Ensemble distribution modeling of the Mesopotamian spiny-tailed lizard, *Saara loricata* (Blanford, 1874), in Iran: an insight into the impact of climate change

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Abstract: Modeling the distribution patterns of species is a generally efficient tool for understanding their ecological characteristics. In this study, we used the ensemble predictions of the best performing models in order to project the probability of the Mesopotamian spiny-tailed lizard's presence in southwestern Iran. The models used in our study showed that two of the variables had the highest importance in describing the distribution of this species. These two were the annual mean temperature and the maximum temperature in the warmest month of the year. All of the models used in this study reached AUC values of above 0.9 (RF (AUC = 1), GBM (AUC = 0.99), MARS (AUC = 0.98), GLM (AUC = 0.97), and Maxent (AUC = 0.95)), indicating good overall prediction accuracy. The accuracy of random forest (RF) was the highest. The most suitable areas for the presence of this species in Iran were located in Bushehr, Khuzestan, southern Ilam, and western Kermanshah provinces. Furthermore, we modeled the extent of the suitable areas under a climate change scenario, where the results showed a potential increase in the area of suitable habitats for the species in the future. An overlay of the Iranian Conservation Network with the habitat suitability map showed poor representation (13% overlap) of the species in the network of nationally protected areas.

Key words: Species distribution models, habitat suitability, *Saara loricata*, climatic factors, Iranian Conservation Network

1. Introduction

Species distribution models (SDMs) are being used for many purposes in biogeography, conservation biology, and ecology (Elith et al., 2006, 2011; Elith and Leathwick, 2007, 2009; Rodriguez et al., 2007; Thuiller, 2007). Detection of the suitable habitats along with the determination of the most important factors influencing species distribution are among the most application of SDMs (Phillips et al., 2006; Peterson et al., 2011; Kalle et al., 2013). Furthermore, SDMs could lead to the detection of new possible habitats for rare and endangered species in remote areas and to evaluation of the protected area's effectiveness (Engler et al., 2004; Araújo et al., 2007; Zhang et al., 2009; Lomba et al., 2010; McKenna et al., 2013; Sousa-Silva et al., 2014), which have important roles in planning and conservation strategies (Cayuela et al., 2009; Domínguez-Vega et al., 2012; Velásquez-Tibatá et al., 2012).

Species modeling techniques are widely used to estimate the potential impacts of climate change (Guisan and Thuiller, 2005; Liu et al., 2011; Velásquez-Tibatá et al., 2012), which has been one of the key factors threatening biodiversity and affecting distribution ranges of many species during the last century (Chen et al., 2011). In addition, climate change has been determined as one of the most important factors affecting the future distribution patterns of biodiversity (Araújo et al., 2006; Bellard et al., 2012; Duckett et al., 2013; Chapman et al., 2014).

Over the last decades, several algorithms have been developed to model species distributions (Guisan and Thuiller, 2005; Elith et al., 2006; Thuiller et al., 2009). Some of these include the generalized linear model (GLM; McCullagh and Nelder, 1989), generalized boosting model (GBM; Ridgeway 1999), multivariate adaptive regression splines (MARS; Friedman, 1991), random forest (RF; Breiman, 2001), maximum entropy (Maxent; Phillips et al., 2006), support vector machines (SVMs; Guo et al., 2005), and artificial neural networks (ANNs; Manel et al., 1999; Spitz and Lek, 1999; Moisen and Frescino, 2002).

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However, they considerably vary in performance and spatial predictions of species distributions (Grenouillet et al., 2011). Some studies have suggested that the accuracy of species distribution predictions could be substantially improved by applying consensus methods (Araújo et al., 2005, 2011; Araújo and New, 2007; Crossman and Bass, 2008; Thuiller et al., 2009).

