Environmental Resources Research (ERR)
Print ISSN: 2345 - 430X
Online ISSN: 2345 - 4318
Gorgan University of Agricultural Sciences and Natural Resources

Habitat suitability modeling for *Astragalus podolobus* (Boiss. & Hohen) using frequency ratio

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Article Info

Article type:
Research Article

Article history:
Received: July 2021
Accepted: September 2021

Corresponding author:
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Keywords:
Conservation
Habitat Suitability
Rangelands
Golestan Province

Abstract

The thornless half-shrub *Astragalus podolobus* is one of the most valuable species in Iran rangelands providing nursing condition with important roles in soil and water conservation together with biodiversity conservation. However, land-use changes and rangeland degradation have represented real threats to this species. To determine how to manage this plant better, its potential spatial distribution was mapped using a bivariate statistical model (FR: frequency ratio) for the Maraveh Tapeh rangelands of Golestan Province, north-east Iran. A total of 115 occurrences of *A. podolobus* were recorded using GPS during field surveys from April to September in 2018 and 2019, then 80 data points (70%) were used in modeling, and the remaining 35 data points (30%) in evaluating the model. A number of 8 digital layers potentially affecting the habitat suitability of the plant were selected as independent variables, including: distance from roads and rivers, elevation, plan curvature, precipitation, slope percentage, aspect and temperature. The results showed that the variables temperature, precipitation, and distance from the roads have larger effects on the presence of *A. podolobus*. The habitat suitability map produced using the FR model provides a powerful tool for development of conservation plans for the degraded habitats of the species. The analytical framework used in this study could be applied to other arid and semi-arid environments to determine habitat suitability of *A. podolobus* and stabilize this species, and to introduce new adaptive rules for rangeland management.

Cite this article: Mojgansadat Azimi, Vahideh Riyazinia, Mahdis Amiri & Giandiego Campetella. 2021. Habitat suitability modeling for *Astragalus podolobus* (Boiss. & Hohen) using frequency ratio. *Environmental Resources Research,* 9 (2), 277-290. DOI: 10.22069/IJERR.2021.19242.1344

 DOI: 10.22069/IJERR.2021.19573.1357
Publisher: Gorgan University of Agricultural Sciences and Natural Resources

Introduction

Rangeland degradation, land-use change, improper utilization and an ever-increasing human population are some of the important factors contributing to species losses and extinction around the world (Barnosky et al., 2011). About one-fifth of the plant species are at risk of extinction (Brummitt and Bachman, 2008). As mentioned by Endangered Species Coalition (2020) "Healthy ecosystems depend on plant and animal species as their foundations. When a species becomes endangered, it is a sign that the ecosystem is slowly falling apart".

With an area of 1,648,195 km^2, Iran has a variety of geographic and climatic conditions, which contribute to its ecological diversity (Azimi et al., 2013). Due to its wide climate variations and plentiful plant genetic resources, rangelands of the country have special place in her natural resources. They make an essential contribution to the country's economy and play important roles in environmental protection and food security. The genus *Astragalus* is quite well represented in Iran with 804 species, 65% of which are endemic to Iran (Masoumi, 2005) and are recognized to be endangered according to International Union for Conservation of Nature and Natural Resources (IUCN) (Jalili and Jamzad, 1999). Golestan Province, located in the north-eastern Iran, enjoys various regions in terms of climate, soil, and distinctive vegetation diversity. More than 76 species of *Astragalus* have been identified in Golestan Province, of them 16 are forage species, growing in winter (low land), and summer (alpine) rangelands. These species are intensively grazed in all areas of north-eastern Iran (Hosseini et al., 2010).

Astragalus spp is a perennial species belonging to order *Rosales*, family Fabaceae, and genus *Astragalus*. It has a broad ecological range, growing in arid and semi-arid areas of Iran and plays an important role as a nurse plant in rangeland (Feizi, 2005 and Masoumi, 2005). Today, due to the high rate of rangeland degradation, the study of habitat suitability for a variety of valuable plant species is recognized to be highly necessary (Zare Chahouki and Piry Sahragard, 2016). Therefore, habitat suitability mapping has been found very useful in improving and propagating rangeland plants and filling the gaps in livestock feed shortage (Hosseini et al., 2010). Most of the scientific research has focused on the quality of *Astragalus* forage, and relatively few studies are found dealing with evaluation of the characteristics of suitable habitat conditions. A variety of statistical and probabilistic models are currently used to determine the spatial distribution of plant species (Qin et al., 2017 and Yost, 2008). Among different models, the frequency ratio (FR) algorithm was applied to predict habitat suitability of plant species based on presence-only data (Mousazadeh et al., 2019). Some researchers affirmed usefulness of the FR model for modeling of potential distribution of landslide and ground water mapping (Jafari et al., 2014; Manap et al., 2014). In general, this model can be a reasonable estimator of plant habitat, too (Mousazadeh et al., 2019). The lack of enough presence-absence information on species is often a problem, so using models that can circumvent this shortage and use presence only data is helpful. In fact, determination of plant distribution and their habitats with predictive models can provide a useful tool for protection and management purposes (Khalasi et al., 2011). The type of information used is one of the most important issues considered in modeling habitat for plant species (Zare Chahouki et al., 2016). In these models, the species presence is usually considered as the response variable and environmental characters are considered as predictive variables to determine the probability of species occurrence in other places. The variables with the highest weights are the most critical ones about the species distribution pattern.

