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ORIGINAL RESEARCH PAPER

Ecological modeling and distribution analysis of digger scorpions: *Odontobuthus doriae*, *Odonthubutus bidentatus* (Scorpiones: Buthidae) and *Scorpio maurus* (Scorpiones: Scorpionidae) in Iran using the maximum entropy method

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Abstract

Prediction models are essential for the potential geographic distribution of scorpions, prevention of scorpion stings and diverse applications in conservation biology. There is limited information about habitat suitability and the factors affecting the distribution of Iranian digger scorpions. This study was undertaken to model the distribution of three types of digger scorpion in Iran, *Odontobuthus doriae* Thorell, *Odonthubutus bidentatus* Lourenco (Scorpiones: Buthidae) and *Scorpio maurus* Pocockin (Scorpiones: Scorpionidae), and investigate the factors affecting its distribution using the maximum entropy method. A total of 20 environmental and climate variables were used for modeling and evaluation of the ecological niche. The similarities and differences between the ecological overlap of the digger scorpions were evaluated using comparative environmental niche model (ENM Tools software). The results showed that the main factors for habitat suitability of *O. doriae* were soil type, mean temperature of the wettest quarter and slope. The variables for *S. maurus* were soil type, precipitation of the coldest quarter and slope. Annual temperature range, mean temperature of the driest quarter and land use had the greatest influence on the distribution of *O. bidentatus*. The ecological niches for *O. doriae* and *O. bidentatus* overlapped. The niche of these species differed from the niche of *S. maurus*. This approach could be helpful for the prediction of the potential distribution of three digger scorpion species and this model can be an effective for the promotion of health.

Keywords Digger scorpion · *Odontobuthus doriae* · *Odonthubutus bidentatus* · *Scorpio maurus* · MaxEnt · Iran

Introduction

Scorpions (class: Arachnida; order: Scorpions) are found the world over, except in Greenland and Antarctica (Cao et al. 2014). They live in a wide range of habitats, from savannas to snow-covered mountains (Petricevich 2010). Scorpions can survive in heat, drought, freezing and desert conditions. They can also survive for months without food (Bawaskar and Bawaskar 2012). Scorpions are important venomous arthropods and the sting of the scorpion has created health problems in southern and central regions (Dehghani and Fathi 2012; Dehghani and Kassiri 2018; Dehghani et al. 2018).

Selection of information on the ecology and evaluation of digger scorpions is important to identifying their type. Digger scorpions are able to burrow into the ground to a depth of 40 cm and are poisonous arthropods with a sting that can be life-threatening (Razai and Malekanead 2008; Vatanpour et al. 2013). The nest of *Scorpio maurus* Pocockin is simpler with shorter tunnel, compared to that of *Odontobuthus doriae* Thorell. There are three species of digger scorpion in Iran: *O. doriae* (Scorpiones: Buthidae) (Thorell 1876), generally, subsist in the areas without stones of Iran and Pakistan. In addition, its sting is life-threatening to humans (Razai and Malekanead 2008; Vatanpour et al. 2013).

Odontobuthus bidentatus Lourenco (Scorpiones: Buthidae) (Lourenco and Pezier 2002), with description of a new

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species which is registered to the southwest regions and Zagros mountains of Iran (Farzanpay 1988) and *Scorpio maurus* Pocockin (Scorpiones: Scorpionidae), which was described by Pocockin 1900 and are found in the desert and low altitude regions of Iran (Azghadi et al. 2014; Dehghani and Kassiri 2017).

Habitat loss can have a negative effect on the richness of endangered species. Species distribution modeling is conducted to analyze the relationship between the presence record of a species and regional environment variables and can be used for conservation and management of species. Prediction models of potential geographic distribution done using the maximum entropy method can be used to determine the effects of environmental and climate change on habitat suitability and species distribution. A map of species distribution can help to prioritize protection of endangered species (Gibson et al. 2003; Haghani et al. 2017; Phillips et al. 2004).