Very little is known about biodiversity and species distributions in the southwestern and western parts of Iran, where the Iran–Iraq war (1980–1990) took place. The Mesopotamian spiny-tailed lizard is an herbivorous lizard inhabiting foothills, open valleys, and plains in the warm and dry areas of the southwestern and western parts of the country (Anderson, 1999; Rastegar-Pouyani et al., 2006). The Mesopotamian spiny-tailed lizard is categorized as Least Concern in the IUCN Red List (Papenfuss et al., 2009), while many populations of this species are at the risk of local extinction due to illegal collection and habitat fragmentation as a result of human activities (Kafash et al., 2014b). The distribution, the environmental factors determining distribution, and the effectiveness of the Iranian Conservation Network (ICN) are poorly known for this species in conservational efforts (Anderson, 1999). Assessing the impacts of climate change on the Mesopotamian spiny-tailed lizard yielded contradicting results depending on the used model (i.e. habitats for the species are likely to expand under the predicted climate change using the maximum entropy model, whereas it was found to decline using the Bioclim model; Kafash et al., 2014a). Hence, we concluded that more studies are needed to accurately determine the impacts of climate change on the species.

The habitat of this species is characterized by high temperature and low level of rainfall, as is typical for other species in this genus (Wilms, 2005; Wilms and Böhme, 2007). Given the habitat characteristics of this species as well as other related species, the climatic factors could potentially play an important role in determination of the species presence or absence (Anderson, 1999). The present study was carried out to identify the potential suitable habitats and geographic distribution of this species as well as determine the effects of climatic, topographic, and anthropogenic factors on its presence; to assess the representation of the Mesopotamian spiny-tailed lizard by the ICN to determine whether it is well presented in the national network of protected areas; and to predict its future distribution under the predicted climate change.

2. Materials and methods

2.1. Species distribution data

The species occurrence data were collected during field sampling in 2012 and 2013, supplemented by additional data provided by other Iranian herpetologists’ observations in recent years (Figure 1). Based on this approach, the data entered into the model could be potentially considered to be free from errors, including any uncertainty in the correct identification of the species in the field as well as errors due to incorrectly located species in the field due to literature records (Liu et al., 2011).

2.2. Environmental data

In this study, environmental variables were used for two modeling approaches. One was a general model to predict the current potential species distribution using three types of variables: climatic variables, topography, and land use/land cover (Lu/Lc) types (Table 1). The other one was a climate-only model to evaluate the possible changes to the species’ habitat under climate change scenarios. Shrub lands, rangelands, and agricultural lands were extracted from the land cover maps provided by the Forests, Rangelands, and Watershed Management Organization of Iran. In order to provide continuity for the variables extracted from the related layer, Euclidean distance was calculated using ArcGIS 9.3. Altitude and slope are generally considered to be maximum. Climatic variables were extracted from the WorldClim database (Hijmans et al., 2005). The database consisted of 19 climatic variables for the earth, based on the interpolation of meteorological data between 1950 and 2000. Due to a high autocorrelation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topography</td>
<td>Slope</td>
<td>U.S. Geological Survey</td>
</tr>
<tr>
<td>Climate</td>
<td>Annual mean temperature (analmean), annual precipitation (analprec),</td>
<td>Hijmans et al., 2005</td>
</tr>
<tr>
<td></td>
<td>precipitation of wettest month (wettest), precipitation of driest month (driest),</td>
<td></td>
</tr>
<tr>
<td></td>
<td>maximum temperature of warmest month (warmest), minimum temperature of</td>
<td></td>
</tr>
<tr>
<td></td>
<td>coldest month (coldest), and temperature seasonality (tmpseas)</td>
<td></td>
</tr>
<tr>
<td>Land cover</td>
<td>Agricultural lands (agri), shrub lands (shrub), rangelands (range)</td>
<td>Forests, Rangelands, and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Watershed Management Organization</td>
</tr>
</tbody>
</table>
between these climatic variables, we extracted their values from the occurrence points of the species and screened them for low correlated variables \( r < 0.7 \). Regarding the grid size of climatic variables at approximately 1 km\(^2\) precision \((30\times30\text{ s})\), all other environmental variables were prepared with the same grid size.