In this study, we focused on *A. podolobus*, a perennial half-shrub growing from 20 to 40 cm in height. This species is the most valuable thornless plant observed in rangelands of the study area. It is a highly palatable feed used by sheep and goats (Hosseini et al., 2010). No previous quantitative studies have been conducted to address the ecological factors of *A. podolobus*. Thus, predicting this plant's habitat suitability is necessary to enable identifying the likelihood of its presence and spatial geographic distribution for its conservation. Literature review suggests that a few studies have applied the frequency ratio model for determining plant habitats. Mousazadeh et al., (2019) modeled habitat suitability of *A. fasciculifolius* in Fars Province, Iran and found that the frequency ratio was a good approach in this connection. Feizi (2005) found that climatic and topographic factors were superior to other environmental factors in locating the potential habitat of *A. podolobus* by conducting AHP model.

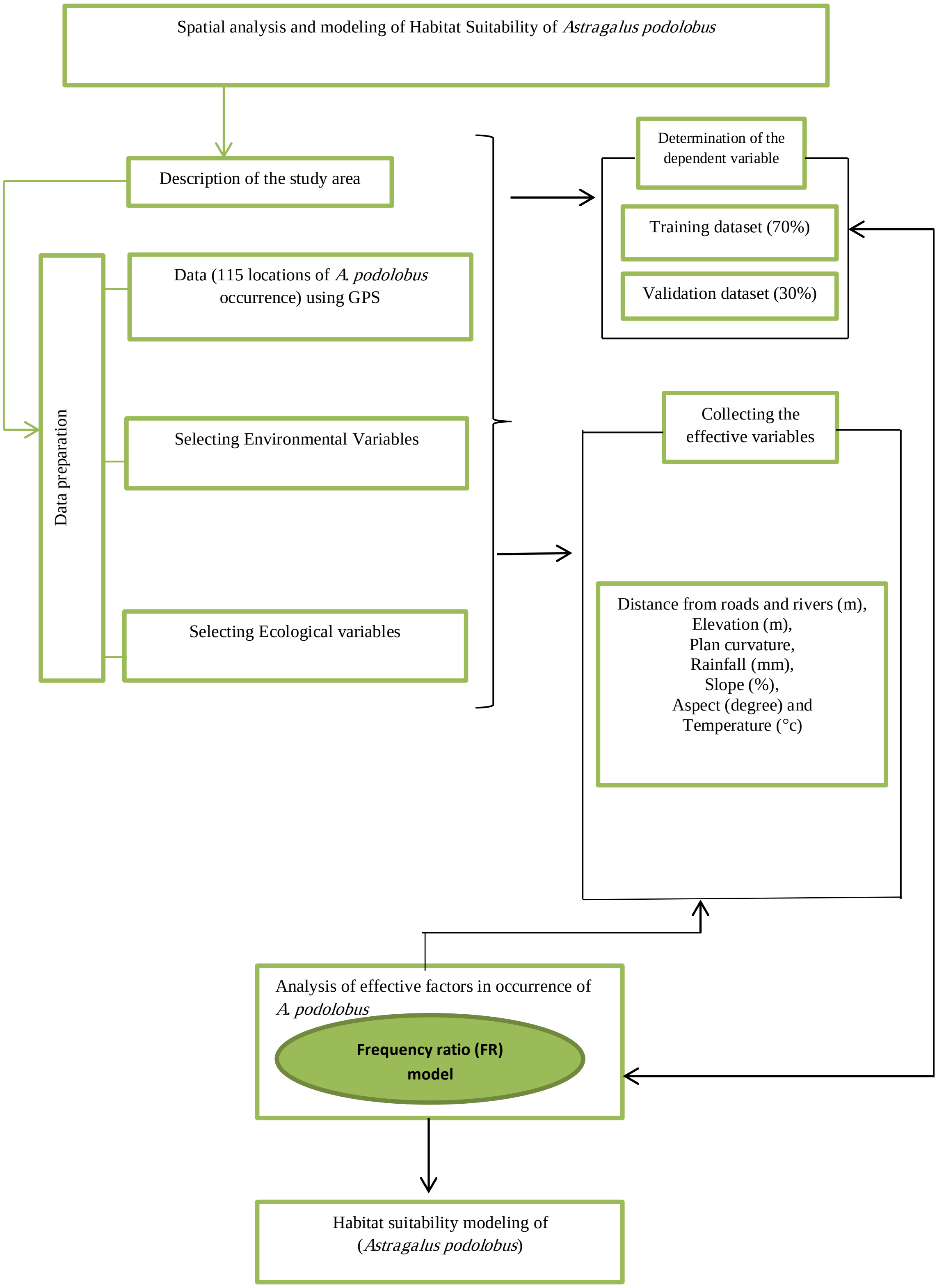


Figure 1. The flowchart of the study

This study mainly focused on the following objectives: (i) to assess the usefulness of FR method for predicting geographical distribution of *A. podolobus*; (ii) to predict the habitat distribution of *A. podolobus* and (iii) to determine the key ecological factors contributing to the distribution of *A. podolobus*.

