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Correspondence

Predicting the potential distribution of the endemic snake *Spalerosophis microlepis* (Serpentes: Colubridae), in the Zagros Mountains, western Iran

Mahboubeh Sadat Hosseinzadeh[1], Parviz Ghezellou[2] & Seyed Mahdi Kazemi[3,4]

[1] Department of Biology, Faculty of science, Ferdowsi University of Mashhad, Mashhad, Iran
[2] Department of Phytochemistry, Medicinal Plants and Drugs Research Institute, Shahid Beheshti University, G.C. Evin, Tehran, P.O. Box 19835-389, Iran
[3] Department of Biology, College of Sciences, Qom Branch, Islamic Azad University, Qom, Iran
[4] Zagros Herpetological Institute, 37156-88415, P. O. No 12, Somayyeh 14 Avenue, Qom, Iran

Corresponding author: Seyed Mahdi Kazemi, e-mail: kazemi_m1979@yahoo.com

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Species distribution models (SDM) are geographical models of biospatial patterns in association with environmental factors (Franklin 1995). The predictive models of species' geographic distributions are important for a variety of applications in ecology and conservation (Graham et al. 2004). Therefore, species' distributions can be modelled to provide suitable information for many rare and poorly known taxa. Some snake species are particularly difficult to detect due to their low densities, elusiveness, or long periods of inactivity (Seigel 1993). Thus, their distribution ranges may be underestimated and less well known than in other reptiles (Santos et al. 2006, Bombi et al. 2009). SDMs can be used to fill these knowledge gaps by mapping potential distribution ranges and so identify sites at which searches are more promising than at others and should be considered for conservation programmes (Peterson et al. 2000).

The genus *Spalerosophis* Jan, 1865 (type species *Spalerosophis microlepis)* includes six species, *S. arenarius* (Boulenger, 1890), *S. atriceps* (Fischer, 1885), *S. diadema* (Schlegel, 1837), *S. dolichospilus* (Werner, 1923), *S. josephscorteccii* Lanza, 1964, and *S. microlepis* Jan, 1865 (Sindaco et al. 2013, Uetz 2015). The genus occurs in arid and semiarid regions, the Saharo-Sindian region, from North Africa in the west through Arabia, Iran, Pakistan, to central India in the east (Baig & Masroor 2008, Sindaco et al. 2013, Uetz 2015). Four taxa of two species of the genus have been recorded from Iran, i.e., *Spalerosophis diadema cliffordii* (Schlegel, 1837), *Spalerosophis d. diadema* (Schlegel, 1837), *Spalerosophis d. schirazianus* (Jan, 1863) and *Spalerosophis microlepis* Jan, 1865 (Marx 1959, Latifi 2000, Firouz 2005, Baig & Masroor 2008, Rastegar-Pouyani et al. 2008, Schätti et al. 2009, Schätti et al. 2010). The latter species is distinguished from *Spalerosophis diadema* by distinctive morphological characters including 41–45 midbody scale rows (Marx 1959, Schätti et al. 2009; Fig. 1).

However, *Spalerosophis microlepis* is a rare and poorly known species and its range is uncertain (Marx 1959, Gholamifard 2011). It occurs in western and central Iran as well as the Zagros Mountains, in Ilam, Lorestan, Fars, Khuzestan, Hamadan, Markazi, Qom, Kerman, Chahar Mahall-va-Bakhtiyari, Kohkiluyeh-va-Boyer Ahmad, and Isfahan provinces (Latifi 2000, Rastegar-Pouyani et al. 2008, Gholamifard 2011, Moradi et al. 2013, Kazemi et al. 2015). Records of this species from Semnan, western Yazd and northern Hormozgan need to be confirmed (Baig & Masroor 2008, Schätti et al. 2009). Additionally, the species might be present in Iraq, although this requires confirmation (Firouz 2005, Baig & Masroor 2008, Schätti et al. 2009, Gholamifard 2011). According to Latifi (2000), *S. microlepis* has been reported to occur in mountainous areas, foothills, fields, grasslands, and semi-desert regions.

The aims of this study are to provide a comprehensive distribution map of *S. microlepis,* to confirm the presence of *S. microlepis* in doubtful localities, and to identify the environmental variables associated with the predicted distribution of *S. microlepis* using a maximum entropy distribution modelling approach.

