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Prediction of Distribution of *Prangos uloptera* DC. Using Two Modeling Techniques in Southern Rangelands of Ardabil Province, Iran

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Abstract. Investigation of the relationship between plant species and environmental factors plays an important role in plant ecology. The present study aimed to develop the best predicting model for distribution of *Prangos uloptera* DC. using Logistic Regression (LR) and Maximum Entropy Methods (MaxEnt) in its habitat in the southern rangeland of Ardabil province, Iran. Vegetation data (presence and absence of *P. uloptera*) and environmental factors (including soil, topography and climatic variables) were collected. The original vegetation type map was prepared using slope and elevation maps (1: 25000 scale) and satellite imagery (Landsat). Vegetation samples were collected in 2016. In each site, three transects of 100 m length were deployed (two transects in the direction of a gradient and one transect perpendicular to the slope direction). On each transect, ten $4m^2$ plots were placed along each transect, and the total canopy cover and plant density were recorded. Overall, 180 plots were sampled in six sites. Soil samples were collected at a depth of 0-30 cm at the beginning and end of each transect. The LR method was performed in the SPSS Ver. 19 software, and the Maximum Entropy method was carried out in the MaxEnt Ver. 3.1 software. The LR model showed that rainfall had the highest effect on the distribution of the *P. uloptera* habitat. The accuracy of the LR method for the prediction map was good (Kappa index= 0.65). The MaxEnt method showed that variables including sand, Nitrogen (N), silt, and potassium (K) had the highest effect on distribution of *P. uloptera* habitat. However, the accuracy of the MaxEnt method was low (Kappa index=0.35). It was concluded that modeling methods could be used as a prediction tool to determine the location of plant species. This may lead to better rangelands management and improvement in areas with similar conditions.

Keywords: Logistic regression, MaxEnt, Environmental factors, Ardabil province

Introduction

Plant species distribution is the result of environmental factors on ecology needs of every plant species in every study area. Additionally, the tolerance of plant species to environmental factors affects their distribution (Bagheri *et al.*, 2018). Prediction of plant species distribution is based on the relationship between vegetation distribution and effective environmental variables. Prediction models could help to understand the plant requirements habitats and to predict plant species distribution potential (Guisan and Thuiller, 2005; Esfanjani *et al.*, 2018). Therefore, the models can be used to assess environmental factors impact on plant species distribution and management of endangered species (Guisan and Thuiller, 2005; Esfanjani *et al.*, 2018).

Modeling methods are based on a) presence and absence of plant species such as LR, Generalized Linear Model (GLM), Generalized Additive Model (GAM) and b) only presence of plant species such as MaxEnt (maximum-entropy), Ecological Niche Factor Analysis (ENFA). The logistic regression method is one of the methods based on the presence and absence of plant species. The logistic regression method establishes a multivariate regression relationship between a dependent variable and several independent variables (Warton *et al.*, 2012). Maximum entropy is one of the methods based on the only presence of plant species. The maximum entropy method is used to compare the differences in imaging methods in various sciences (West *et al.*, 2016; Silva *et al.*, 2017). In this method, the criteria are used based on individuals' judgment (West *et al.*, 2016; Silva *et al.*, 2017). There are some studies as follows in this field. Xue *et al.* (2013) investigated MaxEnt modeling to predict the potential distribution of *Justicia adhatoda* L. in lower Himalayan foothills. They concluded that the MaxEnt model was highly accurate with a statistically significant Area Under the Curve (AUC) value of 92.3. The approach could be promising in predicting the potential distribution of medicinal plant species and thus can be an effective tool in species restoration and conservation planning. Zare Chahouki and Esfanjani (2015) used modeling techniques to predict potential distribution of plant species in the southern rangelands of Golestan, Iran. They reported that the accuracy of the logistic regression results regarding the Kappa Index was higher than that of the Ecological-Niche Factor Analysis method. Piri Sahragard and Zare chahouki (2016) used the maximum entropy method for *Artemisia sieberi* Besser habitat distribution in desert rangelands. Their results showed that soil, pH and lime content in the layer surface (0-30 cm) and silt percent in both soil depths (0-30 and 30-60 cm) had the greatest impact on the distribution of *A. sieberi* in the study area. Similarity of the actual map with the predictive one was assessed at a satisfactory level (Kappa coefficient = 0.70). Piri sahragard and Ajorlo (2018) used logistic regression and maximum entropy for distribution modeling of range plant species in the rangelands of western Taftan, southeastern Iran. They reported that logistic regression and maximum entropy methods had the same efficiency in distribution modeling of plant species with a limited ecological niche. Esfanjani *et al.* (2018) used MaxEnt modeling to predict impact of environmental factors on the potential distribution of *Artemisia aucheri* and *Bromus tomentellus-Festuca ovina* in Iran. They reported that similarity of the actual map with the predictive one was assessed at a satisfactory level of Kappa coefficients as 0.50 and 0.51 for *A. aucheri* and *B. tomentellus-F. ovina*, respectively. Therefore, the MaxEnt method is more successful in predicting *B. tomentellus-F. ovina* habitat than *A. aucheri* habitat since the distribution of *A. aucheri* habitat was vast and outspread in the study area.