Materials and Methods

The methodological flowchart of this study is shown in Figure 1, where the processes including environmental factors preparation, running the model and its validation are illustrated.

Description of the study area

The study area covers a landscape of 187 km^2 in Gharedam Chahargol, Maraveh Tapeh; north of Golestan Province, between 55° 53′ 24″ to 55° 53′ 48 eastern longitudes and 37° 57′ 26″ to 37° 59′ 53 northern latitudes (Figure 2) with the minimum and maximum elevation of 200 and 1200 meters above sea level, respectively. The average annual precipitation ranges from 260 to 316 mm/year. The average annual temperature ranges from 14.7 to 16.1° C and the climate of the region is arid to semi-arid (De Martonne, 1926). Table (1) shows the characteristics of the study area.

Table 1. Some characteristics of the study area.

Location	Other species in the rangeland	Elevation (m)	Soil texture(%)	PH	EC (Ms/cm)	Mean annual Precipitation (mm)
Gharedam Chahargol	*Poa bulbosa* *Medicago sativa* *Artemisia sieberi* *Paliurus spina*	204.5	Loam silty	8.4	2.3	355.3

Field data collection

A total of 115 occurrences of *A. podolobus* were recorded using GPS (Global Positioning System) (Garmin Map 62s) from April to September of 2018 and 2019. Geographic Information System (GIS) was then used to generate environmental variables in the study area. Based on literature review (Feizi, 2005; Zare Chahouki et al., 2016; Mousazadeh et al., 2019), eight variables including distance from roads and rivers, elevation, plan curvature, precipitation, slope percentage, aspect, and temperature were assessed and used as environmental co-variates (Figure 3). Results of the correlation between the independent variables indicated no significant correlation among the selected variables. Using the FR model, the factors affecting the habitat suitability of different individuals of *A. podolobus* were weighted and finally, the habitat suitability map was generated.

Weather data

Weather data (daily precipitation, minimum and maximum temperatures, daily solar radiation) of four synoptic stations (1977–2018) were obtained from Iranian Meteorological Organization (IRIIMO). The uniform spatial distribution of climatic parameters is important in assessing the presence and absence of vegetation in an area (Mousazadeh et al., 2019). The maps of mean annual precipitation and temperature were extracted using Inverse Distance Weighted (IDW) Interpolation approach in Arc. GIS 10.6.1 software (Figure 3A and 3B).

Topographic and Land use data

Topographic data was derived from NASA's Shuttle Radar Topography Mission (SRTM) series (USGS, 2020) and land use/land cover maps from NRWMO (Natural Resources and Watershed Management Organization of Golestan Province). The geographic projection of these layers were in UTM. We used SRTM data to generate aspect, slope, and plan curvature layers.

We also used topographic map of the area from the NRWMO with a spatial resolution of 50 m for extraction of roads and rivers. Using this data, we generated Euclidean distance from the roads and rivers (Figure 3D) and rivers (Figure 3I). The elevation layer was categorized into 8 classes as seen in Figure 3C. The slope map was classified into 8 classes (Figure 3F).

The aspect and plan curvature maps were categorized into 9 (Figure 3H) and 3 (Figure 2J) classes, respectively. In order to classify the layers, the natural break method was used.

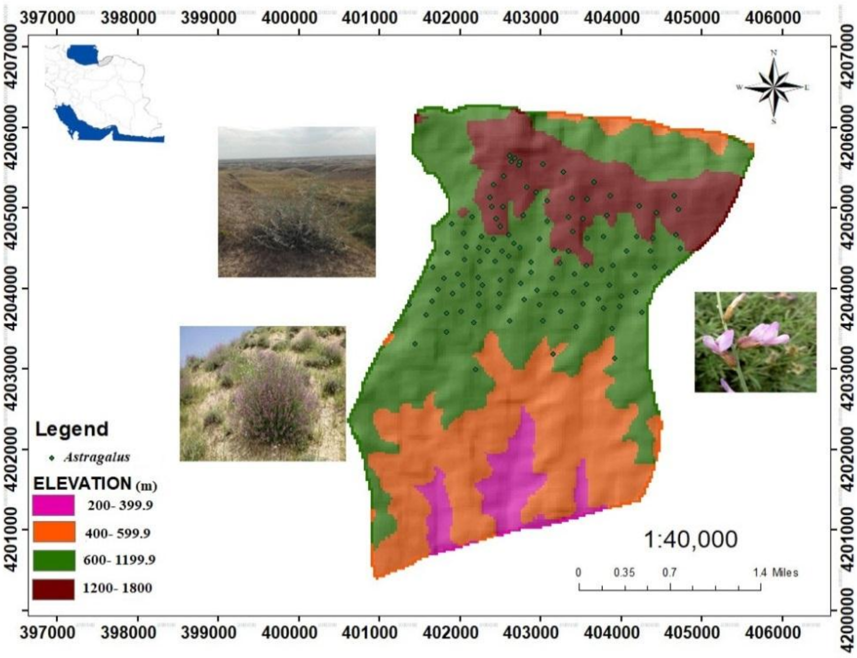


Figure 2. Study area: The Gharedam Chahargol, Golestan Province, Iran.

