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Distribution pattern of the Snake-eyed Lizard, *Ophisops elegans* Ménétriés, 1832 (Squamata: Lacertidae), in Iran

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Ophisops elegans, a common lizard with a wide distribution range in Iran, was selected to investigate the influence of environmental factors on its distribution pattern. Based on a distribution model developed with the software Maxent for *O. elegans*, the most important factors influencing the distribution pattern were found to be high winter precipitation, intermediate levels of Normalized Difference Vegetation Index (NDVI) and intermediate levels of sunshine. It seems that overall plant cover and competition with *Mesalina watsonana* are the main factors which influence the distribution pattern of *O. elegans* in the central Iranian Plateau.

Keywords: Lizards, Maxent, environmental factors, habitat suitability, Central Iran.

Introduction

Environmental parameters such as humidity, temperature, solar radiation and elevation are among the most important factors influencing the distribution pattern of terrestrial organisms, and analyzing the ecological parameters affecting species distributions can help to understand underlying the ecological processes (Graham, Ferrier, Huettman, Moritz, & Peterson, 2004). Predictive modelling of species geographic distribution based on the environmental conditions of sites of known occurrence make a valuable technique in analytical biology, with applications in conservation and protected area planning, ecology, evolution, epidemiology, invasive-species management and other related fields (Phillips, Anderson, & Schapire, 2006). The distribution of reptiles, because of their limited tolerance to environmental factors, is highly regulated by environmental conditions. Consequently, environmental models can be extremely useful in predicting the distribution patterns of lizards (Buckley, Hurlbert, & Jetz, 2012).

The genus *Ophisops* Ménétriés, 1832 is distributed in south-eastern Europe, North Africa, and Asia, with eight currently recognized species (Kyriazi et al., 2008). The Snake-eyed Lizard, *Ophisops elegans* Ménétriés, 1832, is widely distributed throughout Bulgaria and northern Greece, Turkey and south-western Asia, and has also been recorded from North Africa. Its range extends as far east as Pakistan and northwest India (Arnold & Ovenden, 2002; Ananjeva et al., 2006). *Ophisops elegans* is a ground-dwelling lizard, typically found in open and arid plains, cultivated fields and stony hillsides, in areas with sparse vegetation or low shrubs (Arnold & Ovenden, 2002). The

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species has also been found inhabiting areas of Aleppo Pines (*Pinus halepensis*) and open evergreen and deciduous oak forests (Pérez-Mellado, Valakos, Guerrero, & Gil-Costa, 1993; Damhoureyeh et al., 2009). It has been recorded in eastern Turkey at elevations of up to 2,300 metres (Hellmich, 1969). Snake-eyed Lizards use rocks and bare ground for basking (Pérez-Mellado et al., 1993) and appear to be well-adapted to withstand hot environments (Foufopoulos, 1997). The species is considered as one of the most abundant lacertid lizards in Iran. Most of its populations are found along the Zagros Mountains (Anderson, 1999), while it occurs in central Iran in habitats higher than 1000 m, and its populations are separated from each other geographically. Recently found populations of *O. elegans* in Taftan Mountain (Oraie et al., 2012) and south-eastern Iran (Hazar Mountains, Kerman province) are isolated and live at altitudes over 2500 metres (Anderson, 1999). In many region of central Iran *O. elegans* occupies habitats apparently similar to those in which the sympatric *Mesalina watsonana* (Stoliczka, 1872) is found, but they have so far never been found to be syntopic (Anderson, 1999).

In this study, we attempted to identify the ecological parameters which are most influential on the distribution pattern of *O. elegans* using species distribution models (Maximum Entropy), and to find out which environmental parameters have an important role in determining the distribution pattern of *O. elegans* and *Mesalina watsonana* in the central region of Iran.

Material and Methods

The occurrence records for *O. elegans* were obtained from three sources: i) from our own field observations between 2008 and 2013 when we travelled to virtually all regions of Iran; ii) published records from Iran (Anderson 1999); iii) and data from specimens deposited in the following museums: AMNH - American Museum of Natural History, NewYork; BMNH - The Natural History Museum, London; CAS - California Academy of Science, San Francisco; CMNH - Cleveland Museum of Natural History, Cleveland, USA; FMNH - Field Museum Natural History, Chicago; MMTT - National Museum of Natural History, Tehran; MVZ - Museum of Vertebrate Zoology, Berkeley, USA; NMNH - National Museum of Natural History, Washington; RUZM - Razi University Zoological Museum, Kermanshah, Iran; SHUC - Sabzevar University Herpetological Collection, Sabzevar, Iran; TUZM - Tehran University Zoological Museum, Tehran, Iran; YPM - Yale Peabody Museum of Natural History, USA. The final dataset consisted of 272 distribution records from Iran. In order to increase the accuracy of the distribution modelling of *O. elegans* in Iran, some data from specimens sampled from outside Iran (obtained from MVZ and CAS) were also added to the dataset.