There are different methods for species distribution modeling. One of the best methods is the maximum entropy method, which is based on presence record-only data and environmental variables. MaxEnt software can describe more complex relations with the environment. Input data can be used both continuous and categorical layers in MaxEnt (Phillips et al. 2004).

The present study investigated species distribution modeling of *O. doriae*, *O. bidentatus* and *S. maurus* in Iran and the factors affecting their distribution using the maximum entropy method. Furthermore, the similarities and differences between the ecological overlap of *O. doriae*, *O. bidentatus* and *S. maurus* are assessed using ENMTools software (Haghani et al. 2016, 2017; Mirshamsi 2013). This study is the second study of ecological modeling of scorpion and first distribution modeling project on digger scorpions in Iran.

Materials and methods

Data sources and model

Iran has different types of soil and arid or semi-arid climates; thus, it is a natural place for a diversity of scorpion species (Dehghani and Fathi 2012). Information from field researchers and literature records that could be georeferenced was used to provide presence-maps of digger scorpions that these species were observed or captured in different regions of Iran (Dehghani and Fathi 2012; Dehghani and Kassiri 2017, 2018; Mirshamsi et al. 2011; Moradi et al. 2018; Navidpour Sh et al. 2012(. In addition, we can attempt to remove some of the sampling bias by subsampling records in MaxEnt (Phillips et al. 2009). The presence of a species was set using random sampling patterns. The geographic coordinates of presence points (*O. doriae*: 140 points, *O. bidentatus*: 124 points and *S. maurus*: 100 points) were obtained using a global positioning system (GPS). In addition, Coordinate system is set based on WGS_1984_Lambert_Conformal_Conic.

Identification of the effective ecological modeling factors for habitat was done using previous studies on the behavior, interface of species and habitat needs. The environmental variables for modeling and evaluation of the niche consisted of 20 environmental and climate variables (Table 1) with 15 bioclimatic variables, 3 topographic variables (Table 2) and 2 environmental variables. Environmental layers such as elevation, aspect and slope were obtained from the USGS

Table 1 The used environment variables in modeling for three digger scorpions in Iran

No	Variable (unit)	Name abbreviations in MaxEnt
1	Annual mean temperature (°C)	Bio1
2	Max temperature of warmest month (°C)	Bio5
3	Min temperature of coldest month (°C)	Bio6
4	Temperature annual range (°C)	Bio7
5	Mean temperature of wettest quarter (°C)	Bio8
6	Mean temperature of driest quarter (°C)	Bio9
7	Mean temperature of warmest quarter (°C)	Bio10
8	Mean temperature of coldest quarter (°C)	Bio11
9	Annual precipitation (mm)	Bio12
10	Precipitation of wettest month (mm)	Bio13
11	Precipitation of driest month (mm)	Bio14
12	Precipitation of wettest quarter (mm)	Bio16
13	Precipitation of driest quarter (mm)	Bio17
14	Precipitation of warmest quarter (mm)	Bio18
15	Precipitation of coldest quarter (mm)	Bio19
16	Soil	Soil
17	Slope (Percent)	Slope
18	Land use	Land use
19	Elevation (m)	Elevation
20	Aspect	Aspect

Table 2 type of elevation and slope used in modeling for three digger scorpions in Iran

Code	Percent slope.	Elevation
1	0–2	0–1000
2	2–5	1000–2000
3	5–8	2000–3000
4	8–12	3000–4000
5	12–15	4000 <
6	15–18	
7	18–30	
8	$30 < x$	

website at 90 m spatial resolution. In addition, climate data (19 bioclimatic layers) for the current period were obtained from the world clime website at 30 s (~ 1 km^2) (Hijmans et al. 2005; http://www.worldclim.org).

