HALOPHYTE SPECIES DISTRIBUTION MODELING WITH MAXENT MODEL IN THE SURROUNDING RANGELANDS OF MEIGHAN PLAYA, IRAN

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Abstract. The aim of this study is to examine halophyte species (six species) distribution modeling using the maximum entropy (MaxEnt) method in the surrounding rangelands of Meighan playa, central Iran. Sampling method was random-systematic. A total of 150 plots (30 plots of 2 to 25 m^2 in each type) were collected. In each plot, species density and canopy cover were recorded. Soil samples were collected at the start and end of each transect from a depth of 0–30 cm and 30–60 cm. Soil characteristics, including texture, available water, lime, organic matter, acidity (pH), electrical conductivity (EC) and soluble solute (Na+, Ca2+, Mg2+, K+, Co3−2 and Hco3−) were measured in the lab. Maps of environmental variables, including elevation, slope and aspect were prepared using geographic information system (GIS). Soil layer maps were prepared using geostatistical method, including semivariogram analysis and Kriging interpolation. After preparing maps of environmental variables, plant distribution and modeling was conducted using MaxEnt model. Before running the model, the area under the curve (AUC), receiver operating characteristics (ROC) function, equal sensitivity and specificity method, Jackknife test and kappa coefficient were done. Models were built for each species using 70% of the data; the remaining 30% was used to test the models. According to the results, species habitats prefer variables such as soil texture, potassium, lime and organic matter. Kappa coefficient was considered excellent for species habitats of *Halocnemum strobilaceum* M. Bieb., 1819.) (0.91) and *Aeluropus littoralis* (Gouan) Parl., 1850) (0.89), for *Salsola incanescens* C.A. Mey., 1833) (0.84) and *Halimione verrucifera* (M. Bieb) Aellen, 1938) (0.83) as very good, and good for the habitats of *Suaeda aegyptiaca* (Hasselq.) Zohary, 1957) and *Limonium iranicum* (Bornm.) Lincz., 1952) species (kappa for both=0.7). The results of this study could be used in convenient locations that have resuscitation potential habitat for this species.
Keywords: *plant ecology, habitat selection models, occurrence model, maximum entropy, presence-only data, Markazy province*

Introduction

Arid and semi-arid ecosystems are strongly influenced by factors constituting the ecosystem due to physical and environmental conditions (Botha et al., 2003; He et al., 2007; Flowers and Colmer, 2015). The severity of degradation on these ecosystems is more than other ecosystems due to exacerbation of acute environmental conditions such as increasing salinity, fall in the water level, severe reduction in runoff water and excessive utilization of the contained plant species on these regions (Botha et al., 2003; Vaezi et al., 2010). Thus, it is high priority that attention must be paid to conservation, revival and development of plant species in these areas (Vaezi et al., 2010). In

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conservation and management programs of the plants species, determining the status of species distribution and habitat occupied is important (Graham et al., 2004). For this purpose, species distribution models have been used increasingly in plant ecology (Elith et al., 2006; Zare Chahouki et al., 2012). Predicting species distribution has become an important component of conservation planning in recent years and a wide variety of modeling techniques have been developed for this purpose (Anderson et al., 2003; Elith et al., 2006). These models evaluate relations between existence of species and environmental conditions (Guisan et al., 2013). A variety of modeling techniques has been used in predicting vegetation modeling that attempts to predict occurrence of a given community or species in respect to environmental conditions (Anderson et al., 2003; Elith et al., 2006). These models differ in underlying algorithms and in their requirement for species presence-only data or both presence and true absence data (Anderson et al., 2003; Zimmermann et al., 2010). More information relating to species presence and absence data are rarely available. Even if the data is available, the values are associated with doubts (Anderson et al., 2003; Zimmermann et al., 2010). Therefore, modeling methods using the presence-only data are the proper tool to overcome this problem (Graham et al., 2004; Piry Sahragard and Zare Chahouki, 2015). The MaxEnt method does not require absence data for the species being modeled; instead, it uses background environmental data for the entire study area (Phillips et al., 2006). This method can utilize both continuous and categorical variables and the output is a continuous prediction; either a raw probability or, more commonly, a cumulative probability ranging from 0 to 100 indicates relative suitability (Pearson, 2008). MaxEnt applies the maximum entropy principle to describe the relative likelihood of each environmental predictor independently in a bid to define the features of sites in which the species occur compared to features of the environment as a whole (Phillips et al., 2006; Pirathiban et al., 2015), and treats the problem of species distribution modeling as conditional probability estimation (Elith et al., 2011). MaxEnt has been shown to perform well in comparison to alternative methods (Elith et al., 2006; Phillips et al., 2006; Piry Sahragard and Zare Chahouki, 2015). Moreover, when we do not have enough data for model training, one of the proposed solutions is MaxEnt method (Phillips et al., 2006). Studies show that even when samples are low, MaxEnt method can compete in terms of prediction performance with methods that have the highest accuracy and provide acceptable results (Phillips et al., 2006; Pearson, 2008). The most comprehensive set of model comparison to date was provided by Elith et al. (2006). They compared 16 modeling methods using 226 species across six regions in the world. Through comparison of these models, they concluded that MaxEnt was among the best-performing methods. Therefore, we used MaxEnt model in this study.