Model Description

Frequency ratio model is a two-variable statistical model, the values of which are treated in Excel software and a map is made in GIS software. In general, two-variable statistical models are manual models and the users have a direct role in the process. Moreover, the FR model is based on the supposition that a bigger ratio means a stronger relationship between spatial presence of the species and the given geo-environmental variables (Regmi et al.; 2014; Pham et al.; 2015; Mousazadeh et al.; 2019). The frequency ratio is a bivariate statistical model in which the frequency ratio of each variable is taken into consideration (Pham et al.; 2015). This approach is based on the relationship between species spatial distribution and all geo-environmental factors contributing to the species occurrence (Pham et al.; 2015). This model can be expressed by the following FR equation (Pham et al.; 2015, Mousazadeh et al.; 2019). The frequency ratio model is an observation-based approach to mapping habitat suitability (Regmi et al.; 2014). The weight of each of the relevant criteria and classes is calculated from the following equation 1.

$$1)\qquad \boldsymbol{FR} = \frac{\frac{\boldsymbol{Npix(Sa_i)}}{\boldsymbol{\sum_{=1}^{n} Sa_i}}}{\frac{\boldsymbol{Npix(a_j)}}{\boldsymbol{\sum_{=1}^{n} Npix(a_j)}}}$$

Where FR is the frequency ratio, $\frac{Npix(Sa_i)}{\sum_{=1}^{n} Sa_i}$ is the number of pixels where a species is present in the class "i" of the environmental factor a, and $\frac{Npix(a_j)}{\sum_{=1}^{n} Npix(a_j)}$ is the number of pixels of the environmental variables and 'n' is the number of environmental variables affecting the habitat of the target species. A FR value of 1 indicates an area in which the target species is present while a FR value less than 1 shows a lower likelihood of species presence. Therefore, a higher ratio indicates that there is a stronger relationship between the species and the given variables, while a lower value means a lower likelihood of the species occurring within the given variables class attribute (Regmi et al.; 2014; Pham et al.; 2015).

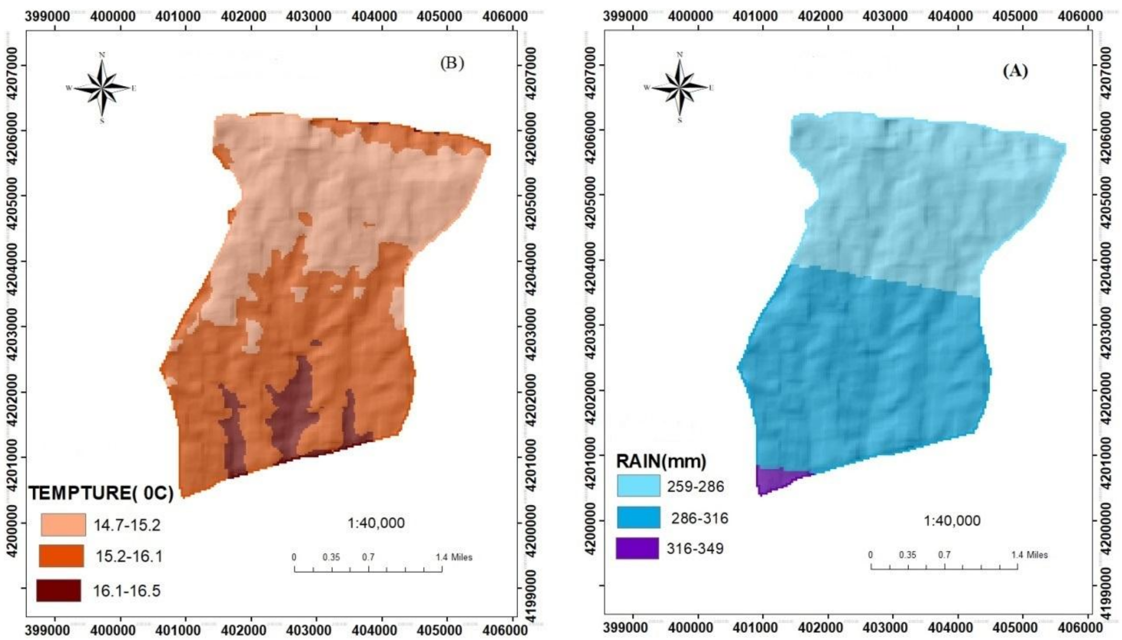
In the present study, the variables mentioned above were used as independent variables to prepare the distribution map for the studied species. For weighting variables, first, the maps were classified based on reliable sources. Then, in order to determine the percentage of each category of variables, we extracted the number of pixels and entered them into Excel. Finally, we obtained the frequency of the species occurrence using the "Extract Value to Point" and using the formula calculations mentioned in the model explanation section.