### 2.3. Assessment of the climate change effect on species’ habitat

In order to assess the impact of climatic change on the species’ habitat, we first constructed the correlation coefficient matrix between 19 climate variables. We then developed several climatic models using seven low-correlated variables for the present and future climate conditions for the year 2070 (average for 2061–2080). We used the output from the general circulation model CCSM4 from the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (https://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm). Based on different inputs of greenhouse gas emission drivers (i.e. population and economic growth, and technological choices), land use changes, environmental policy options, and adaptation processes (Solomon et al., 2007), the IPCC recommended four representative concentration pathways (RCPs) that became a part of the IPCC Fifth Assessment Report finalized in 2014 (https://www.ipcc.ch/report/ar5/). Each pathway is defined by a radiative forcing value, which describes the change in the amount of energy entering the atmosphere and the quantity reflected back, and is expressed in watts per square meter of surface (W/m\(^2\)). We considered RCPs 2.6 and 8.5, which described a possible future range of energy state for the earth on the basis of different trends in climate change drivers. We calculated the entire climatically suitable areas for the species in the present climatic condition and future climatic change scenarios using ArcGIS 9.3. Finally, we compared the suitable areas in the present and the future to show any increase or decrease in the suitable range size under the effect of climate change on the species’ habitat.

### 2.4. Data analysis

We considered five modeling techniques, including maximum entropy (Maxent; Phillips et al., 2006), the generalized linear model (GLM; McCullagh and Nelder, 1989), the generalized boosting model (GBM; Ridgeway 1999), multivariate adaptive regression splines (MARS; Friedman, 1991), and random forest (RF; Breiman, 2001). Species distribution modeling was performed using the BIOMOD platform (Thuiller et al., 2009) for R (R Development Core Team, 2011).

In order to evaluate the model performance, the available data were randomly divided into two subsets: 80% of the data was used for model calibration and the remaining 20% was used for model evaluation. To obtain a measure of the SDM accuracy, the most highly applied metric of accuracy measurement for SDMs, the area under the curve (AUC), was applied (Fourcade et al., 2013). The AUC acts as a measure for the model’s discrimination ability to detect present points from absent ones in a manner that is independent of suitability thresholds. A model with no detectability is expected to represent an AUC of 0.5, while a model with a very high detectability has an AUC value close to 1. The total area of suitable habitat was calculated using ArcGIS 9.3 software for all the models.

### 2.5. Assessment of the species representation by the Iranian Conservation Network

In order to assess the degree of protection granted to the Mesopotamian spiny-tailed lizard in the conservation areas, we overlaid the habitat suitability map of the species with the map of the conservation networks of Iran using spatial analysis tools in ArcGIS 9.3.

### 3. Results

#### 3.1. SDMs for Mesopotamian spiny-tailed lizard

We obtained the records of the Mesopotamian spiny-tailed lizard from 18 localities in Iran (Figure 1). The results of the habitat suitability model for *S. loricata* showed the most suitable habitats for this species to be in Bushehr, central and northern Khuzestan, southern Ilam, and western Kermanshah provinces (Figure 2). We found climatic variables, such as annual mean temperature and maximum temperature in the warmest month of the year, among the most important variables affecting the distribution of this species in Iran (Table 2). In addition, slope and distance to agricultural lands were among the most important nonclimatic variables affecting the distribution of this species.

All of the models used in this study reached an AUC value of above 0.9, indicating good overall prediction accuracy (Table 3). The accuracy of RF was the highest (AUC = 1), followed by GBM (AUC = 0.99), MARS (AUC = 0.98) GLM (AUC = 0.97), and Maxent (AUC = 0.95).