We used Maximum Entropy modelling (Maxent) (Philips et al., 2006; Elith et al., 2011) to assess the potential distribution pattern of *O. elegans* across its distribution range. Maxent is a presence-background method that combines presence data with environmental features and provides a measure of environmental suitability in a given cell, on the basis of environmental features in that cell. Maxent is considered as one of the most efficient approaches to building species distribution models with presence-only data (Elith et al., 2006, 2011). To avoid overly complex response curves, the model was fitted using linear, quadratic and hinge features (Merow, Smith, & Silander, 2013); we used a logistic output, with Maxent suitability ranging from zero (no suitability) to one (maximum suitability).

As environmental predictors, we considered bioclimatic variables that are expected to affect physiological tolerance, metabolism and thermoregulation of reptiles, as well as water availability and productivity of ecosystems (Van Damme et al., 1989). After running the model by standard climatic and land cover variables (Hosseinian et al., 2013) we included the following environmental variables for the final model: minimum temperature of the coldest month; maximum temperature of the warmest month; total precipitation of the summer months, as the warmest season; total precipitation in the winter, as the coldest season (from Worldclim; Hijmans et al., 2005); annual solar radiation in Wh/m^2/day (Watt-hours per square metre per day) (New, Lister, Hulme, & Makin, 2002); and Normalized Difference Vegetation Index (NDVI), which is a measure of

Table 1. Relative importance of variables included in the best model. To evaluate the relative importance in each iteration of the algorithm, the increase in regularized gain was added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda was negative. Relative importance was calculated as the average over the ten replicated runs.

Variables	Percent contribution
Winter precipitation	43.4%
NDVI	21.5%
Solar radiation	13.8%
Summer precipitation	11.1%
Maximum temperature	7.2%
Minimum temperature	3.0%

primary productivity (Gutman, Tarpley, Ignatov, & Olson, 1997). All variables were at the resolution of 10 × 10 arc primes. Certain regions, and particularly the most accessible ones, may receive better sampling and thus provide more accurate data, which in turn may affect the outcomes of the distribution models (Phillips et al., 2009; Ficetola, Bonardi, Sindaco, & Padoa-Schioppa, 2013; Merow et al., 2013). In our models, therefore, we used accessibility as a measure of sampling bias, assuming that the sampling may be easiest in the most accessible regions (Ficetola et al., 2013; Nelson, 2008; Uchida & Nelson, 2010). Furthermore, to further diminish the accessibility effect, we considered no more than one presence point per each 10 × 10 arc primes cell.

Cross validation was utilised to evaluate the predictive performance of the model, and to take into account stochastic processes into the model. Data were split into ten sets and then ten models were built. Each model was built using 90% of the data for calibration, and its predictive performance was assessed on the basis of the remaining 10% (test data) (Hijmans 2012). This procedure was repeated ten times, each time using a different set of calibration and test data (Nogués-Bravo, 2009; Merow et al., 2013). Subsequently, we used a Z test comparing observed frequencies of correct and incorrect predictions to evaluate whether the model predicts distribution significantly better than expected under random expectations. For this test, we assumed that a cell is suitable if its suitability score was higher than the maximum test sensitivity plus specificity threshold (Gallien et al., 2012). We also calculated the area under the curve (AUC) of the receiver operator characteristic (ROC) curve for the test data, and averaged the AUC over the ten replicated runs, as an additional measure of model performance. Models with AUC = 0.5 indicate a performance equivalent to random; those with AUC > 0.7 indicate a useful performance, those with AUC > 0.8 indicate a good performance and finally models with AUC ≥ 0.9 indicate excellent performance (Manel et al., 2001; Swets, 1988). The suitability map was calculated as the average suitability across the ten runs of cross-validation.

Results

The Maxent model described our distribution data well. The average AUC for test data was 0.861, indicating good performance. Models consistently predicted suitability in test data (average success of prediction of test data= 91%), and prediction success was much better than expected by chance ($P<0.0001$ in all runs), confirming their good performance. Winter precipitation, NDVI and sunshine were the variables with the highest contribution to the model (Table 1). Specifically, suitability was highest in regions with high winter precipitation, but with dry summers, intermediate levels of NDVI, and intermediate levels of sunshine (Figure 2).

