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Modelling the potential distribution of the Bridled Skink, *Trachylepis vittata* (Olivier, 1804), in the Middle East

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The Bridled Skink, *Trachylepis vittata*, is widespread in the Middle East and eastern coastal Mediterranean areas and inhabits foothills throughout the arid regions of the Middle East. With the help of more than 146 distribution records from Iran, Turkey, Syria, Israel, Jordan, Cyprus, Egypt, Lebanon and Libya, we analysed the influence of climate on the distribution pattern. According to the Maximum Entropy model, the most influential factors that determined *T. vittata* distribution are: precipitation of coldest quarter, Normalised Difference Vegetation Index (NDVI) and precipitation in the warmest quarter. The model suggests that the western slopes of the Zagros Mountains in Iran and slopes in the southern regions of Anatolia around the Mediterranean Sea are suitable for this species. The species is associated with areas with intermediate NDVI (150-180) (a measure of primary productivity), high winter precipitation (>300 mm) and dry summer (<50mm). The association with rainy winter limits the presence of the species in lowlands. The Zagros Mountains may act as a biogeographic barrier that limits the species dispersal eastward, because of their scarce precipitation.

Keywords: *Trachylepis vittata*, Maximum Entropy, Middle East, widespread taxon, arid region.

Introduction

Seventy-eight species are currently recognized in *Trachylepis* (Mausfeld et al., 2002; Rastegar-Pouyani, 2006), but only a few species are found in the Middle East (Sindaco, Metallinou, Pupin, Fasola, & Carranza, 2012). Three species of *Trachylepis* are found in Turkey (Durmuş et al., 2011): *Trachylepis aurata* (Linnaeus, 1758), which is distributed in much of Anatolia (except the north) and a few islands of the east Aegean (Durmuş et al., 2011), *T. vittata* (Olivier, 1804), which has a wider distribution, ranging from central and southern Anatolia to northern Africa and southwest Asia, and *T. septemtaeniata* (Reuss, 1834), which until 2003 (Mausfeld & Schmitz, 2003) was considered a subspecies of *T. aurata*. *Trachylepis aurata* and *T. septemtaeniata* are found to be sympatric in southeastern Anatolia (Moravec, Franzen, & Boehme, 2006), but the reliability of this is questioned by Durmuş et al. (2011).

Trachylepis vittata was first recorded in Turkey from Mersin in southern Anatolia. Later on this species was found in Eskişehir, Adana, Konya, Mut, Silifke (Mersin), Kozan (Adana), Ekbez, Hassa, Samandağ (Hatay) and Tektek Mountains (Şanlıurfa) (Budak, 1973; Baran et al., 2001; Özdemir, Durmuş, Kete, & Yılmaz, 2001; Kumlutaş

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et al., 2004; Afşar & Tok, 2011) with Tokat being the northernmost record of this taxon in Turkey. Records in Iran come from Kermanshah and western Iran (Anderson, 1999). The Cypriot populations are morphologically identical to the Anatolian ones (Tok, Göçmen, & Mermer, 1999). It is also known from Algeria, Tunisia, Libya, Egypt, Syria, Israel, Lebanon, Jordan and Iraq (Anderson, 1999). In Egypt, Tunisia and Jordan the species is found in sand dunes and wetlands (Disi, 2011), while in Turkey and Lebanon, it is found in mountain regions (Nassar et al., 2013).

As the distribution pattern shows some gaps, the aim of this paper is to analyse the distribution pattern, to identify ecological parameters which determine the distribution, and to provide a distribution model for the potential distribution of *T. vittata* in the Middle East.

For identifying the potential distribution of *T. vittata* in the Middle East, Ecological Niche Modelling (ENM) was applied, which is a useful approach to identify highly suitable areas for a given species or group of species, to inform conservation programmes or to find new insights about the historical biogeography of a given taxon (Araujo & Guisan, 2006). Ecological Niche Modelling can also provide information on local adaptations and niche differentiation among taxa. For instance, it allows one to evaluate whether isolated populations of a species inhabit similar niches even when they are allopatric (Kozak & Wiens, 2006; Sillero, 2011; Warren, 2012).

Habitat suitability prediction is a good method that employs occurrence data and climatic data as environmental layers to predict highly suitable areas for species distribution and to uncover which factors delimit the species dispersal (Graham et al., 2004; Phillips et al., 2006).