Land use and soil maps (Table 3) were created by the Iranian natural resources organization. These layers were portrayed at 1-km of spatial resolution in Arc GIS 10.3 (Iranian Natural Resources 2016). Pearson's correlation coefficient was calculated to intercept the correlation between variables in SPSS software. The variables with a correlation value of ± 0.85 were removed (Tanghe et al. 2013). These variables can be affected directly or indirectly by niche modeling of species (Li et al. 2016).

Species distribution modeling and evaluation of the most important factors affecting the distribution of species were conducted using the maximum entropy method in MaxEnt (Phillips et al. 2004). Models were formed using a total 370 presence points of digger scorpion. The models were regulated with 5000 iterations, convergence threshold of 1.0E − 5, regularization value and number of replicates was set, respectively, 1, 5 and replicated run type was set to subsample. In addition, we use the 75% of data to provide the model (training datasets), and 25% were used to evaluate the model (test datasets) (Phillips et al. 2006). The final habitat suitability map of *O. doriae*, *O. bidentatus*, and *S. maurus* was based on the logistics model in MaxEnt. It was regrouped using the "Maximum training sensitivity plus specificity" into two classes for potential habitats (suitable and unsuitable) provided by MaxEnt and Arc GIS 10.3, with the results of threshold 0.395 to *O. dorea*, 0.259 to *O. bahiensis* and of 0.332 to *Scorpio maurus*. The accuracy of the prediction model was determined using the receiver operating characteristic curve (ROC) analysis and the area under the curve (AUC). An AUC score of 1 means perfect prediction with zero omissions (Phillips et al. 2006; Reed et al. 2008).

Overlaps of the ecological niche for *O. doriae*, *O. bidentatus* and *S. maurus* were generated based on Schoener's D index in ENMTools. Similarities and differences between environmental niche models were obtained by comparing the estimates of each grid cell of the species distribution modeling in the study area using ENMTools and MaxEnt. A D index of between 0 and 1 (0 = ecological niche models do not overlap; 1 = all grid cells of ecological niche model are suitable for both species and completely overlap) (Haghani et al. 2017; Warren et al. 2010).

Table 3 The land use and soil type used in modeling for three digger scorpions in Iran

No	Land use	Soil
1	Pastures	Bare lands
2	Lakes and gulf	Coastal sands
3	Hills	Dune lands
4	Agricultural lands	Kalut
5	Steppe with scattered trees	Marsh
6	Rain farming	Playa
7	Flood plains and sand dunes	Rock outcrops/entisols
8	Forests of oak, pistachio, almonds	Rock outcrops/inceptisols
9	Northern Forests of Iran	Rocky lands
10	Desert	Salt flats
11	Lands without vegetation-Sabulous	Salt plug
12	Swamp	Urban
13	–	Water body
14	–	Alfisols
15	–	Aridisols
16	–	Entisols/aridisols
17	–	Entisols/inceptisols
18	–	Inceptisols
19	–	Inceptisols/vertisols
20	–	Mollisols

Results

The performance of models for prediction of the digger scorpions distribution indicates that the final distribution maps of *O. doriae*, *O. bidentatus* and *S. maurus* as produced by MaxEnt were classified as suitable and unsuitable (Fig. 1). The AUC ROC shows the model accuracy of *O. doriae*, *O. bidentatus* and *S. maurus* (Fig. 2). The AUC value for *S. maurus*, *O. bidentatus* and *O. doriae* for learning data and testing data was, respectively, 94%, 95% and 88%. The results showed the excellent performance of the model for *O. doriae*, *O. bidentatus* and *S. maurus* in Iran. An AUC value of 0.5 shows that the performance of the model is random, but values closer to 1.0 show good model performance (Phillips et al. 2006).

The results of the D test for *O. doriae*, *O. bidentatus* and *S. maurus* are shown in Table 4. According to the results, the highest amount of the overlap was observed for *O. doriae* and *O. bidentatus* and the lowest amount of the overlap was for *O. bidentatus* and *S. maurus*. The jackknife isothermal evaluation results of each variable for *O. doriae*, *O. bidentatus* and *S. maurus* distribution are shown in Fig. 3.