P. uloptera belonging to the Apiaceae family is one of the most important rangeland plants in Iran. This species is at risk of extinction due to improper use. There are 15 species of this genus in Iran. These plants are important in terms of fodder, conservation, medicinal and industrial aspects (Mossivand *et al.*, 2017). This genus is cultivated in highlands. It is the best forage for livestock in the winter. This plant species has high nutritional value and is suitable to improve degraded mountain rangelands. It grows in rocky soils with shallow depth. This plant produces high humus that led to soil fertility and easily grows in harsh conditions (cold, frost, steep slope and shallow soil) (Mossivand *et al.*, 2017). Additionally, it is an indicator species in the southern rangelands of Ardabil province, Iran. The aim of this study was to develop the best predicting model for distribution of *Prangos uloptera* using logistic regression (LR) and Maximum Entropy Methods (MaxEnt) in its habitat in the southern rangeland of Ardabil province, Iran.

Materials and Methods

Study area

The study area is located in the southern rangeland of Ardabil province, Iran. The overall vegetation communities in the studied area are: 1) *Juniperus sp.* 2) Meadow 3) Cold steppe Shrubs 4) Semi-steppe plants 5) Hyrcanian Forests. The altitude of area varies from 500 to 3200 m above sea level, with geographical position of 37°12' to 38°07' N and 47°51' to 48°48' E (Fig. 1). The annual precipitation varies from 200 to 500 mm, and the average annual temperature ranged from 0.4 to 17°C (Ghorbani *et al.*, 2012; Mossivand *et al.*, 2017).

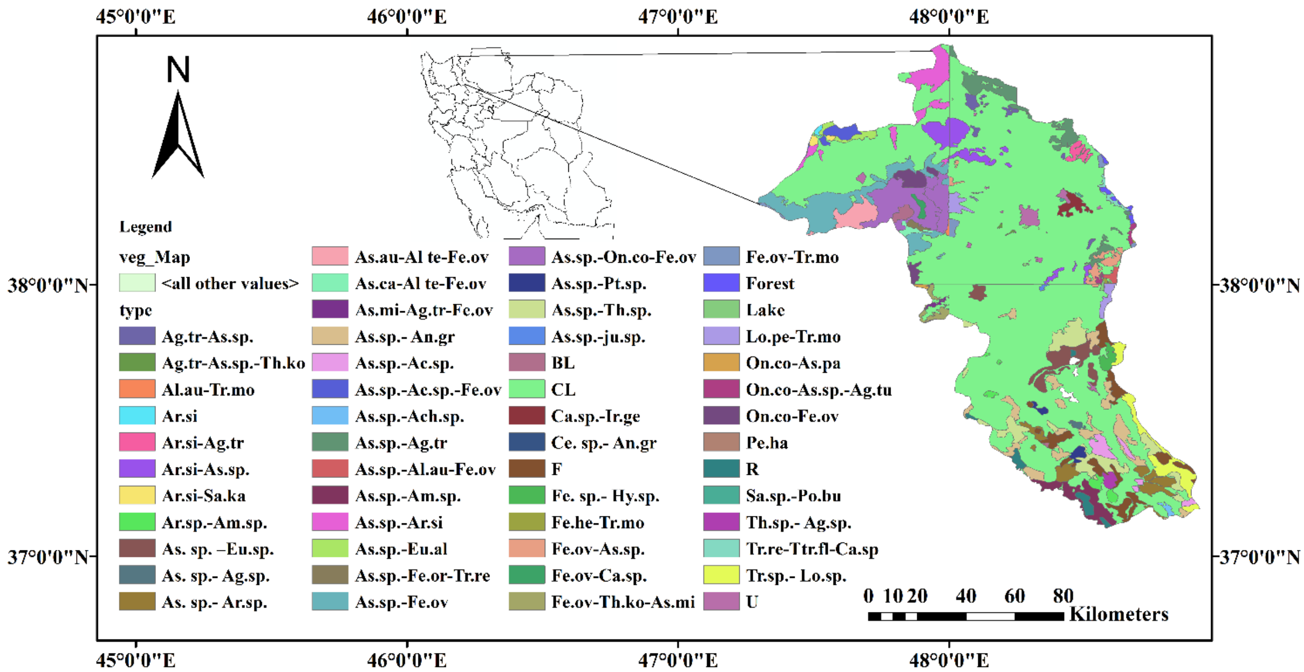

Fig. 1. Location of the study area in southern rangeland of Ardabil province in Iran (R=Rock, F= abandoned Fields, BL=Bare Land, U= Urban and CL= Cultivated Land)

Sampling Method

Three transects of 100 m were established (distance of transects was 50 m from each other) in the key area in April 2016. The plots were established at 10-m intervals (the plot size: 4 m^2 (Ghorbani *et al.*, 2012).