#### 3.2. The effects of climate change on species habitat

All of the climatic-only models reached an AUC value above 0.9, indicating good overall prediction accuracy, with the highest accuracy observed in RF (Table 3). The ensemble model showed that in current climatic conditions and in those anticipated for the year 2070, the most important climatic variable for prediction of this species’ presence would be the annual mean temperature \((35–55\text{ °C})\) (Figure 3). According to the ensemble model, 19.48% of the study area was suitable for the species at present (Figure 3A). However, under the 2.6 and 8.5 scenarios of the CCSM for the future, this area was predicted to be increased to 25.48% and 26.41% of the study area, respectively (Figures 3B and 3C).
3.3. Effectiveness of Iranian Conservation Network
The results of the assessment of the ICN’s effectiveness in protecting suitable habitats for the Mesopotamian spiny-tailed lizard indicated that only 13% of the suitable habitats are covered by the ICN (Figure 4). Furthermore, the results showed several highly suitable patches distributed far from the protected area, mostly located in Bushehr, the south of Khuzestan, Ilam, and Kermanshah provinces.

4. Discussion
4.1. SDMs and environment factors for the Mesopotamian spiny-tailed lizard
The present distribution of any type of organism is generally attributed to a set of historical and ecological factors (Monge-Nájera, 2008). The modeling results of this study showed that the main factors influencing the presence of the Mesopotamian spiny-tailed lizard were climatic variables (annual mean temperature). This confirmed the assumption that climatic parameters were the most important factors affecting the distribution of this species.

High temperature has been defined as one of the most important features for the species’ habitat (Wilms and Böhme, 2007). In our study, habitat suitability increased where the annual mean temperature reached 35–55 °C in Khuzestan and Bushehr provinces. Because this species deposits eggs underground, it could also depend on suitable temperatures for egg incubation (Madjnoonian
et al., 2005). This factor was also considered as a critical factor in the life cycle of arid and semiarid dwelling lizards, such as the Mesopotamian spiny-tailed lizard. Furthermore, this species is found in plains and flat areas with relatively low slopes of less than 10°, while it avoids areas with high slopes (Anderson, 1999; Rastegar-
Therefore, it can be inferred that highland areas with a high slope might act as an effective barrier limiting the distribution of the species expansion (Anderson, 1999). The most important physiographical barrier for this species was the Zagros Mountains that prevented the species from entering the Central Iranian Plateau.

The distance from the agricultural lands was identified as an effective variable for the habitat suitability of the species. We found a sharp suitability decrease with an increase in the distance to agricultural lands (up to 250 m). A distance of more than 250 m could potentially increase the risk of predation due to the long distance to burrows that play an important role in the species’ survival. It was inferred that agricultural lands could provide a good food supply during spring and summer, especially in summer when the high temperature (35–55 °C) reduces vegetation resources.

### Table 2. Variable importance in the five models used in the present study (for variable descriptions, see Table 1).

<table>
<thead>
<tr>
<th>Model name</th>
<th>GLM</th>
<th>GBM</th>
<th>RF</th>
<th>MARS</th>
<th>Maxent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agri</td>
<td>0.000</td>
<td>0.012</td>
<td>0.009</td>
<td>0.161</td>
<td>0.047</td>
</tr>
<tr>
<td>Analmean</td>
<td>1.000</td>
<td>0.639</td>
<td>0.233</td>
<td>0.410</td>
<td>0.948</td>
</tr>
<tr>
<td>Analprec</td>
<td>0.136</td>
<td>0.020</td>
<td>0.065</td>
<td>0.353</td>
<td>0.000</td>
</tr>
<tr>
<td>Coldets</td>
<td>0.492</td>
<td>0.005</td>
<td>0.127</td>
<td>0.881</td>
<td>0.000</td>
</tr>
<tr>
<td>Driest</td>
<td>0.178</td>
<td>0.028</td>
<td>0.004</td>
<td>0.000</td>
<td>0.004</td>
</tr>
<tr>
<td>Range</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Shrub</td>
<td>0.099</td>
<td>0.039</td>
<td>0.058</td>
<td>0.083</td>
<td>0.000</td>
</tr>
<tr>
<td>Slope</td>
<td>0.120</td>
<td>0.232</td>
<td>0.040</td>
<td>0.025</td>
<td>0.093</td>
</tr>
<tr>
<td>Tmpseas</td>
<td>0.000</td>
<td>0.000</td>
<td>0.076</td>
<td>0.626</td>
<td>0.000</td>
</tr>
<tr>
<td>Warmest</td>
<td>0.470</td>
<td>0.015</td>
<td>0.204</td>
<td>0.670</td>
<td>0.000</td>
</tr>
<tr>
<td>Wettest</td>
<td>0.482</td>
<td>0.304</td>
<td>0.108</td>
<td>0.447</td>
<td>0.030</td>
</tr>
</tbody>
</table>