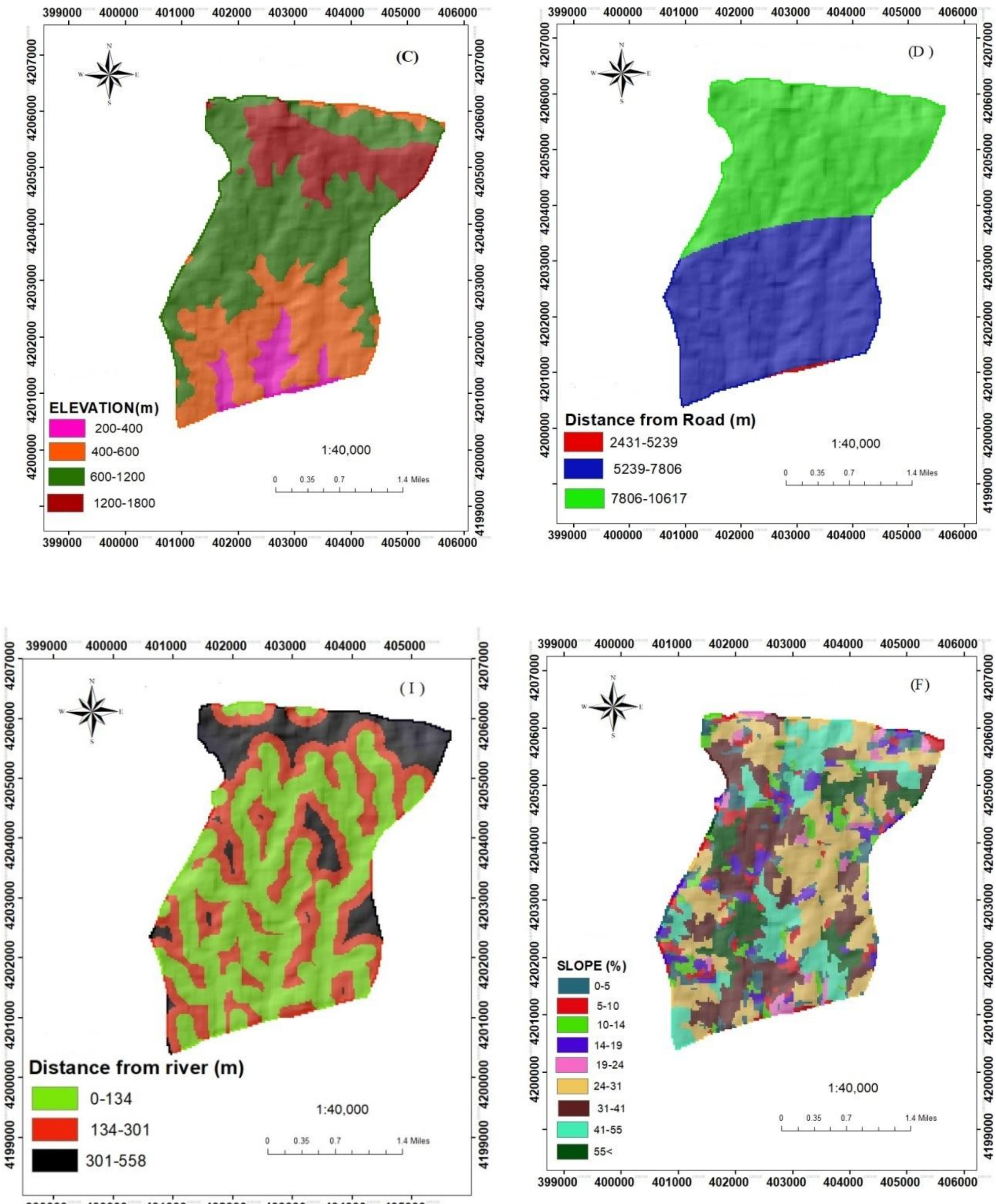
Model validation

In order to evaluate the developed frequency ratio model, 30% of the randomly selected presence points that had been set aside for evaluation were used (Amiri & Pourghasemi, 2020). The FR model was thus validated through the threshold-independent area under the curve (AUC) of receiver operating characteristics (ROC). This approach is one of the most widely used statistics for model evaluation (Kurpis et al., 2019). The AUC value ranges from 0.5 to 1.0, where value <0.5 describes no fit to the data; in contrast, 1.0 value indicates a perfect model performance, and a value of > 0.9 implies a very high performance. In general, the higher AUC value shows the higher performance of the model (Mousazadeh et al., 2019).

Results

According to the results of frequency ratio modeling and the effect of environmental factors on the habitat suitability of *A. podolobus* (Table 2), the highest recorded presence for the studied species was in the slope class 14-19% with a frequency ratio of 1.65, and the lowest occurred in the slope class of more than 31% with a frequency ratio of 0. For variable aspect, the highest and lowest FR values (0.37 and 1.36) were found in the 90°east and 45°northwest in the region, respectively. As shown in Figure 4, based on the obtained FR value, climatic factors such as rainfall and temperature and the distance from the roads have the highest FR value, which indicates the greater impact of these factors than other environmental factors on the presence of this species.