The results showed that soil, mean temperature of the wettest quarter and slope for *O. doriae*, the soil type, precipitation of the coldest quarter and slope for *S. maurus*, and the annual temperature range, mean temperature of the driest quarter and land use for *O. bidentatus* were the factors most effecting the distribution model of the digger scorpion habitats in Iran. Figure 4 shows how each environmental

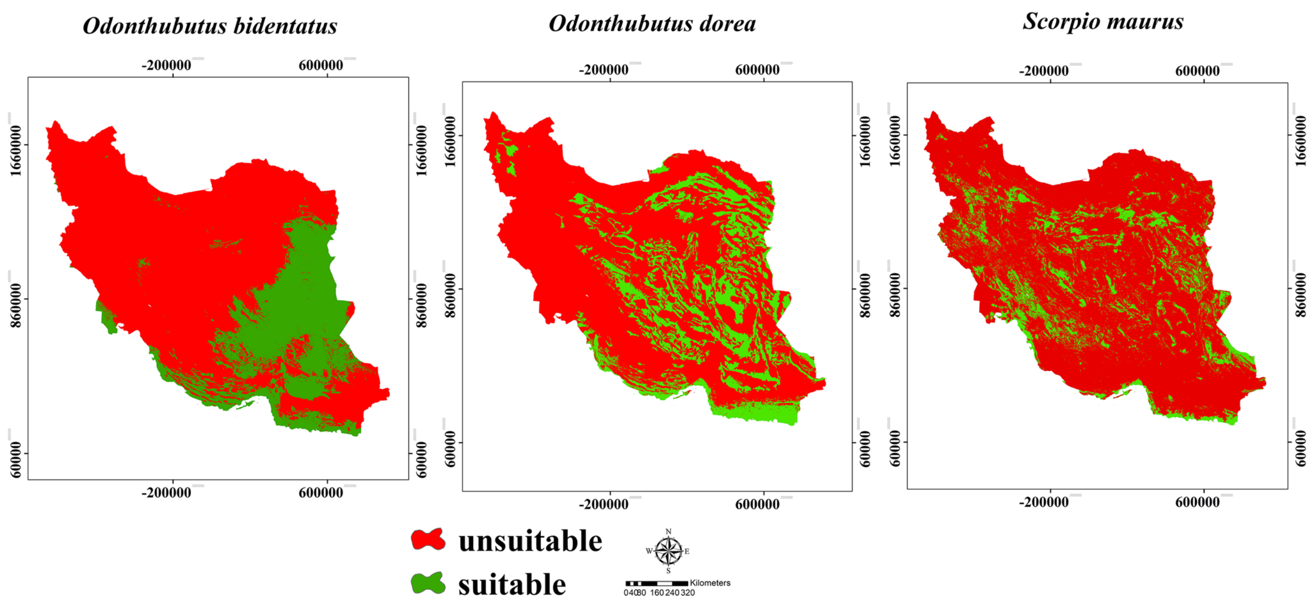

Fig. 1 Final distribution map of Odontohubutus Dorea, Odontohubutus bidentatus, and *Scorpio maurus* in Iran