### Table 3. The AUC values of the five models used in the present study.

<table>
<thead>
<tr>
<th>Model name</th>
<th>GLM</th>
<th>GBM</th>
<th>RF</th>
<th>MARS</th>
<th>Maxent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current general model</td>
<td>0.973</td>
<td>0.999</td>
<td>1.000</td>
<td>0.980</td>
<td>0.952</td>
</tr>
<tr>
<td>Current climatic-only model</td>
<td>0.975</td>
<td>0.996</td>
<td>1.000</td>
<td>0.968</td>
<td>0.946</td>
</tr>
<tr>
<td>Future_2.6 climatic model</td>
<td>0.960</td>
<td>0.991</td>
<td>1.000</td>
<td>0.970</td>
<td>0.944</td>
</tr>
<tr>
<td>Future_8.5 climatic model</td>
<td>0.967</td>
<td>0.998</td>
<td>1.000</td>
<td>0.972</td>
<td>0.940</td>
</tr>
</tbody>
</table>

4.2. The impacts of climate changes

Many studies have recently attempted to develop models and methods to predict the potential effects of future climate changes on biodiversity (Dawson et al., 2011; McMahon et al., 2011; Bellard et al., 2012). At least 10% of species could potentially face extinction by 2100, due to climate changes (Maclean and Wilson, 2011). However, similar studies related to monitoring and recording climate changes among the Iranian herpetofauna are scarce (Kafash et al., 2013, 2014a). Our modeling revealed that the optimal habitat for this species will likely increase due to climate changes, which suggests that the species climate niche could benefit from the predicted future climate conditions (Bellard et al., 2012). Results of assessing the impacts of climate change on the Mesopotamian spiny-tailed lizard using ensemble modeling were in accordance with results of the maximum entropy model, whereas it did not match the results of the Bioclim model (Kafash et
al., 2014a). Because of the better predictive performance of ensemble models (Araújo and New, 2007), we concluded that the maximum entropy model had better ability in prediction of the impacts of climate change on biodiversity compared to the Bioclim model. Since Mesopotamian spiny-tailed lizards inhabit southwestern Iran and are well adapted to warm climates (Anderson, 1999), increasing temperature under climate change could cause an increase in the habitat suitability. Shifting and shrinking species ranges have been shown in the literature under the predicted climate changes (Parmesan and Yohe, 2003; Chapman et al., 2014); however, here we presented evidence of possible future range expansion under climate change for a desert dwelling lizard in southwestern Iran. We further speculated that there could be similar patterns present, sympatric with the Mesopotamian spiny-tailed lizard.
4.3. Effectiveness of Iranian Conservation Networks
Potential distribution modeling is a key to identifying species distribution. Consequently, it is essential in biodiversity management and conservation (Whittaker et al., 2005; Williams et al., 2009) as it could reveal the efficiency of conservation networks in a country. Our results showed that this species, as well as 18 cohabitant species (Anderson, 1999; Latifi, 2000; Rastegar-Pouyani et al., 2006), were poorly represented by the ICN (13% overlap). This could be a concern for a species with such an unknown ecology under the risk of local extinction. For this reason, a systematic in depth review is suggested for the ICN.

Acknowledgment
The authors are grateful to Mr Omid Mozaffari for providing some information about the areas that the species inhabited.

Figure 4. Overlay of Iranian Conservation Network with the habitat suitability map of the Mesopotamian spiny-tailed lizard.
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