(C)
ELEVATION(m)
200-400
400-600
600-1200
1200-1800
1:40,000
(D)
Distance from Road (m)
2431-5239
5239-7806
7806-10617
1:40,000
(I)
Distance from river (m)
0-134
134-301
301-558
1:40,000
(F)
SLOPE (%)
0-5
5-10
10-14
14-19
19-24
24-31
31-41
41-55
55<
1:40,000

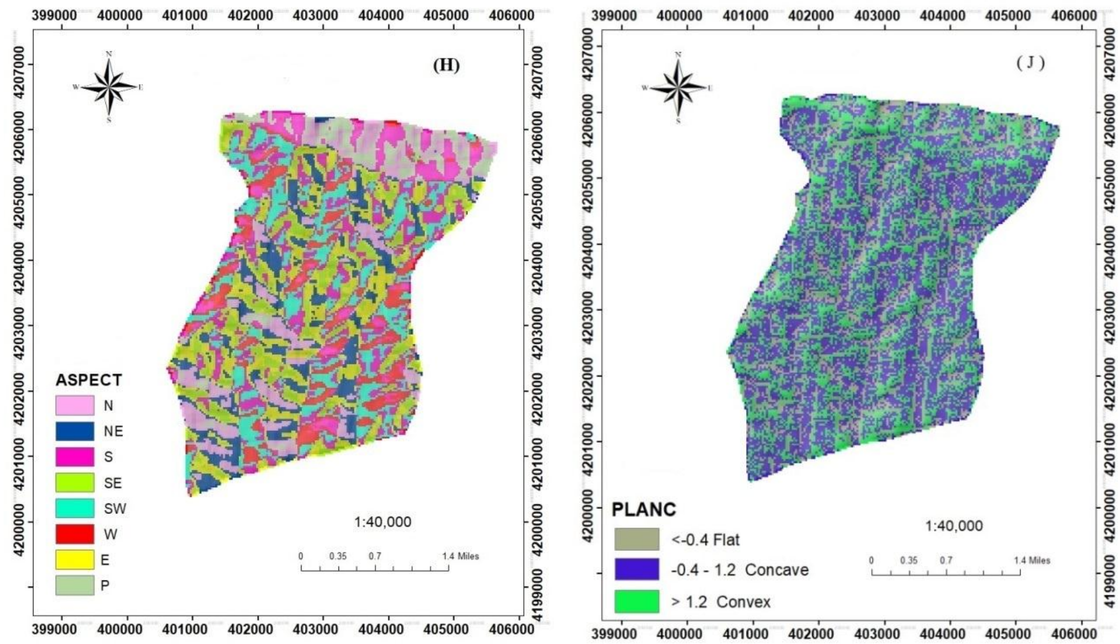


Figure 3. Thematic maps of the study area: (A) Precipitation; (B) Temperature; (C) Elevation; (D) distance from roads; (F) slope percent; (H) Aspect; (I) distance from rivers; (J) Plan curvature;

As for the effect of elevation the highest FR (2.98) was recorded in the class ≥ 1200 m and the lowest (0) was in the class ≤600 m. Considering the distance from the rivers, the highest species presence and FR (1.22) was recorded for the class 134–301m, while the lowest FR (0) was found in the class > 558 m. For rainfall, the class 259–286 mm with FR (3.44) had a higher value than the rainfall class > 316 mm. For temperature the highest FR (3.46) was in the class 14.7–15.2 ° C and the lowest (0) in the class ≥ 16 ° C. The effect of distance from the roads indicated the highest FR (3.41) was in the class > 7806m and the lowest (0) in the class≤5239 m. For the surface curvature, the highest value was recorded for the class > 1.18 and a morphological convexity of 1.2, and the lowest value was seen for the concavity class 0.85. Also, a higher FR (2.49) was found for the Kat class in the lithology map compared to other class (Table 2). Eventually, among the environmental factors affecting the habitat suitability of *A. podolobus* based on the FR and weighting the effective variables, the priority of the effective variables was determined to be as follows: temperature, precipitation, distance from roads, elevation, slope, aspect, distance from rivers and surface curvature respectively. The results of the spatial effects between the presence of A. *podolobus* and the environmental variables using the frequency ratio model is presented in Table 2.

Figure 5 shows the habitat map of *A. podolobus*. In the present study, habitat suitability was classified in four classes, low, moderate, high, and very high. Based on the integration of the digital layer of the presence points of the species and by examining its habitat suitability map, it can be seen that the highest density of points in the study area is concentrated in the high and very high range.