On each transect, ten $4m^2$ plots were located, and the total canopy cover and density of plants within plots were recorded. Overall, 180 plots were sampled in six sites. The presence and absence of plant species were recorded along each transect. Latitude and longitude locations were recorded using GPS. The data of density (The presence and absence of plant species) and canopy cover were used as dependent variables. Independent variables were environmental factors such as elevation, slop and aspect, climatic factors (temperature, rainfall) and soil properties (from 0 to 30 cm depth). Soil properties including pH (potentiometric method), organic matter content (Walkely and Black, 1979), absorbed phosphorus (calorimetric method), exchangeable potassium (colorimetric method), and EC (saturated extraction method) and soil texture (Bouyoucos hydrometer method) were measured (Esfanjani *et al.*, 2017). To prepare physiography maps, the first DEM map (1:25000) of the Iran was obtained from 20 × 20 pixel maps. Then, elevation, slopes, and aspect maps were obtained from the DEM map. Finally, the amount of each of the physiography parameters for the sampling points was obtained in the GIS 10.4.1 software. The environmental factors maps were made with existing data and using spatial statistics methods (Ghorbani *et al.,* 2018).

Interpolation Method

To draw predictive mapping, it is necessary to prepare the maps of all affective factors of models. Topographic data (elevation, slope, and aspect) were derived from DEM with accuracy of 10 m. Map soil characteristics (spatial statistic method) including variogram analysis and Kriging interpolation were used by the GS+ Ver. 5.1.1 software, a program that is based on obtained predictive models for plant species through MaxEnt and LR methods. To select the best modeling based on the only presence of plant species and absence-presence of plant species, the Logistic Regression (absence-presence of plant species) and MaxEnt (only presence of plant species) were used.

Logistic Regression Model:

In general, the logistic regression model predicts the presence and absence of plant species with equation 1 (Wharton *et al.*, 2012):

Equation1:

$$Y = (\mathrm{Exp}(b0 + b1x1 + \cdots + bnxn)) / (1 + \mathrm{Exp}(b0 + b1x1 + \cdots + bnxn))$$

Where:

Y=the occurrence of species probability, and (b_1, b_2 and b_n) =regression model coefficients, and

x= variables (environmental factors). In this method, plant species as a binary variable was considered a dependent variable, and environmental variables were regarded as an independent variable. Finally, the prediction map will be provided for plant species (Wharton *et al.,* 2012). This method was performed in the SPSS Ver. 19 software.

MaxEnt Method:

In the maximum entropy method, the geographic coordinates of all maps were converted to the ASCII format to be analyzed in the MaxEnt Ver 3.1 software. Then, the probability of species presence ranging from 0 to 1 was estimated. Owing to continuous output of MaxEnt, the optimal threshold value was determined for presence or absence of the target species (Phillips *et al.,* 2006; Negga, 2007). The quantitative models were developed in the MaxEnt method using the Receiver Operating Characteristic curve (ROC) analysis. In the ROC analysis, the accuracy of each model was expressed in terms of the surface area below the curve (0 to 100), and the graphical representation of the model accuracy was possible (Elith, 2006; Bagheri *et al.,* 2018). The Area Under the Curve (AUC) of receiver operating characteristic function was used to evaluate discrimination ability (Fielding and Bell, 1997).

The AUC ranges from 0.5 for an uninformative model to 1 for perfect discrimination. Jackknife analysis was also used to determine the importance of variables.

Accuracy of prediction maps:

The final prediction map was based on two levels of presence (1) and absence (0) of plant species in the GIS 10.4.1 software environment. The accuracy of the prediction map with the actual maps was investigated by calculating the kappa coefficient in the IDRISI Selva 17 software (Esfanjani *et al.,* 2018).

Results

The accuracy of interpolation methods was investigated for all environmental variables using the intersection method. The results showed that the actual values and predicted values were more consistent with the point Kriging method. For example, Table 1 shows the rainfall results. While the Mean Absolute Error (MAE), Mean Bias Error (MBE) and Root Mean Square Error (RMSE) low or close to zero indicating a good method has been used to simulate reality (Khosravi and Abbasi, 2014). Table 1 shows the best interpolation method (point Kriging method). Table 2 shows the components to change the measured variables. It shows three parameters (Nugget, Sill and Range parameter) that are fundamental in creating interpolation.

Table 1. Assessing one of the environmental variables (rainfall) using cross-validation methods to illustrate the best method (point kriging)

Environment factor	Error	Point kriging	Block kriging	IDW	NDW
Rainfall	Mean Absolute Error (MAE)	0.005	16.73	1.730	13.6
	Mean Bias Error (MBE)	-0.005	-16.73	-1.730	-13.6
	Root Mean Square Error (RMSE)	0.825	4.63	8.054	1.52