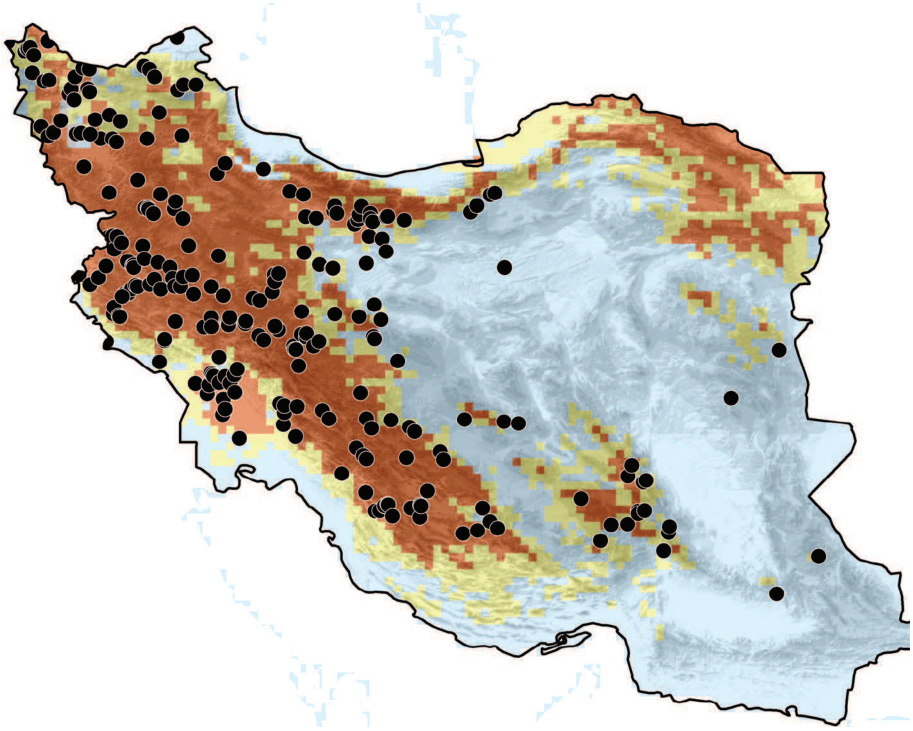

Figure 1. Potential distribution modelling of *Ophisops elegans* in Iran. Colours on the map indicate different suitability values: Blue: suitability <0.27; Yellow: 0.27 ≤ suitability < 0.5; and Orange: suitability >0.5. The maximum test sensitivity plus specificity threshold is 0.27, and it indicates suitability for the species (Gallien et al., 2012); values >0.5 indicate very high suitability, as 0.5 is the typical MaxEnt suitability of presence points used for calibration (Elith et al., 2011). Black dots represent known presence records.

Discussion

Our study confirms the previous distribution data of *Ophisops elegans*. According to the model, the Zagros Mountains, southern slopes of the Elburz Mountains, the Hazar Mountains in Kerman province and the Kopet Dagh Mountains had highest suitability, which, with the exception of the last locality, are also the areas where most known populations of the species occur (Anderson, 1999). Apparently in some cases unintentional errors have been made during coordinate point registration, as such points are outside of the known range of *O. elegans*. In this regard, according to the model prediction, these points are far from potentially suitable habitats for *O. elegans* (Figure 1). For example, two points marked in eastern Iran close to the Afghanistan border related to two samples, one (CAS-141302) from 41 km SW Bijar, Western Iran, and the other (AN 07) collected by Nikolsky (1896) near Ahvaz, south western Iran (Anderson, 1999).

Based on the results, winter precipitation and intermediate levels of NDVI play the most important roles on *O. elegans* distribution patterns. These results are in line with a new finding in Qom province, Central Iran, where the abundance of *O. elegans* was related to the overall plant cover and where it significantly avoided habitats with low overall plant cover (Ebrahimi et al., 2013). In some regions of Iran *O. elegans* occupies habitats apparently similar to those in which the sympatric *Mesalina watsonana* is