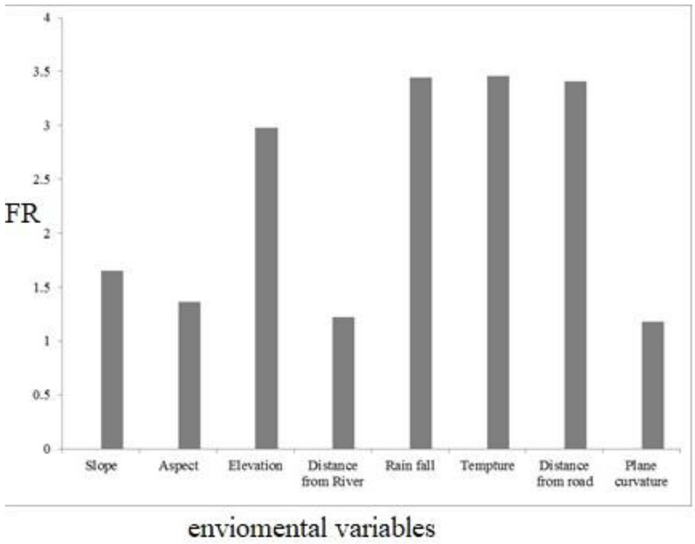


Figure 4. Frequency ratio of the environmental variables affecting habitat of *Astragalus podolobus*

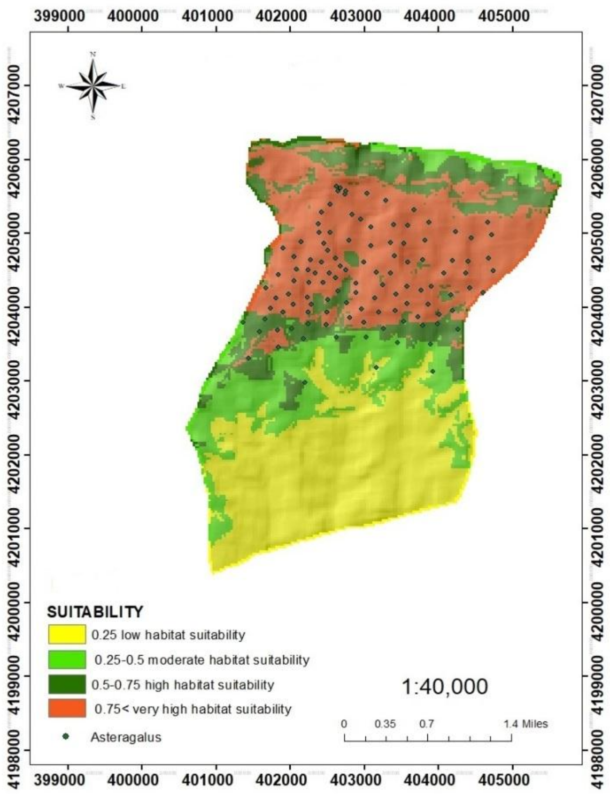


Figure 5. Habitat suitability map of *Astragalus podolobus*

As mentioned earlier, we used 80 points (70%) for frequency modeling and 35 points (30%) for model assessment and validation using receiver operating characteristics (ROC) and area under the curve (AUC). Table (3) shows a ROC with an AUC of 0.783 for the accuracy of the developed FR model for the habitat of *A. podolobus*.

Table 2. The spatial effects environmental factors on the presence of *A. podolobus* using the FR model

Data layers	Class	Pixels	%Class Pixel	Plant-based pixels	%Plant-based pixels	FR
slope (degrees)	0–5	6624	16.73	8	9.87	0.58
	5–10	9745	24.62	15	18.51	0.75
	10–14	8979	22.69	21	25.92	1.14
	14–19	6781	17.13	23	28.39	1.65
	19–24	3986	10.07	12	16.04	1.59
	24–31	1982	5.00	1	1.23	0.24
	31–41	1072	2.70	0	0	0
	41–55	342	0.86	0	0	0
	55<	59	0.14	0	0	0
		39570	100	80	100	
Aspect	P	2975	6.60	2	2.5	0.37
	N	4037	8.96	5	6.25	0.69
	NE	5575	12.38	11	13.75	1.11
	E	6179	13.72	15	18.75	1.36
	SE	7298	16.20	13	16.25	1.00
	S	5698	12.65	12	15	1.18
	SW	6042	13.41	13	16.25	1.21
	W	4199	9.32	8	10	1.07
	NW	3023	6.71	1	1.25	0.18
		45026	100	80	100	
Elevation (m)	0–100	11	0.02	0	0	0
	100–200	2888	7.29	0	0	0
	200–400	15106	38.17	0	0	0
	400–600	7986	20.17	0	0	0
	600–1200	10101	25.52	59	73.75	2.88
	1200–1800	3482	8.79	21	26.25	2.98
		39574	100	80	100	

Table 2. Continued**.**

Data layers	Class	Pixels	%Class Pixel	Plant-based pixels	%Plant-based pixels	FR
Distance from River(m)	0–134	19478	49.23	42	52.5	1.06
	134–301	13688	34.59	34	42.5	1.23
	301–558	6397	16.16	4	5	0.31
	558–1066	1	0.002	0	0	0
		39564	100	80	100	
Rain fall(mm)	259–286	9909	25.02	69	86.25	3.44
	286-316	11972	30.23	11	13.75	0.45
	316-349	9036	22.82	0	0	0
	349-385	8674	21.90	0	0	0
		39591	100	80	100	
Temperature(c)	14.7-15.2	8856	22.36	62	77.5	3.46
	15.2-16.1	13162	33.24	18	22.5	0.67
	16.1-16.5	7755	19.58	0	0	0
	16.5-17.1	9818	24.79	0	0	0
		39591	100	80	100	
Distance from road(m)	0-2431	10226	25.84	0	0	0
	2431-5239	8373	21.16	0	0	0
	5239-7806	10674	26.97	9	11.25	0.41
	7806-10617	10291	26.01	71	88.75	3.41
		39564	100	80	100	
Plan curvature(1/m)	<-0.4 Concave	6921	17.49	12	15	0.85
	_0.4-1.2 Flat	21426	54.14	41	51.25	0.94
	>1.2 Convex	11223	28.36	27	33.75	1.18
		39570	100	80	100	