IDW =Inverse Distance Weighing

Table 2. Variogram values of the environmental factor for maps production

Environmental factors	Model	Nugget C_0	Sill C_0+C	Range Parameter A_0	R^2
Rainfall(mm)	Gaussian	10.00	21.010	80300	0.70
Clay (%)	Gaussian	14.90	70.800	12160	0.21
Sand (%)	Spherical	0.100	104.700	31800	0.40
Silt (%)	Spherical	29.700	161.00	39200	0.26
N (%)	Linear	0.0006	0.004	65842	0.48
P (ppm)	Gaussian	0.325	2.660	17400	0.15
K (ppm)	Spherical	10.00	896.**0**	1310	0.10
EC (Ds/m)	Spherical	0.006	0.131	9400	0.05
Ph (Degree)	Gaussian	0.003	0.031	14900	0.51
Temperature max (^{0}c)	Spherical	8.530	29.970	32700	0.34
Temperature min (^{0}c)	Gaussian	12.960	25.930	21000	0.13
Temperature mean (^{0}c)	Linear	0.0002	0.740	65842	0.63
Total carbon total	Spherical	0.100	82.500	194000	0.18
Precipitation _min (mm)	Exponential	192.80	428.900	16500	0.40
Precipitation _max (mm)	Spherical	47.80	143.700	10200	0.70

Logistic Regression Method

The spatial statistics method (point Kriging method) was used to prepare the rainfall map (among environmental factors, only the rainfall was introduced into the model (Fig. 2) since the MAE, MBE and RMSE were low or close to zero (Khosravi and Abbasi, 2014). Table 3 shows the results of the change of evaluated variables. Equation 2 is the result of the logistic regression model; it is a relation between presence and absence of plant species habitat and environmental factors. According to Equation 2, the presence and absence of *P. uloptera* habitat are directly related to rainfall. If the amount of Hosmer–Lemeshow (HL) is high, the result is greater compliance. The significance of this model with the coefficients of diagnosis and HL statistic shows the significance of these relationships at (P<0.01) (Zare Chahouki and Esfanjani, 2015). The result is a good correlation between the logistic regression and the data studied (Table 3).

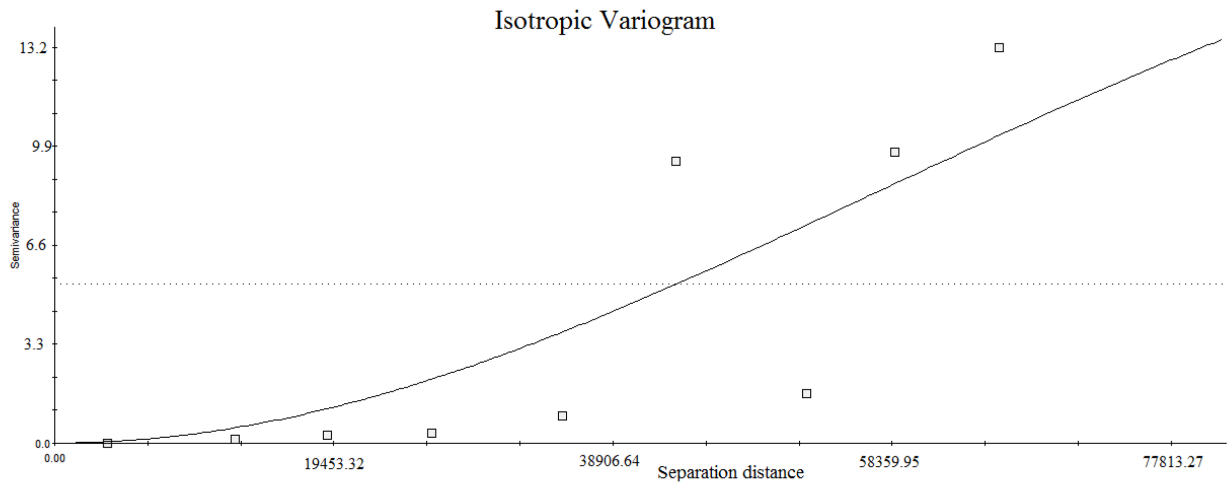

Fig. 2. The Gaussian model's variogram of the selected environmental factor (rainfall)

Equation 2:

P (*Pr.ul*) = Exp (3.004 rainfall-1091.61)/1+Exp(3.004rainfall-1091.61)

Table 3. Logistic regression statistics to predict presence and absence of habitat

Habitat species	R^2	HL statistic
P. uloptera	0.74	1.00^{**}

** Significantly at a level of 99 percent

HL=Hosmer-Lemeshow test

In the next step, the rainfall (the main environmental factor effective in *P. uloptera* habitat) map was prepared using the point Kriging interpolation method in the GIS 10.4.1 software. Rainfall coefficients were obtained based on the regression relation and applied to the environmental layers, and the prediction map was prepared for the habitat species *P. uloptera*. Then, the final prediction map was based on two levels of presence (1) and absence (0) of plant species. Fig. 3 shows the map prepared to be compared to the actual plant map.