Meighan playa in central Iran (Markazy province), like other desert regions, is an arid ecosystem that been created due to the geomorphological condition. This playa is a sedimentary inland and closed basin. In this playa, water level is controlled by the amount of rainfall, evaporation and groundwater. Vegetation around this playa is mainly halophytes. This, in addition to forage production, maintains the relationship between water and soil. The microclimate of the region is stylized, in terms of ecology, and can demonstrate the ecosystem’s performance. Halophytes are flexible compared to other species in saline environments such as Meighan playa. The physiology of halophytes, with its focus on adaptations, enable these fascinating plants to live in challenging environments that the vast majority of species cannot inhabit (Flowers and Colmer, 2015). Therefore, it is necessary to increase understanding of the habitat of distributed

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species using an appropriate method in these desert ecosystems. Thus, the aim of this study was to model the distribution of halophyte species (six species) in the surrounding rangelands of Meighan playa using MaxEnt model, and highlight the important variables in presence and distribution of the selected species.

Materials and methods

The study area

The study area of 140 hectares, which is part of Meighan playa (34°09′–34°16′N and 49°45′–49°55′E), is located 15 km northeast of Arak county, Markazy province, Iran (*Fig. 1*). Altitudes range from 1,129 to 2,260 m a.s.l., and slopes range from 1 to 5%. Mean annual precipitation and temperature are 196.5 mm and 13.2°C, respectively. The land is arid with saline soils, generally composed of sand and silt. At the study area, dominant plant species are *Halocnemum strobilaceum, Suaeda aegyptiaca, Salsola incanescens, Aeluropus littoralis, Salsola incanescens, Halimione verrucifera* and *Limonium iranicum*, which were identified as five vegetation types (*Fig. 1*).