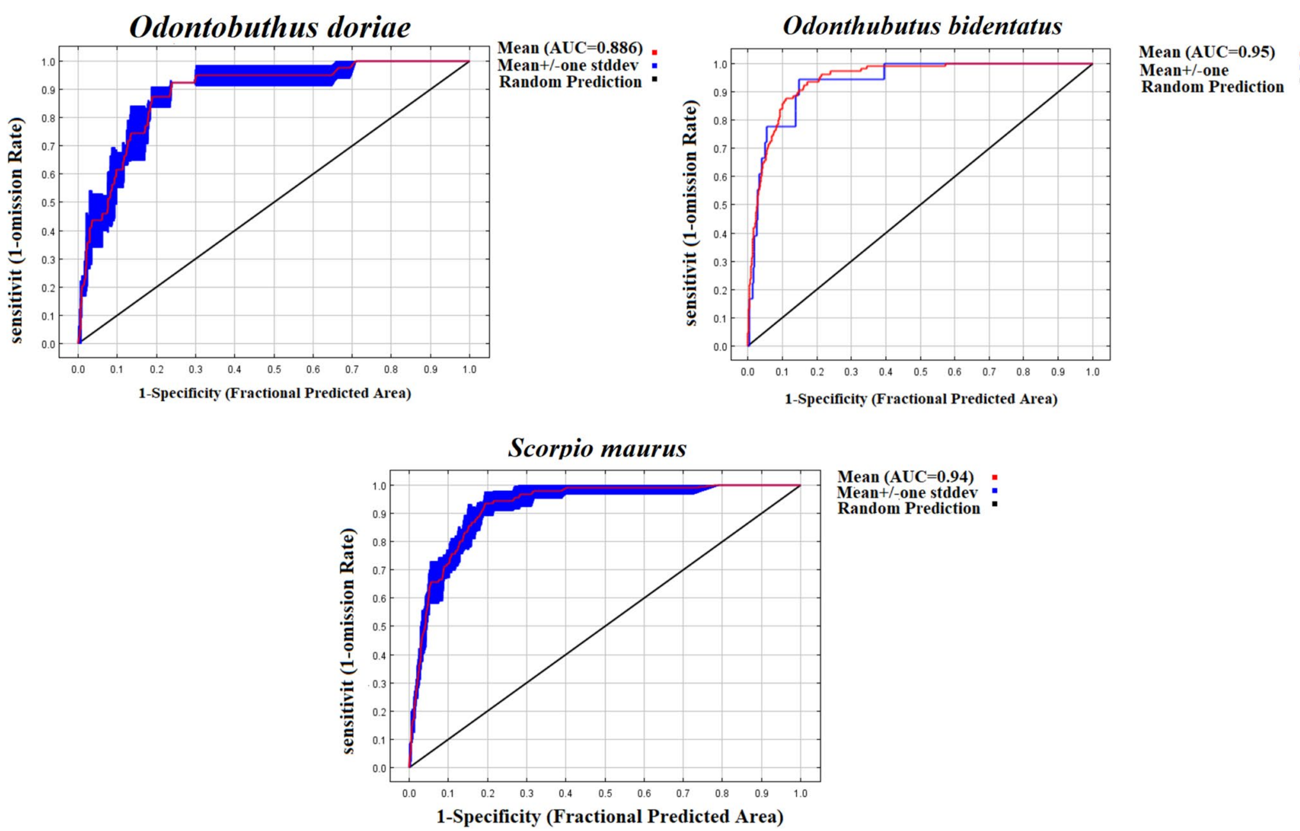

Fig. 2 ROC curves and AUC value model for the distribution of three digger scorpions in Iran

variable affects the MaxEnt prediction. The diagrams show how the logistic prediction changes as each environmental variable changes when all other environmental variables are held at their average sample values.

Table 4 *D* test ranges for sampled species in the study areas

Species	Value *D*
O. doriae–Scorpio maurus	0.575
O. doriae–O. bidentatus	0.6
O. bidentatus–Scorpio maurus	0.520

Discussion

The maximum entropy method is promising for the prediction of the potential distribution of scorpion and other species that can be a valuable tool in the planning of species conservation and species distribution. This model can