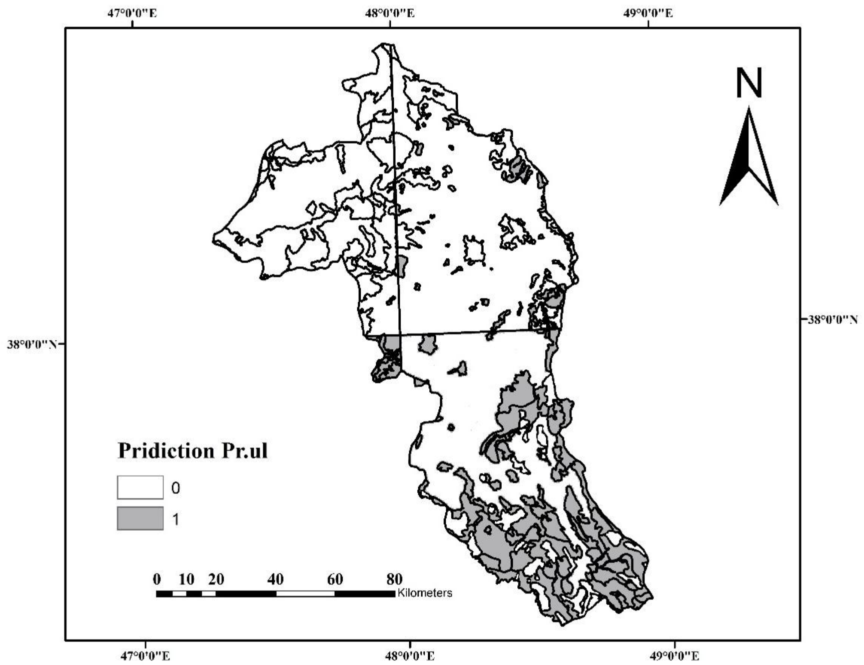

Fig. 3. The predicted distribution for *P. uloptera* habitat with LR model. The species as (a binary variable) (0=absence of *P. uloptera*, 1=presence of *P. uloptera)*

MaxEnt Method

In the maximum entropy method, the coordinates of all maps of geographic coordinates were converted to the ASCII format to be analyzed in MaxEnt. If the pixel has similar environmental conditions in the form of educational data in the study area, higher values are allocated to it. Furthermore, pixels with different conditions have lower values (Negga, 2007).

The results of MaxEnt modeling are as follows:

a) ROC curves of sensitivity vs. specificity for *P. uloptera:*

Test gain and AUC are given only when a test sample file is provided or when a specified percentage of the samples is set aside for testing (Esfanjani *et al.,* 2018). According to the AUC classification, model predictive accuracy of *P. uloptera* habitat was assessed as an excellent level (AUC = 0.94) (Fig. 5)

b) Jackknife of regularized training gain for *P. uloptera*:

Jackknifing is useful to identify which variables contribute the most individually. It shows that the training gain of each environmental variable if the model is run in isolation, and compares it to the training gain with all environmental variables (Philips *et al.,* 2006). Based on the jackknife operation results (Fig. 6), sand, N, silt and K were the most important variables in the distribution of *P. uloptera* habitat. The *P. uloptera* has a suitable habitat with higher sand, N, silt and K in the study area.

c) Response Curves:

This curve can provide useful information about the required environmental threshold for optimal growth of plant species. It shows environmental variables affecting the suitable habitat distribution of plant species (Fig. 7). The response curve analysis showed that the most important variables affecting *P. uloptera* habitat were sand amount (49-51%) and N amount (0.13-0.15) in surface soil depth, and silt amount (36-40%) and K amount (2.70-3.05) (Fig. 7).

d) Prediction map:

It was based on two levels of presence and absence of *P. uloptera*. Fig. 4 presents the map prepared for comparison to the actual plant map.

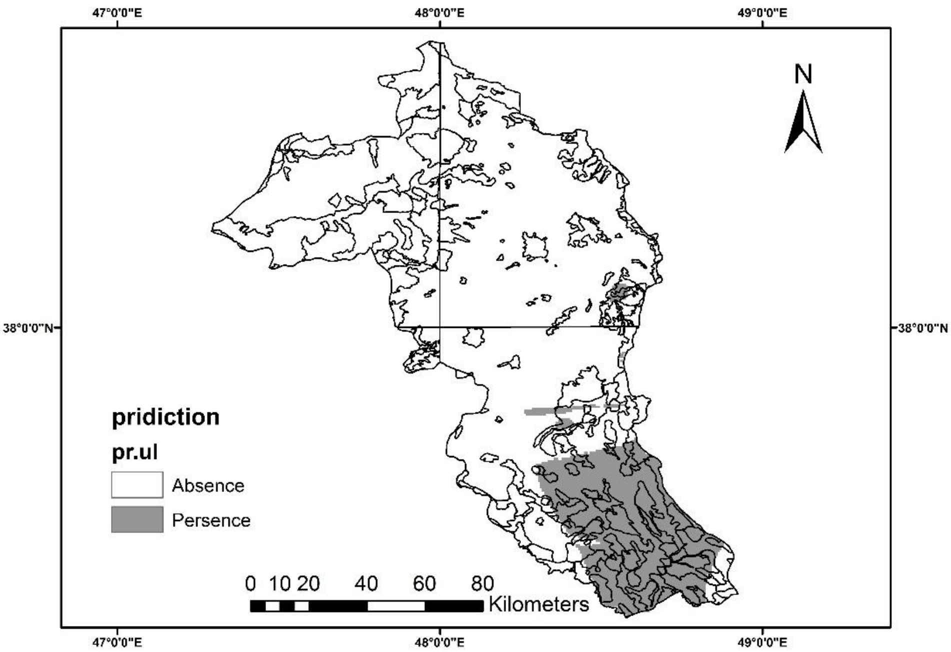

Fig. 4. The predicted distribution for *P. uloptera* habitat from the MaxEnt model **(**actual map: White part of the map, predicted map**:** Dark part of the map)