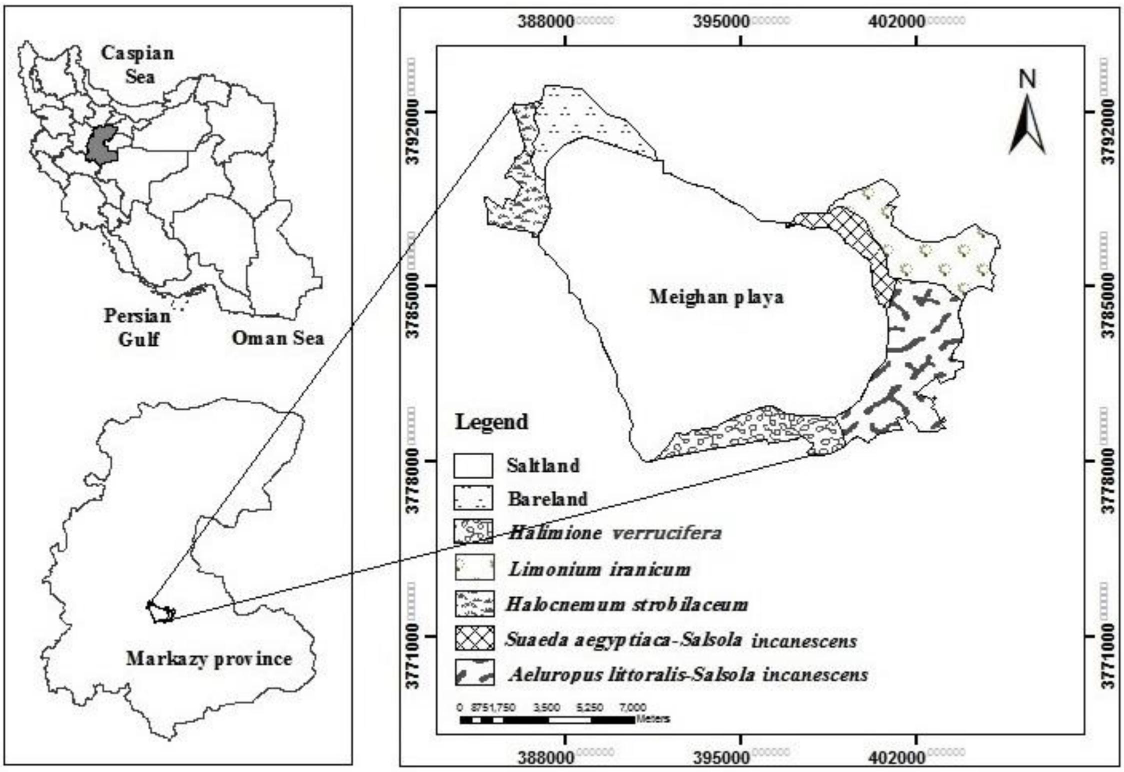

Figure 1. *Vegetation types and location of the study area in Markazy province and Iran*

Sampling of vegetation and soil, and mapping and preparing environmental predictor variables

Determining the spatial variability of plant species and soil properties need an adequate number of samples and the application of spatial analysis methods (Shen et al., 2005). Digital topographic maps of the study area at the scale of 1:25000 from the National Cartographic Center of Iran were used for creating a digital elevation model

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(DEM, pixel size 30m×30m). Elevation, slope and aspect layers were extracted from DEM. Homogeneous units or final vegetation type using DEM, aspect, slope, geology and existing vegetation type maps were determined. In the homogeneous units, vegetation samples were collected using random-systematic method via plots established along three transect with 1,000 m length in each type. Depending on the plant species, plot sizes were determined using minimal area method from 2 to 25 m^2. The sample size used was determined to be 30 plots with respect to vegetation cover variation using statistical method in each type (totally 150 plots on five vegetation types). Vegetation samples were collected from the key area of homogeneous units. Canopy cover percent and density of each species were recorded in each plot. Soil samples were taken from the start and end of each transect (six holes were drilled in each vegetation type and samples were taken from 0 to 30 and 30 to 60 cm depths). Since most of the root activities is within 0–30 cm depth, some activities were also within 30–60 cm, thus 0–30 cm and 30–60 cm depth ranges were selected as the first and second soil layers, respectively. The position of sampling points was recorded using Global Positioning System (GPS). Soil characteristics, including texture, available water, lime, organic matter, acidity (pH), electrical conductivity (EC) and soluble solute (Na^+, Ca^{2+}, Mg^{2+}, K^+, Co_3^{-2} and Hco_3^-) were measured by routine methods (*Table 1*). Soil property maps were produced using geostatistical methods, including semivariogram analysis and kriging interpolation in the same spatial resolution (pixel size 30m×30m). Thus soil digital layers were prepared and stored in GIS environment. ArcGIS10 and GS^+5 software were used for mapping different layers.

Table 1. *List of habitat variables in the dataset*

Variable	Code (0-30cm)	Unit	Mean ± standard deviation	Code (30-60cm)	Mean ± standard deviation
Elevation	Abs	m	1666± 5.25	-	-
Slope	Slope	%	4±1.90	-	-
Clay	Clay1	%	14.89± 6.77	Clay2	15.67± 8.16
Silt	Silt1	%	26.06± 15.29	Silt2	25.39±11.69
Sand	Sand1	%	59.06± 16.82	Sand2	58.94± 16.32
Available water	Aw1	%	60.31± 13.38	Aw2	56.49± 22.91
Organic matter	OM1	%	0.3± 0.05	OM2	0.2± 0.08
Lime	Lime1	%	18.93± 9.90	Lime2	21.94± 12.50
pH	pH1	-	8.14± 0.38	pH2	8.08± 0.33
EC_e	EC_e1	ds/m	4.17± 2.40	EC_e2	3.19± 1.36
Potassium ion (K^+)	K1	ppm	70.62± 23.23	K2	8.026± 39.94
Sodium ion (Na^+)	Na1	ppm	4.93± 1.30	Na2	4.84± 1.30
Magnesium (Mg^{2+})	Mg1	ppm	37.14± 20.77	Mg2	34.5± 14.31
Calcium ion ($Ca^{2+)}$	Ca1	ppm	19.11± 10.57	Ca2	19.92±8.30
Bicarbonate (HCO_3^-)	$(HCO_3^-)1$	ppm	11.67±3.90	$(HCO_3^-)2$	11.32±3.30

Correlation of environmental variables was analyzed using principal component analysis (PCA) in the IDRISI Selva17 software. From the pair, variables that had a correlation above 0.8, one of them was removed. Accordingly, among the 28 primary environment variables, 20 were used in the modeling process. Based on the results of the PCA, the elevation, calcium, clay, EC, potassium, bicarbonate, sodium, magnesium and silt of both depths, and OM, pH and sand of the first depth were selected as input for the MaxEnt model. Aspect map was eliminated owing to lack of variation.