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Material and Methods

Species distribution data. All distribution data for *T. vittata* were assembled by searching the available literature (Leviton, Anderson, Adler, & Minton, 1992; Baran & Atatür, 1998; Anderson, 1999) and by carrying out extensive field work in Iran and Turkey in 2011. Apart from these published records, distribution records were gathered from museums and field work. Occurrence points from museums are as follows: BMNH - The Natural History Museum, London, UK (35 records) and CAS - California Academy of Science, California, USA (4 records). Literature localities were checked by Google Earth to confirm their accuracy, and those validated were added to the main dataset. Records from countries in North Africa were used in the analyses and, because that region was far from the main aim of this study, we then extracted the Middle East part from the primitive map.

Data preparation and Analyses. Maximum Entropy modelling (MaxEnt) was used to model the potential distribution of *T. vittata* (Phillips et al., 2006; Elith et al., 2011). MaxEnt is a presence-background method to estimate the Species Distribution Modelling (SDM) with a combination of species presence data and environmental features (Pearce & Boyce, 2006; Renner & Warton, 2013). Environmental suitability was modelled with the base of presence localities together with environmental data in order to detect the specialization and marginality of species distribution (Hirzel et al., 2002; Phillips et al., 2006). MaxEnt is among the most efficient approaches available to build species distribution models when absence data are not available (Elith et al., 2006; Elith et al., 2011). To avoid overly complex response curves, the model was fitted using linear, quadratic and hinge features; we used a logistic output for overall model accuracy from zero (no suitability) to one (maximum suitability).

A preliminary model of 500 random points which were obtained from Middle East countries where the species is present and distributed was run using Openmodeller ver. 1.0.7 (Muñoz et al., 2009) with all climate variables to obtain correlation between them and select uncorrelated variables (Pearson correlation value less than 0.75) (Table 1). Pearson's correlation between variables was evaluated using the raster package in R (Hijmans, 2013). Environmental variables were: 1. Minimum temperature of the coldest month, 2. Maximum temperature of the warmest month,

Table 1. Pearson's correlation among environmental variables. After calculating the correlation with other variables, altitude was not included in the MaxEnt model due to the strong correlation with temperature. NDVI = Normalised Difference Vegetation Index.

	T_{min}	T_{max}	summer precip.	winter precip.	sunshine	NDVI
Minimum temperature	0.602					
Summer precipitation	-0.482	-0.666				
Winter precipitation	-0.296	-0.449	0.381			
Sunshine intensity	0.607	0.613	-0.672	-0.574		
NDVI	-0.374	-0.570	0.685	0.727	-0.630	
Altitude	-0.858	-0.508	0.275	0.238	-0.424	0.203

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Table 2. Relative importance of variables included in the best model.

	Percent contribution	Permutation importance
Winter precipitation	62.6	10.3
NDVI	14.6	51.4
Summer precipitation	10.1	14.3
Minimum temperature	7.0	10.9
Sunshine	5.3	11.2
Maximum temperature	0.5	1.9

3. Total precipitation during the warmest quarter of the year (summer), 4. Total precipitation during the coldest quarter (winter) (from WorldClim; Hijmans et al., 2005), 5. Annual solar radiation in $Wh/m^2/day$ (Watt-hours per square metre per day) (New et al., 2002), and 6. Normalized Difference Vegetation Index, which is a measure of primary productivity (Gutman et al., 1998). We did not include altitude because of the very strong negative correlation with temperature (Table 1). All variables were at the resolution of 10 km^2 as the occurrence point's accuracy. Certain regions, and particularly the most accessible ones, may receive better sampling, and this can have a severe impact on the results of species distribution models (Phillips et al., 2009; Ficetola et al., 2013; Kramer-Schadt et al., 2013). We used two approaches to limit the impact of oversampling in certain regions. First, we considered only one presence for each of the 10 km^2 cells (i.e., minimum distance among points used for analyses: 14 km). Removing presence points that are too close is among the most effective approaches to limit the impact of sampling bias (Kramer-Shadt et al., 2013). Furthermore, we integrated accessibility (Nelson, 2008; Uchida & Nelson, 2010) as a measure of sampling bias, assuming that sampling may be easiest in the most accessible regions (Ficetola et al., 2013; Hosseinian Yousefkhani et al., 2013; Kramer-Shadt et al., 2013).