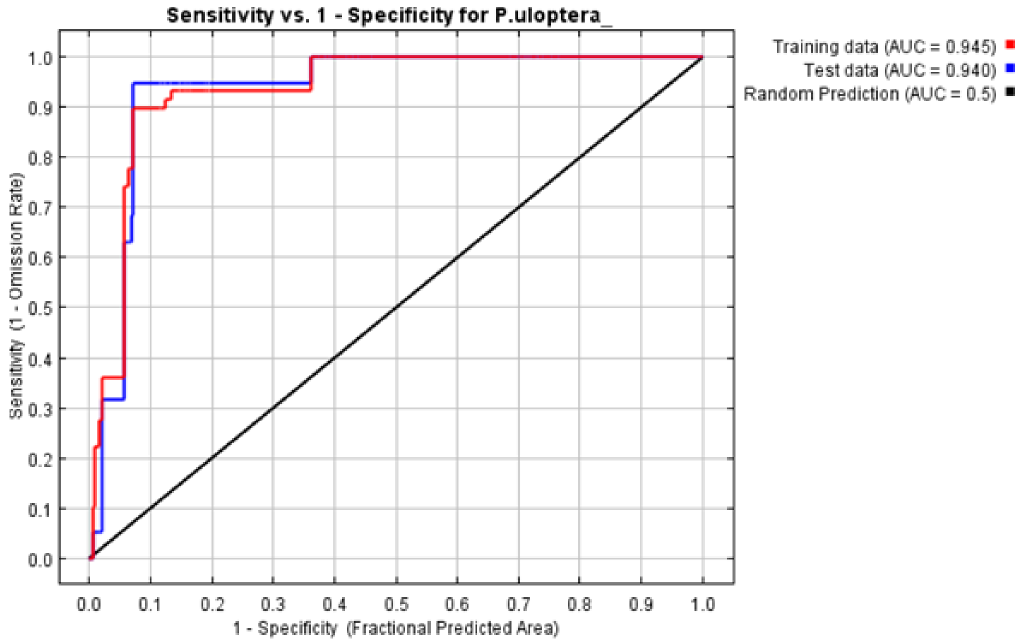

Fig. 5. ROC curves of sensitivity vs. specificity.

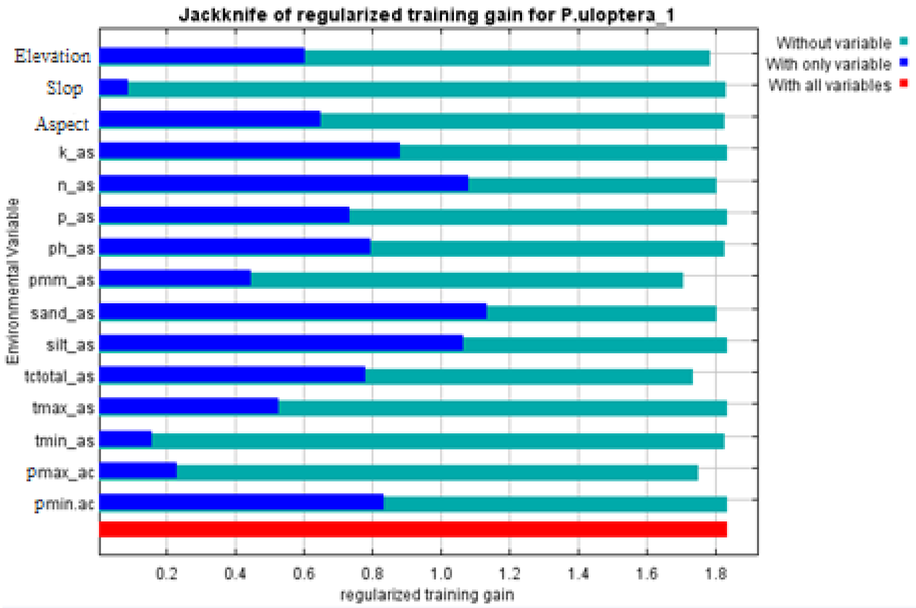

Fig. 6. Jackknife results of variable importance (sand, N, Silt and K) for *P. uloptera*