Table 3. The area under curve (ROC) showing accuracy of the FR Model

Area Under the Curve				
Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
0.783	.052	.334	.680	.885

a. Under the nonparametric assumption

b. Null hypothesis: true area = 0.5

Discussion

Understanding habitat suitability of plants is a fundamental step in their conservation and regeneration (Yost, 2008; Qin et al., 2017 and Mousazadeh et al.; 2019). *A. podolobus* has high palatability for grazing and a protective role in reducing soil erosion process in Iran rangelands. The result of this study showed that temperature, rainfall and distance from the roads had high effects on the presence of this plant. It means that rainfall and temperature change can have high effects on the habitant of *A.podolobus*. Decreasing precipitation or increasing temperature can adversely affect plant activities. Dry climates can influence photosynthetic process either through pathway adjustment by stomata shut and subtractive flow of CO_2 into leaves (Flexas et al., 2004), or by physiological responses of plant to stresses, such as high radiance and low vapor pressure fraction causing smaller values of maximum stomata conductance to control photosynthesis for the decreased evapotranspiration (Azimi et al., 2013). The effect of climatic parameters had been noticed in different studies (Ainsworth and Rogers, 2007; Bloor et al., 2010; Azimi et al., 2013; Li et al., 2019). Vittoz et al. (2009) reported that plant communities can respond to warming quickly as long as colonization is simplified by available space or structural change. According to Meier et al. (2012), plants change their spatial habitat configuration based on climatic conditions, and re-adjustments of species ranges to climate changes. Climate change affects plant species indirectly by decreasing the accessibility of habitats (Morris, 2010). Next to the climate parameters, the distance from roads was found to be the most important parameter on the occurrence of *A. podolobus*. The results we obtained were similar to some previous studies (Zeng et al., 2011, Li et al., 2014). Rural and nomadic roads are common in rangelands. Coffin (2007) showed that roads change the levels of available resources, such as water, sunlight, and nutrients, thus affecting the plant communities.

Another influential parameter controlling the presence of this plant is elevation. The significance of this parameter is also emphasized by Safaei et al. (2018) and Mousazadeh et al., (2019).

For a general overview; the environmental variables such as slope, aspect, distance from rivers and curvature had positive or negative impacts on the presence of the studied plant. Previous research (Mousazadeh et al., 2019; Safaei et al., 2018; Khalasi Ahwazi et al., 2015; Hosseini et al., 2013; Hosseini et al., 2010) also emphasized the effects of these parameters on habitat of legumes such as *Astragalus*. Habitat suitability modeling of the endangered plant (*A. podolobus)* can help identify the interactions of environmental and human variables on this plant's communities, and determine suitable locations for its expansion. The results of the model in this study could be applied to conserve and stabilize the species in natural habitats via introducing new adaptive rules in management, and improving and propagating thid plant in arid and semi-arid environments.

Conclusion

Habitat suitability mapping of the endangered plant (*A.podolobus*) was performed for the arid and semi-arid regions of Golestan Province, namely Maraveh Tapeh rangelands of Iran. The FR modeling method was used to identify the suitable habitat for the species and to determine the most important environmental factors affecting it. The FR modeling showed the importance of environmental variables in the growth of *A. Podolobus*. Our results indicated that the occurrence of the plant was highly correlated with environmental factors such as climatic parameters, distance from roads and elevation. The highest presence of this plant was recorded at temperatures ranging from 14.7 to 15.2 °C and at an elevation of over 1200 m, with an average rainfall of 277 mm. The species in question mainly prefers hilly habitats with an elevation ranging from 300 to 2700 m above sea level. The soil moisture and fertility conditions of the roadside soil reduced the likelihood of the species presence. Based on the model results, the highest presence for this plant is found in the third class of the distance from the roads. The consistency of the habitat suitability map with the filed data indicates the high efficiency of the FR model in the preparation of habitat suitability maps. The model performance evaluation and validation using ROC and and area under the curve (AUC) of 0.783 showed the high accuracy of the model. Since most of the arid and semi-arid rangelands in Iran are used as winter rangelands and *A. Podolobus* has a relatively large ecological range in these ecosystems, locating the suitable habitats to encourage the growth and distribution of this plant seems necessary to provide forage as well as soil and water conservation. Also, due to the natural and relatively good regeneration of this species, its cultivation is recommended to improve the rangelands' condition in arid and semi-arid areas of Iran.

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