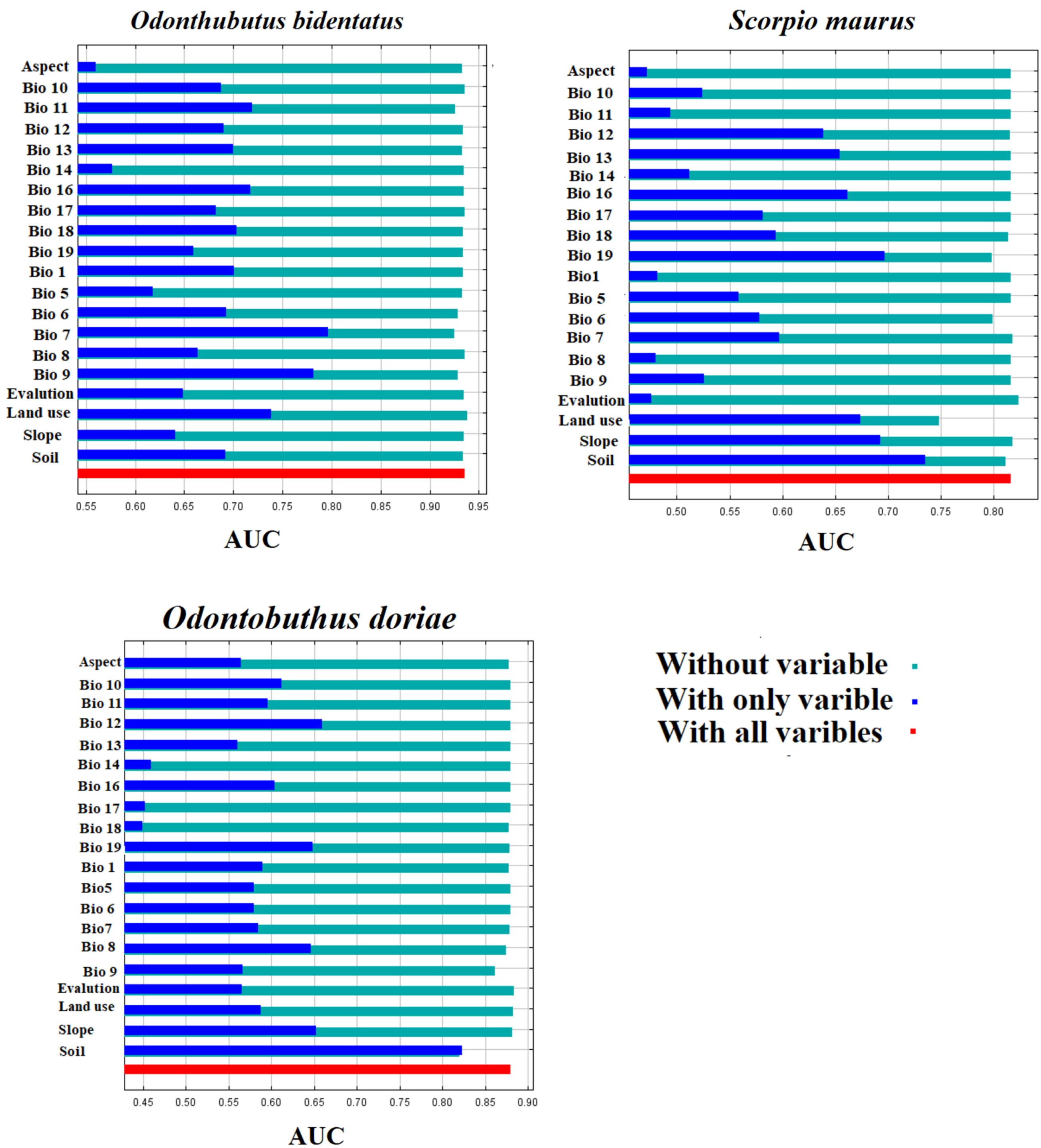

Fig. 3 The Jackknife test for evaluating the relative importance of environmental variables for the distribution of three digger scorpions in Iran