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Model development and accuracy evaluation

Predicting modeling of potential distribution of halophyte species was based on the maximum entropy (MaxEnt) technique, after preparing the environmental variable maps in raster format with the same cell size, extent and coordinate system, using the MaxEnt 3.3.3 software. The area under the curve (AUC) of receiver and operating characteristic (ROC) function were used for the evaluation of discrimination ability (Sweet, 1988; 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. Probability of species presence was estimated ranging from 0 to 1, in which 0 and 1 stand for the lowest and highest probability rates, respectively. Owing to continuous output of MaxEnt, it is necessary to determine an optimal threshold for determining the presence or absence of the species (Monserud and Leemans, 1992; Phillips et al., 2006; Negga, 2007). After determining the optimal threshold using equal sensitivity and specificity method, species presence or absence maps were generated and their coincidence with the actual maps investigated by calculating kappa coefficient in the IDRISI Selva Ver17 software. Models were built for each species, using 70% of the data, the remaining 30% being used to test the models.

Results

According to the prediction maps (*Figure 2*), which were obtained from the six halophyte species, distribution modeling in the rangelands around Meighan playa are consistent and have a good to excellent agreement (kappa coefficient > 0.70 / *Table 2*) with their actual ground map. Despite *Halocnemum strobilaceum, Aeluropus littoralis* and *Halimione verrucifera* species being predicted in the distribution map, there are more habitats than what was shown in the actual ground map. Also, *Halocnemum strobilaceum* distribution is limited to only the northeastern parts and *Halimione verrucifera* distribution is limited only to the southern parts of the actual ground maps. Threshold values (*Table 2*) show that the lowest is related to *Limonium iranicum* and *Suaeda aegyptiaca*. Evaluation of the correspondence between the actual and predictive maps using kappa coefficient reveals that MaxEnt model is predicted in *Halocnemum strobilaceum* and *Aeluropus littoralis* habitats at an excellent level. *Halimione verrucifera* and *Salsola incanescens* habitats have a very good agreement and the habitats of *Limonium iranicum* and *Suaeda aegyptiaca* have a good agreement with the ground truth maps.

Table 2. *Optimum probability threshold for all models based on test data and levels of matching prediction maps with actual map on each type*

Habitat/ Vegetation type	Selection method of threshold	Optimum threshold	Kappa coefficient	Levels of matching
Halocnemum strobilaceum	Equal test sensitivity and specificity	0.35	0.91	Excellent
Suaeda aegyptiaca	Equal training sensitivity and specificity	0. 33	0.70	Good
Aeluropus littoralis	Equal test sensitivity and specificity	0.39	0.89	Excellent
Limonium iranicum	Maximum training sensitivity plus specificity	0.31	0.70	Good

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Halimione verrucifera	Maximum test sensitivity plus specificity	0.43	0.84	Very good
Salsola incanescens	Maximum training sensitivity plus specificity	0.40	0.82	Very good