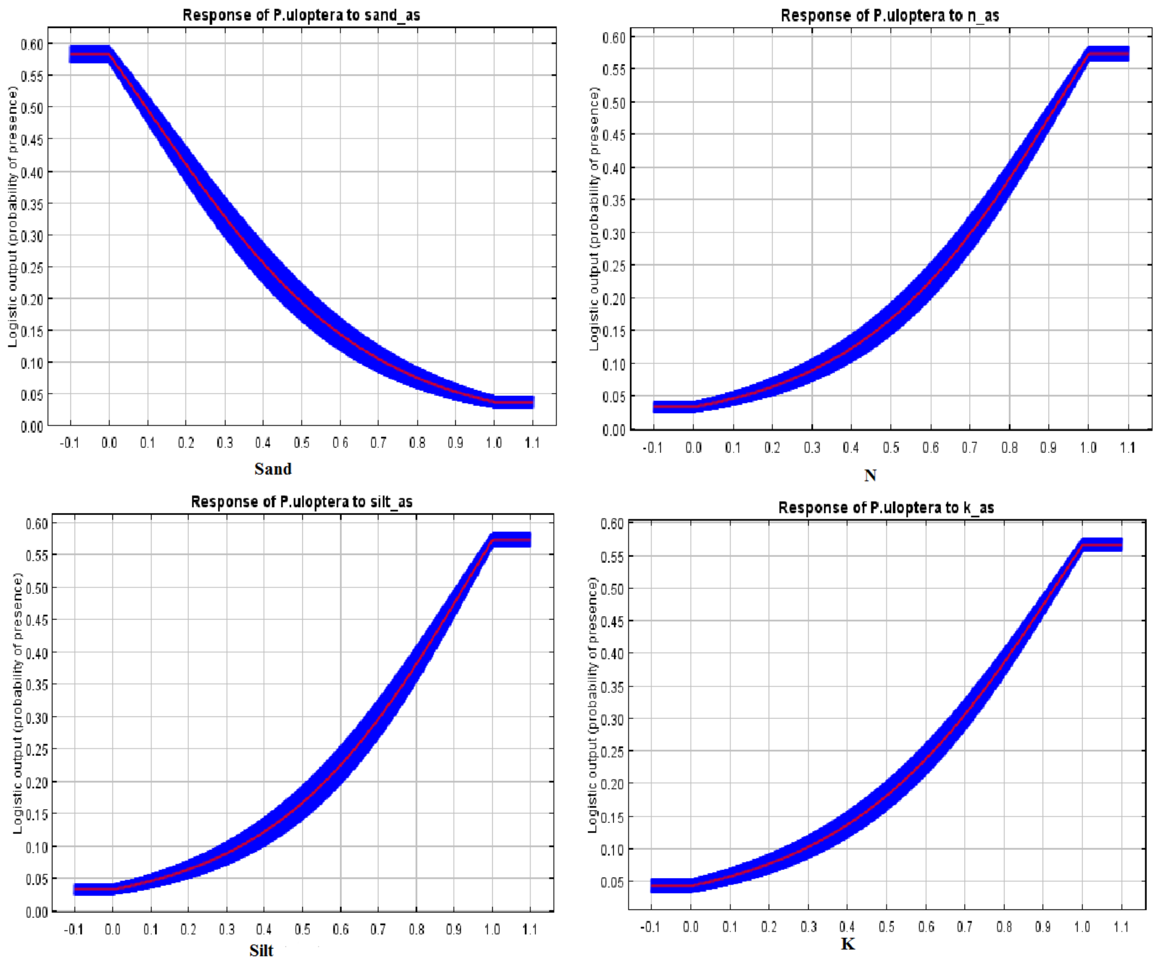

Fig. 7. Response curves of the most influential predictors for *P. uloptera*

Discussion

According to the results, the logistic regression method was more accurate than the MaxEnt method, since the accuracy of the MaxEnt method was low (Kappa index= 0.35) (Monserud and Leemans, 1992). Therefore, the accuracy of logistic regression method was good (Kappa index= 0.65). The logistic regression analysis considers the qualitative variable for presence and absence of data of plant species (Zare Chahouki, 2010), but the MaxEnt method considers number of environment variables for analysis (Philips *et al.*, 2006). In the present research, spatial distribution of environmental factors (soil factors, climatic factors) is based on the Kriging method in geostatistical techniques (Ghorbani *et al.*, 2018; Piri Sahragard and Ajorlo, 2018).

According to the results from the geostatistical techniques, the point kriging method was used since its RMSE and MAE and MBE were closer to zero and less than those of other geostatistical techniques.