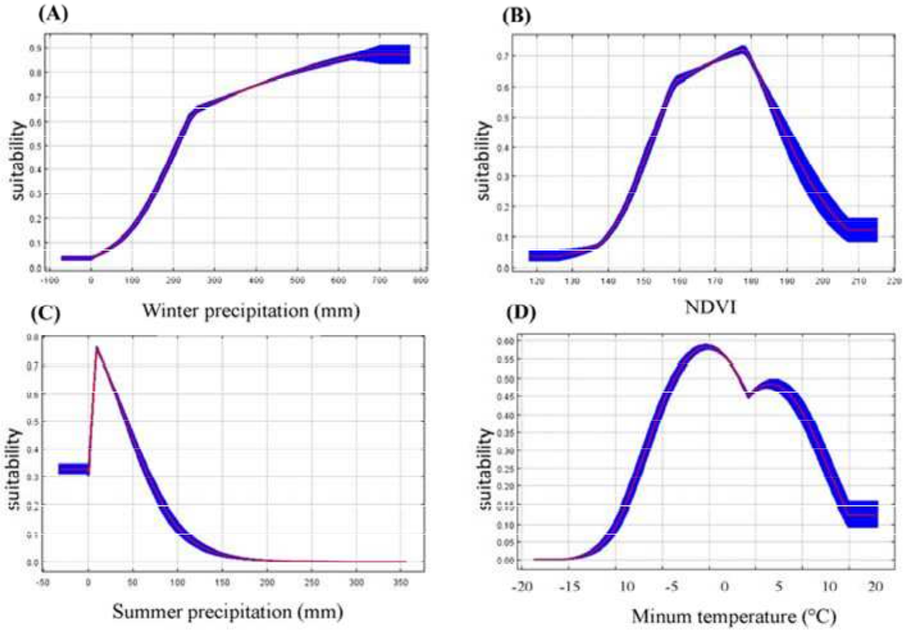

Figure 1. Four important environmental variables that limit the distribution of *Trachylepis vittata*: A) Winter precipitation; B) NDVI; C) Summer precipitation; D) Minimum temperature.

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Cross validation was used to take into account stochastic processes in our model and to evaluate its predictive performance. First, the data were split into ten sets (Nogués-Bravo, 2009; Merow et al., 2013) and we then compared observed frequencies of correct and incorrect predictions using a Z-test. This allowed us to evaluate whether the model predicts distribution significantly better than expected under randomness. This situation enabled us to establish whether model predicted distribution was significantly better than expected under randomness or not. For this test, it was assumed that a cell was "suitable" if the MaxEnt suitability score was higher than the maximum test sensitivity plus specificity threshold (Gallien et al., 2012). Additionally, we calculated the area under the curve of the receiver operator plot (AUC) for the test data. The AUC value, averaged over the ten replicated runs, was considered as an additional measure of model performance. Models with AUC=0.5 indicate a performance equivalent to random; AUC>0.7 indicates useful models and AUC≥0.9 indicates models with excellent performance (Manel et al., 2001). The suitability map was calculated as the average suitability across the ten runs of cross-validation. The lowest threshold for this species was about 0.17 and the medium suitable value is between 0.17 and 0.5. Suitability values >0.5 indicate high suitability for the species.

Results

In this study, 49 new localities were found through field work in Iran and Turkey, and we expanded the known distribution of the species in the Middle East and North Africa by using 97 localities from the literature and museums. The areas with highest suitability were western Iran, northeastern Iraq, southern and southwestern Turkey and the eastern coasts of the Mediterranean Sea (Figure 1). 103 presence points remained available after the nearby localities were filtered out. Winter precipitation, Normalised Difference Vegetation Index (NDVI) and summer precipitation were the variables with the

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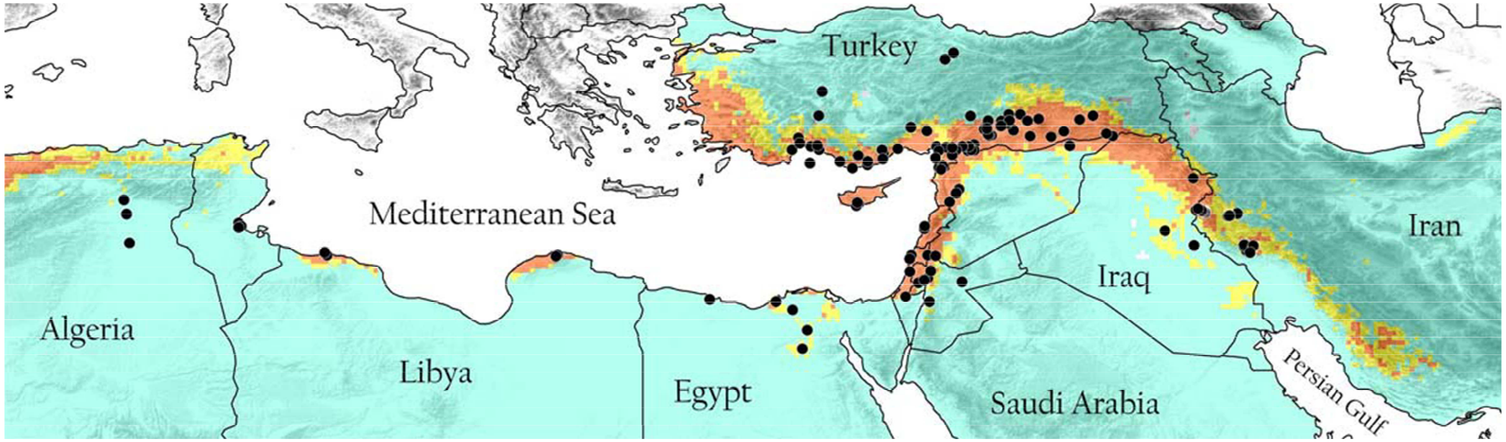