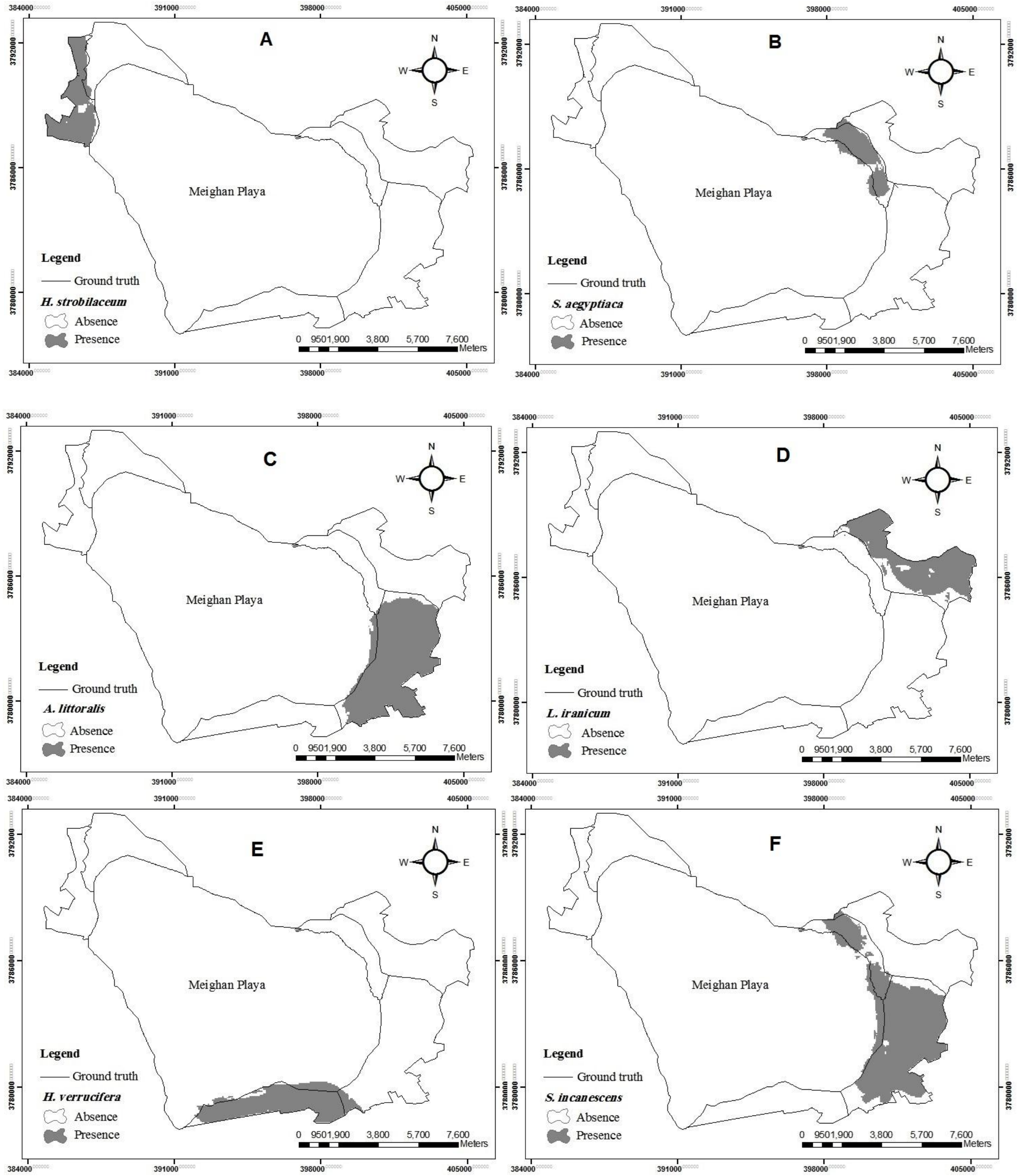

***Figure 2.** Actual and predicted species distribution maps for **A:** Halocnemum strobilaceum, **B**: Suaeda aegyptiaca, **C**: Aeluropus littoralis, **D**: Limonium iranicum, **E**: Halimione verrucifera and **F:** Salsola incanescens (predictive maps is shown darker)*

Based on the Jackknife test results (*Table 3*), Clay1, Clay2, Lime1 and Lime2 are the most important variables when they were used separately on the probability of presence of

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*Halocnemum strobilaceum.*These variables have a greater effect compared to other environmental variables.

Moreover, Jackknife test results indicate that habitat distribution of *Suaeda aegyptiaca* is meaningfully influenced by K2, Sand1 followed by OM1, Lime2 and Silt2. The most important environmental variables of other species are also the same in *Table 3*.

Table 3. *Jackknife test results to determine the importance of environmental variables*

Habitat/ Vegetation type	Importance of environmental variables
Halocnemum strobilaceum	Clay1*, Clay2, Lime1, Lime2.
Suaeda aegyptiaca	K2, Sand1, OM1, Silt2.
Aeluropus littoralis	Abs, OM1, K2, Sand1.
Limonium iranicum	Abs, Lime2, Lime1, Clay2.
Halimione verrucifera	Ec2, K1, Silt2, pH1.
Salsola incanescens	OM1, Abs, Sand1, Ca1.