According to the results, given the logistic regression method: The rainfall amount had the most effect on distribution of *P. uloptera* habitat. The varying climates (including rainfall) and the soil parameters affect the diversity of plant species (Zare Chahouki and Esfanjani, 2015). Rainfall can influence plant species population dynamics through germination, water limitation and competitive suppression mechanisms. Determining when each process is dominant is important. The plant species can respond to different climates (wetter or drought) of the future, or the hotter temperatures that will presumably accompany germination-inducing rains. In addition, assessment of environmental factors is important to predict beneficial effects of environmental variability on sustainability. If population variability is controlled by seed germination, the environmental factors could prevent plant species extinction via soil bank storage (Chesson, 1990; Pake and Venable 1996; Levine *et al.*, 2008). Many studies have had investigated the impact of climatic factors on species distribution (Mirdavodi *et al.*, 2013; Asadian *et al.*, 2017), but in the present study, the use of the MaxEnt method, sand, N, silt, K factors had the most effect on the distribution of *P. uloptera* habitat. Based on the jackknife operation results, sand, N, silt and K were the most important variables in the distribution of *P. uloptera* habitat. The *P. uloptera* has suitable habitat with higher sand, N, silt and K in the study area. In using the MaxEnt method, sand and N had the greatest impact on the *P. uloptera* habitat. One of the most important factors was soil texture in determining habitat suitability of this plant species since the effect of soil, moisture and plant available nutrients and ventilation is important in vegetation distribution (Rangel *et al.*, 2006). Nitrogen and K are critical determinants of plant growth and productivity, and both plant growth and root morphology are important parameters to evaluate the effects of supplying nutrients (Razaq *et al.*, 2017).

Conclusions

According to the results of this study, we developed a model of the vegetation habitat using binary methods based on the presence and absence of plant species (logistic regression) and based on only the presence of plant species (MaxEnt). Both methods determine the most important environmental factors affecting the distribution of plant species. In this study, the factors affecting the presence of plant species were determined (in the MaxEnt method, sand, N, silt, K factors have the most effect on the distribution of *P. uloptera* habitat, and for the logistic regression method, the rainfall amount had the most effect on distribution of *P. uloptera* habitat). Therefore, focusing on environmental factors affecting the distribution of plant species will be useful in similar areas. In addition, time and costs are reduced. The predictive maps derived from the logistic regression and the MaxEnt method had the potential distribution map of the plant species. These can play a crucial role in proposing species that are consistent with different physiographic conditions in rangeland regeneration programs. These can also be used to determine the areas with the potential for the emergence of valuable medicinal species or rare and endangered species.

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پیش‌بینی پراکنش جاشیر *Prangos uloptera* DC. با استفاده از دو روش مدل‌سازی در مراتع جنوبی استان اردبیل، ایران

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چکیده. بررسی رابطه بین گونه‌های گیاهی و عوامل محیطی در اکولوژی گیاهان از اهمیت بالایی برخوردار بوده است. هدف از این مطالعه مدل‌سازی با روش‌های رگرسیون لجستیک (LR) و آنتروپی حداکثر (MaxEnt) برای زیستگاه *Prangos uloptera* در مراتع جنوبی استان اردبیل، ایران بود. داده‌های گیاهی (حضور و عدم حضور *P. uloptera*) و برخی از عوامل محیطی (از جمله خاک، توپوگرافی و متغیرهای اقلیمی) جمع‌آوری شد. نقشه تیپ گیاهی با استفاده از نقشه‌های شیب و ارتفاع (مقیاس ۲۵۰۰۰: ۱) و تصاویر ماهواره‌ای تهیه شده است. نمونه‌های پوشش گیاهی در سال ۱۳۹۵ جمع‌آوری شد. در هر مکان، سه ترانسکت ۱۰۰ متری مستقر شد (دو ترانسکت در جهت شیب و یک ترانسکت عمود بر جهت شیب مستقر شدند). در هر ترانسکت، ده پلات ۴ مترمربعی قرار گرفت و کل تاج پوشش و تراکم گیاهان ثبت شد. به‌طورکلی، ۱۸۰ پلات در شش سایت، نمونه‌برداری شد. نمونه‌های خاک در آغاز و انتهای هر ترانسکت در عمق ۰ تا ۳۰ سانتی‌متر جمع‌آوری شدند (عمق خاک بر اساس فعالیت ریشه گونه‌های گیاهی انتخاب شد). روش LR با استفاده از نرم‌افزار SPSS ورژن ۱۹ و روش آنتروپی حداکثر در نرم‌افزار MaxEnt ورژن ۳،۱ انجام شد. مدل LR نشان داد، بارندگی بیش‌ترین تأثیر را در پراکنش رویشگاه *P. uloptera* داشت. صحت روش LR برای نقشه پیش‌بینی خوب بود (شاخص کاپا = ۰/۶۵). روش MaxEnt نشان داد که متغیرهایی از جمله شن، نیتروژن، سیلت، پتاسیم بیش‌ترین تأثیر را در پراکنش رویشگاه *P. uloptera* داشت. صحت روش MaxEnt کم بود (شاخص کاپا = ۰/۳۵). بنابراین، صحت روش LR در مقایسه با روش MaxEnt قابل اطمینان‌تر است. بنابراین می‌توان از روش‌های مدل‌سازی برای پیش‌بینی موقعیت گونه‌های گیاهی به منظور مدیریت بهتر و بهبود مراتع استفاده کرد و می‌توان آن را در مناطقی با شرایط مشابه گسترش داد.

کلمات کلیدی: رگرسیون لوجستیک، MaxEnt، عوامل محیطی، استان اردبیل