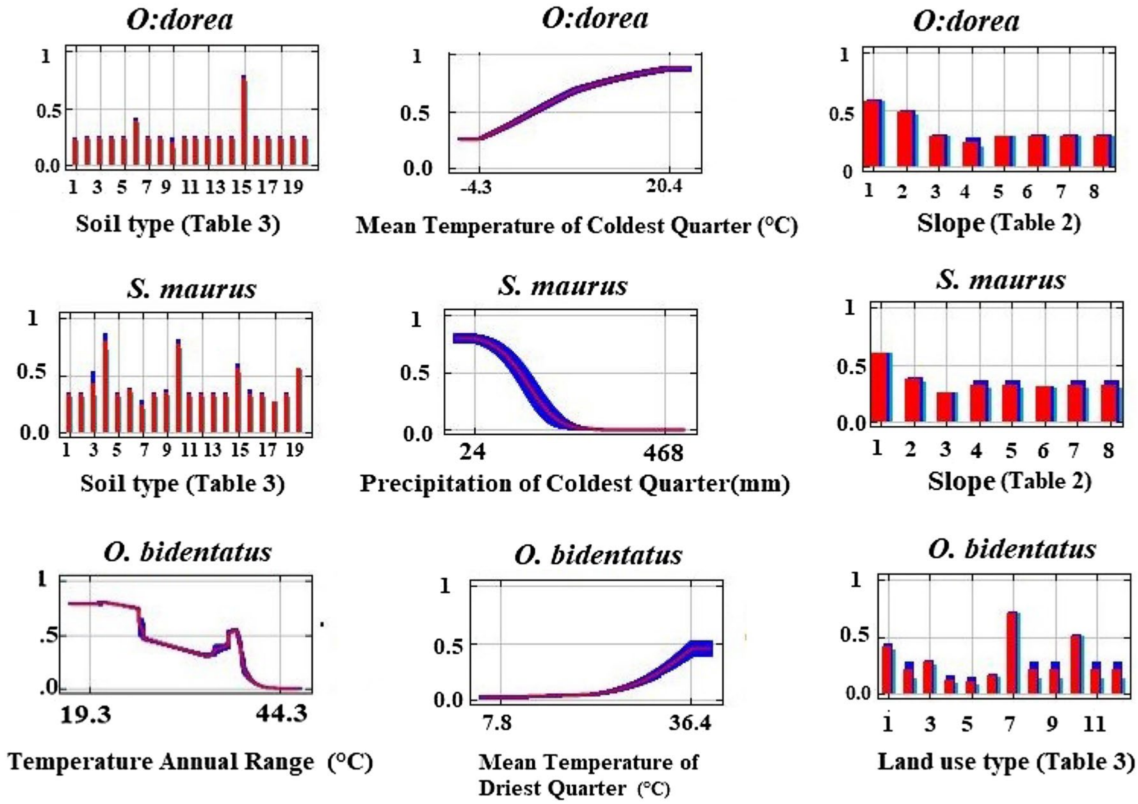

Fig. 4 The response curve of species show how the most important environmental variable affects MaxEnt and how logistical prediction changes as each environmental variable is varied (axis *x*: Value of habitat suitability based on logistic model in MaxEnt that o is minimum value of habitat suitability and 1 is maximum value of habitat suitability; axis *y*: Environmental variable)

be an effective tool in promoting health, reducing scorpion stings and for species restoration and conservation planning. This research is the first to model the habitat of digger scorpions and second study of ecological modeling of scorpion in Iran. The results revealed the factors effecting the distribution of digger scorpions and overlap of their ecological niches in Iran. The model accuracy for prediction of the potential distribution of the digger scorpions was excellent. The present study indicated that the geographical distribution of digger scorpions depends on environmental conditions and climate in Iran.

Recently, Hidan et al. (2018) developed five bioclimatic features, altitude and slope were found to act a significant role in determining *Androctonus* scorpion species distribution.

Modeling of spatial distribution for scorpions of medical importance was performed using maximum entropy in the São Paulo State, Brazil, the results showed that mostly contributed to the scorpion's species distribution model were tree cover (28.2%) and rain precipitation (28.9%) for the *T. serrulatus* and temperature (45.8%) and thermal amplitude (12.6%) for the *T. bahiensis* (Neto and Duarte 2015).