1 is the first soil depth (0-30 cm) and 2 is the second soil depth (30-60 cm)

Evaluation of the obtained predictive models showed that considering the AUC values, accuracy of predictive models for each habitat has been shown (*Table 4*). These results indicate good predictive model accuracy for all species habitats. Moreover, this shows that environmental variables used in the final models have the capability to predict potential distribution of the studied species.

Most important response curves of the species to environmental variables are presented in *Figure 3*. These response curves show how each environmental variable affects MaxEnt predictions. Shadows around response curves are showing confidence intervals for the possibility of species presence. The narrow confidence interval represents high power. Thus, it can be decided based on places that have narrower confidence interval. *Halocnemum strobilaceum* have strong relationship with the increase in Clay1 to 55%. Moreover, presence of this species has positively correlated with Lime1 and Lime2 to 5 to 10%, while it dramatically decreased at higher values showing that *Halocnemum strobilaceum* has a strong relationship with low-lime soils. Furthermore, habitat suitability of this species is correlated with low-sand (20–25%) texture in soil surface. The results show the soil texture's importance in the habitat desired for this species. The possibility of the presence of *Aeluropus littoralis* has increased with the increase in Abs and OC1, and in contrast, it has reduced by increasing K2, while the possibility of presence of *Suaeda aegyptiaca* is positively correlated with high amounts of K2 (60–180 ppm). Habitat suitably of *Suaeda aegyptiaca* has increased with gradual increase in OC1 (0.15–0.45%), and has reduced with the increase of Lime1. Analysis of response curves suggests that habitat suitability of *Halimione verrucifera* has a strong relationship with the increase of Sand1 to 40%. The optimum range of Clay1 for this species distribution is 15%. Increasing Clay1 has negative impact on the presence of this species. In addition, *Halimione verrucifera* has given negative response to lime percent (10–55%) and confidence domain of the curve is thinner in Lime1 at 30%. For *Salsola incanescens* habitats, the most important of the response curves is related to OC1. This species also has high habitat suitability in areas with Clay1 at more than 15 to 25%, and EC1 optimum range for this species-suitability habitat is 2 to 10 ds/m. *Figure 3* shows that increase of elevation to 1,680 m leads to

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increase in presence probability of *Limonium iranicum*. This figure also shows that *Limonium iranicum* grows in areas with high Sand1 (25–70%), while soil Clay1 percent has a negative effect in the suitable preference of this species, and the optimum Clay1 value for suitability in the habitat for this species is lower than 15%.