Figure 2. Suitability map of the potential distribution of *Trachylepis vittata* in the Middle East (equidistant cylindrical projection). The black dots represent species records. Probability of presence increases from blue to red.

highest percent contribution to the model (Table 2). Specifically, *T. vittata* was positively associated with winter precipitation (more than 600 mm). Minimum temperature and sunshine were also important variables, according to the permutation importance test (Table 2). After taking into account the effect of winter precipitation, suitability was highest in areas with intermediate NDVI (between 160 to 180), and with low summer precipitation (less than 100 mm). Suitability was also associated with intermediate to high values of minimum winter precipitation.

Cross validation indicated excellent performance of the models. Models correctly predicted 81.2% of our test data, and the predictiveness of our test data was significantly higher than expected under randomness (expected prediction rate: 15.0%; $P<0.0001$). The excellent model performance was also confirmed by the high value of cross-validation AUC (0.909 ± 0.045).

The map does not show "most suitable areas" in the lowlands of Syria and Iraq; it shows only suitable areas in coastal Syria and the mountainous (Kurdish) northern Iraq.

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Discussion

The results obtained from the MaxEnt model are in good agreement with the known distribution of *Trachylepis vittata* except in western Anatolia in Turkey. Among six layers of climate that are used in this study, the most important factors are the high precipitation in winter (BIO19) and intermediate values of productivity (NDVI), as these variables contributed 62.6% and 14.6% respectively to the *T. vittata* distribution model. The presence of this species in Kermanshah and Ilam provinces of Iran has been confirmed and studied carefully, but the model also suggests suitability for this species in the southern part of the Zagros Mountains in Fars province. However, the suitable regions in Fars are occupied by another species (*T. septemtaeniata*) (Sindaco & Jeremčenko, 2008) and we do not know of any record of *T. vittata* in that area. It is also possible that additional factors play some role. For instance, it is possible that the species has not been able to reach this region for some reason such as time, unsuitable conditions in intermediate areas, and so on. Unsuitable conditions in northeastern Khuzestan province limit species distribution towards the south.

According to the model, suitability is highest in southern and southeastern Anatolia where most known records are found. The species was also found at a few isolated localities in central and northern Anatolia (e.g. Tokat province) (Baran, 1977; Baran & Atatür, 1998) even though it seems to be unsuitable for *T. vittata* according to the MaxEnt model.

In south Anatolia, the climate is warm with rainy winters and hot and dry summers. The average annual rainfall in the region, in which the main distribution sites of *T. vittata* exist, varies from 600 to 1200 mm. The average rainfall is usually over 1000 mm on the southwestern slopes of the Taurus Mountain and the Mediterranean coast (Antalya 1052 mm, Adana 647 mm, Hatay 1124 mm.). Almost half of the total annual rainfall occurs in the winter season, especially December and January (Atalay, 2008). Depending on the ecological conditions in the southeastern part of Anatolia, one of the main distribution zones of *T. vittata*, it is divided into two subregions: steppe and xeric forest. In the steppe region, the average annual rainfall varies from 350 to 450 mm. More than half of the total annual rainfall falls during the winter season. In this region, the winter season is rainy and the summer season is without precipitation. The average annual rainfall varies from 400 to 1200 mm (Atalay, 2008).

According to the results using our model, one of the suitable regions for *T. vittata* is south-western Anatolia, but the species is absent there. This region shows some similarity with south Anatolia in terms of vegetation types and precipitation (average annual rainfall varies between 600 and 1000 mm and the majority of rainfall occurs during the winter season, Atalay, 2008). As we mentioned above, the main factor for suitable habitat prediction, is winter precipitation. Absence of the species in the region depends on the time and the vegetation, because on the one hand the species has probably not had enough time to reach the area and on the other hand changes in vegetation type (but not density) can affect the species dispersion as the NDVI index shows the density of vegetation and does not refer to the type of the vegetation. Plant type certainly plays an important role in lizard dispersal (Rasmussen, 1998).

In conclusion, we suggest undertaking a comprehensive study on this complex (*Trachylepis aurata* complex group), to determine the distribution mode for each species and to compare them for niche overlapping as an ecological factor.

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