In this study, all environmental variables act to contribute positively to habitat suitability modeling and factors affecting the distribution of digger scorpion in Iran. According to the results of the current study, the response curve for soil types indicate that soil type Aridisol (Table 3, No: 14) and slope 0–2% (Table 2, No: 1) had the maximum effect on the distribution modeling of 0:dorea. An increase in mean temperature of the wettest quarter (Bio8) has increased the desirability of habitat for *O. doriae* (Fig. 4). In addition, we found that the frequency of *O. doriae* nests can be related to the soil texture. The Soil type is relevant to zoology, botany, and soil sciences. Whereas *O. bidentatus* was indicated that an increase in the annual temperature range (Bio 7) can result in a decrease in habitat desirability of *O. bidentatus* and an increase in mean temperature of the driest quarter (Bio 9) can result in a decrease in habitat desirability. Land use variables such as flood plains and sand dunes (Table 3, No: 7) have the greatest effect on habitat desirability (Fig. 4). *O. bidentatus* has not been well investigated. The soil type variables such as Aridisols and salt flats (Table 3, No: 10) and slope 0–2% (Table 2, No: 1) had the greatest effect on habitat desirability of *S. maurus*. In addition, an increase in precipitation during the coldest quarter (Bio19) can decrease habitat desirability for *S. maurus* (Fig. 4). This research showed that *S. maurus* primarily nests on steep slopes in soft soil.

Some differences were observed between the scorpions relating to habitat suitability and burrowing activity. The habitat suitability and nest morphological characteristics of the digger scorpions consisting of length, depth, diameter and shape differ according to species, climate factors, soil texture, land use, slope area, geographical direction and evaluation. The results from this study are similar to other studies. Rahbar et al. (2016) observed that the majority of *S. maurus* built their burrows in low-sloped areas and a minority built their burrows on the mountain slopes. Vazirianzadeh et al. (2017) observed that nest morphological characteristics of *S. maurus* and *O. bidentatus* differed based on species, soil moisture, region conditions and soil texture.

The soil texture for *O. doriae* burrows was soft to gravel. The burrowing habits varied between species depending on the species, soil moisture and type and environmental conditions (Rahbar et al. 2011). Dehghani et al. (2017) showed that burrows of *O. doriae* were in sloped areas and had oval entrances. Another study determined that the frequency of *O. doriae* nests in Taljerd soil was different from Golshahr soil of Esfahan (Dehghani et al. 2017; Dehghani and Kamiabi 2017). The amount of the soil excavated from the nest was proportional to the size of the scorpion. Nesting on steep slopes causes less erosion and degradation of scorpion nests (Rutin 1996). The ecological niche modeling of two scorpion species *Mesobuthus eupeus* and *M. phillipsii* was conducted using maximum entropy, from the Iranian Plateau and Zagros region. According to the results of this study, the divergence between these two species is associated with significant divergence in their ecological niches (Mirshamsi(2013)).

The results of the niche overlap test of *O. doriae*, *O. bidentatus* and *S. maurus* show that the ecological niche overlap of *O. doriae* and *O. bidentatus* are similar and the nests of these species are different from the niche of *S. maurus*. The results support that the determination of desirable and undesirable habitat areas of scorpions can reduce the bite of a scorpion, determination of healthy locations and improving the health of the human community in Iran. In addition, the development of a habitat map for digger scorpions will help during military maneuvers and at tourist sites.

Conclusion

This study indicates the ability of maximum entropy method to the ecological modeling and distribution analysis of digger scorpions in Iran and used to predict the distribution of species related to diseases transmission. In addition to overlapping of the ecological niche and mapping digger scorpion. This model had high predictive success. Finally, the ecological niche of digger scorpions depends on environmental conditions (especially the soil type) and climate in Iran. In addition, the ecological niches for *O. doriae* and *O. bidentatus* overlapped and niche of these species differed from the niche of *S. maurus*.

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