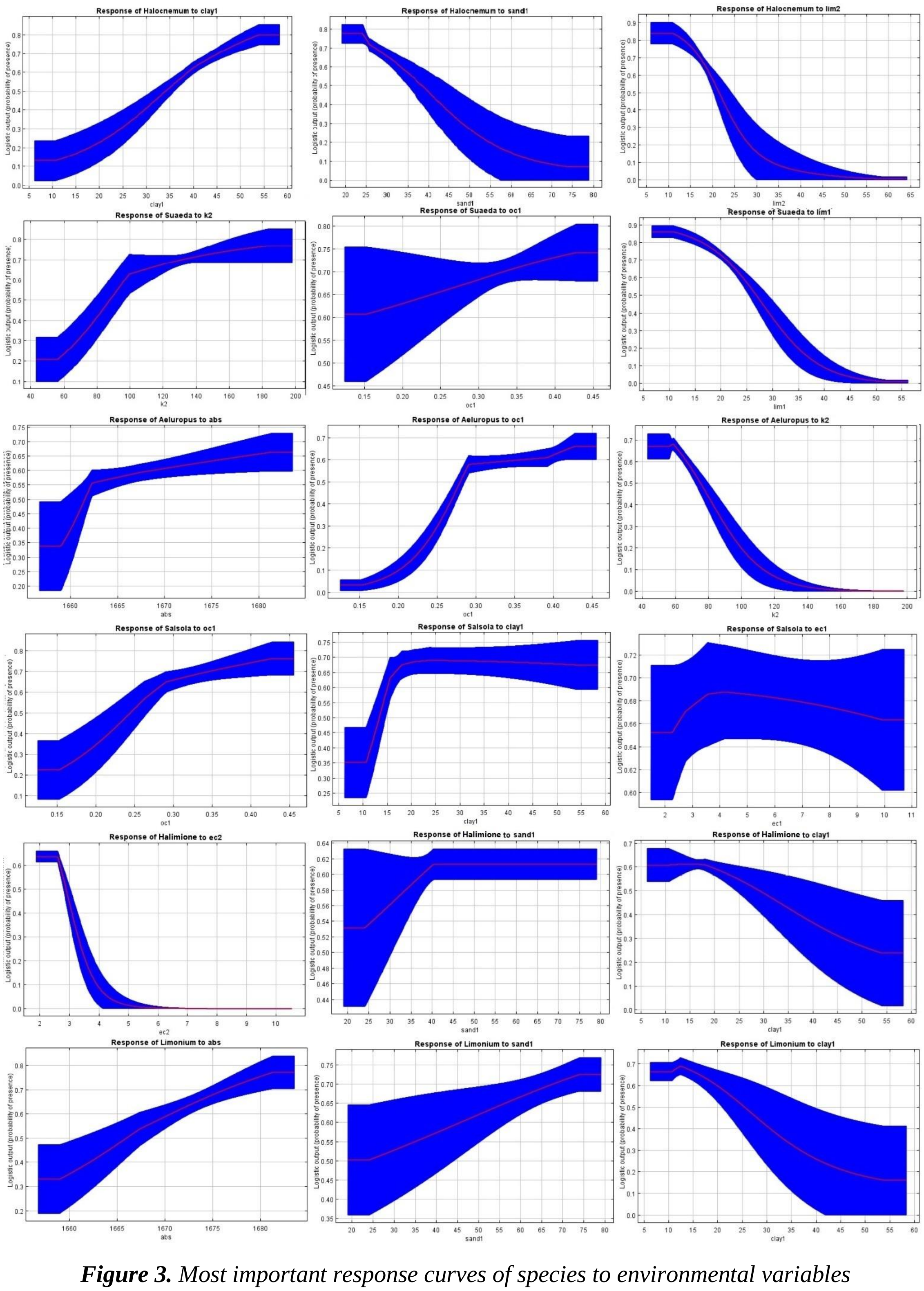

Figure 3. *Most important response curves of species to environmental variables*

Table 4. *AUC values and classification accuracy of predictive studied habitats models*

Habitat / Vegetation type	AUC	Classification accuracy
Halocnemum strobilaceum	0.95	Good
Suaeda aegyptiaca	0.91	Good
Aeluropus littoralis	0.94	Good
Limonium iranicum	0.92	Good
Halimione verrucifera	0.92	Good
Salsola incanescens	0.90	Good

Discussion and conclusion

Based on the results, assessment of agreement and disagreement of prediction models with actual maps showed that *H. strobilaceum* and *A. littoralis* have an excellent agreement, *H. verrucifera* and *S. incanescens* very good agreement and *S. aegyptiaca* and *L. iranicum* good agreement. Thus, results show good performance of species distribution model used in this study for six halophyte species distribution models. Some references reported that the kappa amount of more than 0.75 represents an excellent model (Landis and Koch, 1997), which by considering the amount of kappa for the studied species, except for *S. aegyptiaca* and *L. iranicum* and four other halphyte species, was more than 0.75. Thus, model performance was excellent. Moreover, AUC values were obtained for all species as higher than 0.9, which, considering the accuracy of predictive models based on the values for AUC, was at a good level. In fact, AUC can be interpreted as the probability that a model will correctly distinguish between a presence record and an absence record if each record is selected randomly from the set of presence and absence (Fielding and Bell, 1997; Pearce and Ferrier, 2000). Previous studies such as Piry Sahragard and Zare Chahouki (2015) reported that MaxEnt model, compared to the Logistic Regression and Artificial Neural Network models, is more appropriate for species distribution modeling, thus supporting our results.

The spatial structure of plant species distribution as observed under natural conditions is a result of the variation in soil conditions and biotic interactions (Ghorbani and Asghari, 2014; Ghorbani et al., 2015). Comparison of the selected ecological factors (20 variables) in the habitats with the presence of species demonstrated that most of the selected variables have significant effects on the target species distribution. According to the results, increase of clay in soil surface has positive influence in *H. strobilaceum* distribution, while increase in sand has a negative impact on the presence of this species. Thus, this species prefers heavy texture soils. Previous studies (Ghorbani and Asghari, 2014; Ghorbani et al., 2015) have also reported the importance of soil texture in species distribution because soil texture controls dynamics of soil organic matter or organic matter decomposition and formation. Soil texture also influences infiltration, moisture retention and availability of water and nutrients to plant species (He et al., 2007; Ghorbani et al., 2015). Moreover, the probability of this species existence has decreased with gradual increase in lime of both soil depths. Downward trend of *H. strobilaceum* has probability of distribution which is more severe in the lime of underneath soil depth and in 65% of the cases, it decreases to zero distribution. *A. littoralis* distribution is related to increase of Abs, OC and sand in soil surface and the decrease of K in the depth of the soil. Optimum K2 for this species is 40 to 60 ppm and

