches and it is necessary to pay special attention to this species in conservation and utilization of vegetation in the region. In addition, soil properties such as EC, lime content, organic matter, moisture content and texture play a pivotal role in vegetation distribution compared to other environmental factors in the study area. Therefore, by focusing on these characteristics in future research and using the MaxEnt method, the success of utilization projects and vegetation sustainable protection can be increased in addition to saving the cost and time.

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تعیین رویشگاه بالقوه گونه‌های گیاهی مرتعی با استفاده از روش آنتروپی حداکثر

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چکیده. هدف این مطالعه شناسایی متغیرهای مهم فیزیکی مؤثر در پراکنش رویشگاه چهار گونه مرتعی (*Salsola rigida* و *Tamarix aphylla, Calligonum comosum, Prosopis spicigera*) و تهیه نقشه رویشگاه بالقوه این گونه‌ها با استفاده از روش آنتروپی حداکثر (MaxEnt) در مراتع جیرفت، استان کرمان، در جنوب شرق ایران بود. برای این منظور، نمونه‌برداری از پوشش گیاهی شامل نوع گونه‌ها و درصد پوشش به روش تصادفی-منظم در سال ۱۳۹۵ انجام شد. تعداد نمونه ۶۰ کوادرات در ابعاد ۲۵ تا ۱۰۰ مترمربع تعیین شد. برای نمونه‌برداری خاک هشت پروفیل در هر رویشگاه حفر و نمونه‌ها از دو عمق صفر تا ۳۰ و ۳۰ تا ۶۰ سانتی‌متر برداشت شدند. نتایج نشان داد که صحّت طبقه‌بندی مدل قابل قبول بوده و متغیرهای خاک شامل EC، درصد آهک، ماده آلی، درصد رطوبت و بافت بیشترین اثر را در پراکنش رویشگاه گونه‌های مطالعه شده دارند. همبستگی بین نقشه‌های واقعی و پیش‌بینی برای گونه‌های *Tamarix aphylla* و *Calligonum comosum* در سطح خیلی خوب با مقدار ضریب کاپای به‌ترتیب ۰/۸۱ و ۰/۷۹ و برای گونه *Prosopis spicigera* در سطح خوب با ضریب کاپای برابر با ۰/۷۵ و در نهایت برای گونه *Salsola rigida* در سطح متوسط با مقدار ضریب کاپای ۰/۵۳ بود. این نتایج حاکی از آن است که روش آنتروپی حداکثر می‌تواند اطلاعات ارزشمندی درباره شرایط فیزیکی رویشگاه گیاهان در مناطق خشک ارائه نماید. آگاهی از ویژگی‌های فیزیکی رویشگاه‌های گیاهی می‌تواند در تعیین رویشگاه بالقوه و برنامه‌های اصلاح مرتع مفید باشد.

کلمات کلیدی: پراکنش گیاهی، رویشگاه بالقوه، MaxEnt، شاخص کاپا، مرتع جیرفت