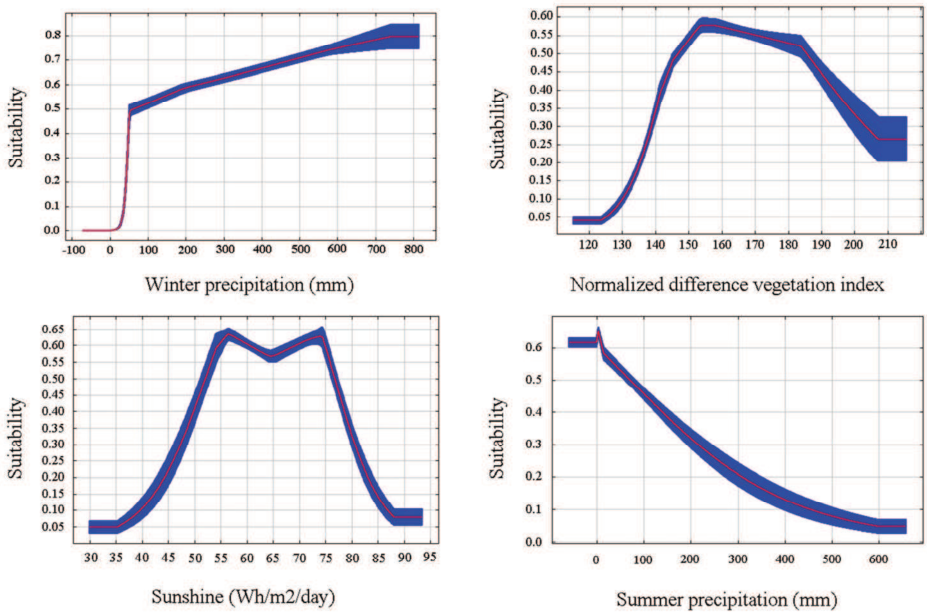

Figure 2. Response curves of the four environmental variables with highest contribution to the Maxent model (see Table 1). These curves show the relationship between each environmental variable and suitability, as predicted by the Maxent model, while keeping all the other variables at their average value. Curves represent the mean response of the 10 replicate runs ± SD.

found, but they are never found to be syntopic (e.g. Anderson, 1999). Recent studies illustrated that slopes steeper than 10.5° (Hosseinian et al., 2013) and high elevation (Ebrahimi et al., 2013) are the most important parameters that restrict the distribution of *M. watsonana*. But these factors do not have a restrictive effect on *O. elegans* distribution which is common on stony plains and hillside habitats (Anderson, 1999).

Most of the known populations of *O. elegans* occur along the Zagros Mountains (Anderson 1999), with ecosystems such as the forest and forest steppe areas with a semi-arid climate and an annual precipitation of 400–800 mm (Frey & Probst 1986). It is not surprising that, according to the model (Figure 1), the Zagros Mountains had highest suitability for *O. elegans*. However, the Zagros Mountains have been interpreted as an impenetrable biogeographic barrier for *Mesalina wastsonana* (Šmíd & Frynta, 2012), because most of its habitats are at high altitudes and have slopes steeper than 10.5° which are the main limiting factors for *M. watsonana* (Ebrahimi et al., 2013; Hosseinian et al., 2013). But it seems that these factors do not have a restrictive effect on *O. elegans* distribution. *O. elegans* has spread easily along the Zagros and is a common lacertid lizard with an almost continuous distribution in those regions (Figure 1).

According to our model (Figure 1), suitable habitats for *O. elegans* are limited in central Iran, and restricted to regions with a high elevation. The combined results of this study and of others (Ebrahimi et al., 2013; Hosseinian et al., 2013) can be interpreted as showing that the distribution pattern of *O. elegans* in central Iran was affected strongly by interspecific competition with the ecologically equivalent *M. watsonana*. Based upon relevant evidence in the sympatric region where the two species occur together (such as Qom Province; Kalmand and Bahadoran, Yazd Province), *O. elegans* has been pushed back into microhabitats with properties (slopes steeper than 10.5° and higher elevation) which are the limiting factors for *M. watsonana* (Ebrahimi et al., 2013; Hosseinian et al., 2013). In habitats where *M. watsonana* is not present, especially on the western slopes of the Zagros Mountain (e.g. Dare Shahr, Ilam Province), *O. elegans* occurs in habitats below 1000 m elevation.

The distribution range of *O. elegans* on its northern front is confined by the Elburz Mountains. The model prediction also confirmed the absence of any suitable habitats for *O. elegans* on the northern slopes of the Elburz Mountains. The outer Elburz terrain in the north, overlooking the Caspian Sea, enjoys a semi-Mediterranean climate, with an average precipitation from 700 mm in the mountains up to 2000 mm in the coastal plain (Khalili, 1973).

The Maxent model identified potentially suitable regions outside the known range of *O. elegans* in Iran. For instance, the Kopet- Dagh Mountain chains in north-eastern Iran have potentially suitable abiotic conditions for *O. elegans*. But so far *O. elegans* has not been recorded from those areas, and during our field work no sign of its occurrence was found in that area. This might have been due to the dispersal potential of *O. elegans*, so that from the easternmost boundary of its known distribution range, on the southern slopes of the Elburz (Damghan), to the first suitable habitats in north-eastern Iran, there are many areas that could have restricted the dispersal of *O. elegans* historically. These areas are typically regions with very low winter precipitation, bare ground and scattered shrubs (low NDVI), high value for solar radiation, and finally a high air temperature during summer. All these factors would have had a negative influence on the dispersal of *O. elegans* eastwards. Figure 1 shows that suitable regions in the north-east are almost separated from easternmost records. On the other hand, biotic interactions such as interactions with ecologically or taxonomically related species (e.g. *M. watsonana* and *Eremias* spp.) (Anderson, 1999; Sindaco & Jeremčenko, 2008) in this region, or a combination of biotic and abiotic factors, may have restricted the dispersal of *O. elegans.*

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