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optimum Ca1 for its presence is 5 to 12 ppm. By increaseing K2 from 60 ppm, the probability of presence of this species goes down, and in 160 ppm, it has zero chance of distribution. Moreover, a gradual increase of the clay in soil surface from 10 to 50%, and increases of Na in both depths have positive effects on the distribution of *A. littoralis*. *S. aegyptiaca* habitat suitability increases with rise in K2, OC and pH in soil surface. So, the least amount of K2 in this species habitat is 60 ppm and probability of presence increases with the increase in K2 from 60 to 180 ppm. *S. aegyptiaca* has negative correlation with the increase of Clay1, Lime1, Lime2, Ca1 and Mg2 and positive correlation with the increase of Silt2, Na1 and Abs. Other *Suaeda* species such as *S. salsa* (Zhang and Zhao, 1998), *S. maritima* (Wetson and Flowers, 2010), *S. aegyptiaca* (Askari et al., 2006), *S. asparagoides* (Ayarpadikannan et al., 2012), *S. fruticosa* (Khan and Ungar, 1998), *S. glauca* (Yang et al., 2008), *S. physophora* (Song et al., 2009) and *S. corniculata* (Pang et al., 2016) have also been reported for their ability to survive in high salty conditions, similar to Meighan playa. Important environmental variables that have a significant impact on the presence and distribution of *H. verrucifera* can be expressed as the areas with high levels of Lime2 (10–60%) and pH1 (5.7–8), and poor EC and K of both depths can provide suitable habitat for *H. verrucifera*. This means that reduction in EC and K, and increase in Lime2 and pH make conditions suitable for this species distribution, and presence of *H. verrucifera* has a high correlation with these variables. Effects of soil texture variables is perceptible in this species distribution. Thus, a suitable habitat of *H. verrucifera* is associated with increasing amount of Sand1 from 25 to 40% and increase of Silt in both depths from 15 to 30%. Optimum amount of clay in both depths for *H. verrucifera* presence is about 5 to 10%, and with increasing clay percent, its distribution reduces. Based on the results, the most important factor affecting *S. incanescens* distribution is OC1 in around the rangelands of Meighan playa. The importance of OC in soil quality (Stevenson, 1994) and improving soil physical properties such as soil aggregate stability (Eneje et al., 2007) help species distribution and this has been reported by Ghorbani and Asghari (2014) and Ghorbani et al. (2015). Moreover, increasing Abs and Mg1 has positive impact on distribution. Generally, higher probability of occurrence of *S. incanescens* is in places where the soil has OC1 between 0.15 and 0.45%, Sand1 from 50 to 60%, Clay1 from 10 to 30%, pH1 from 7.6 to 9, and Na1 of 3 to 7 ppm. Habitat's suitability of *L. iranicum* requires increase in Abs from 1,660 to 1,680 m asl, increase in pH from 7.6 to 9.0, increase in K in both depths, increase in Sand1, reduction in Clay in both depths and reduction of Lime2 in the study area. In other words, *L. iranicum* prefers light soil texture, and high amount of pH1, K1 and K2. Moreover, increasing EC in both depths and Lime2 reduces probability of presence. In this study, elevation varation is only a few meters, and there is no rainfall and tempreture change. However, it has a positive correlation with distribution of the selected species. Results of Ghorbani and Asghari (2014) and Ghorbani et al. (2015), which are similar to our study, have also reported the importance of elevation in species distribution modeling. Thus, ecological requirements of the selected species and environmental characteristics of the distribution ranges of these species are different. In general, it can be stated that the halophyte species distribution model using MaxEnt technique revealed reliable results in arid and saline conditions of Meighan playa in central Iran. Results from species distribution model could be applied to the same species in other sites. Using the findings of the present study and identifying factors influencing the presence of species studied in the rangelands of Meighan playa could save time required for similar studies. Details

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of this study can be useful in optimal management of arid rangelands. In addition, according to the survey results and discrimination of habitats related to the halophyte species studied and the effects of ecological factors on their distribution, these findings could be used for the improvement and restoration of the rangelands discussed.

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