All records of *S. microlepis* are based on our own fieldwork as well as those from the literature (Frynta et al. 1997,

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Table 1. Percentages of contributions of variables included in the best-fitting distribution model for *Spalerosophis microlepis*.

Environmental variables	Percent contribution	Permutation importance
Bio18, precipitation in the coldest quarter	40	38.1
Bio12, annual precipitation	20	4.4
Bio8, mean temperature in the wettest quarter	15.6	0.4
Slope	10.5	23.6
Bio17, precipitation in the driest quarter	8.5	0.8
Bio2, mean diel temperature range (monthly mean [max.–min.])	3.1	0.4
Bio14, precipitation in the driest month	1.1	0.3
Bio5, maximum temperature in the warmest month	0.6	16.4
Bio7, annual temperature range	0.5	15.6
Bio15, precipitation seasonality	<0.1%	<0.1%

Latifi 2000, Schätti et al. 2009, Sindaco et al. 2013). Additionally, we included point localities based on museum specimens. The records that were used in this study are from the following museums: The Natural History Museum, London (BMNH); Field Museum of Natural History, Chicago (FMNH); Muséum d'Histoire naturelle, Genève (MHNG); National Museum of Natural History, Washington D.C. (USNM); Museo ed Istituto di Zoologia Sistematica dell' Università, Torino (MZUT); Zoological Museum Shahid Bahonar University of Kerman (ZMSBUK); Razi University Zoological Museum (RUZM); Zagros Herpetological Institute Museum (ZHIM); and Department of the Environment of Qom Zoological Museum (DOEQZM). A total of 33 locality records for *S. microlepis* were gathered and used in the maximum entropy distribution modelling approach (Maxent). 20 environmental variables, describing temperature, precipitation, seasonality, altitude, all with 30-arc-seconds resolution, were obtained from the Worldclim data set (http://www.worldclim.org/; Hijmans et al. 2005). In addition, a slope layer was built from altitude layer information in ArcGIS 10 using the spatial analyst toolbox. First, correlations between all 21 environmental variables were measured with Pearson's correlation coefficient in SPSS 16. The variables with a correlation coefficient > 0.75 were excluded from species distribution modelling (Rissler et al. 2006). Then, 10 out of 21 environmental variables were chosen and used in this study; see Table 1 for more details.

Figure 1. Male specimen of *Spalerosophis microlepis* from central Iran, Qom.

Maxent is a modeller approach associated only with species presence data that enables the construction of well-fitted predictive performance and ecological data. It is considered one of the most efficient approaches for predicting species distribution models based on presence data (Elith et al. 2006, Phillips et al. 2006, Elith et al. 2011). However, testing is required to assess the predictive performance of the model. Therefore, the most usual approach is to divide data into 'training' and 'test' datasets, thus creating relatively independent data for model testing (Fielding & Bell 1997, Guisan et al. 2006). Consequently, Maxent was used with default settings when separating records into training and test samples (75 and 25%, respectively) with ten replicates, which is a technique that has been proven to achieve high predictive accuracy (Phillips & Dudík 2008). Convergence threshold and maximum number of iterations were carried out by default (0.00001 and 500, respectively). We used cross-validation to evaluate the predictive performance of the model. Jackknife testing was used to produce estimates of the average contribution and response of each variable to the model.

Our model was tested with 'area' under the receiver-operating characteristic curve (AUC) that has been used extensively in assaying species' distribution models, and measures the ability of a model to differentiate between sites where a species is 'present' versus 'absent' (Phillips et al. 2006, Elith et al. 2006). Models with AUC = 0.5 indicate a performance equivalent to random; AUC > 0.7 indicates useful performance, AUC > 0.8 indicates good performance, and AUC ≥ 0.9 indicates excellent performance (Manel et al. 2001).

The variables that contribute the most include: bio18 (40%), bio12 (20%), bio8 (15.6%), slope (10.5%), bio 17 (8.5%), bio2 (3.1%), bio14 (1.1%), bio5 (0.6%), bio7 (0.5%), and bio15 (< 0.1%) (Table 1). The AUC value of our model was 0.986 ± 0.005.

Modelling of the potential distribution of *S. microlepis* reveals the most suitable habitat to lie in mountainous regions, including the Zagros highland and northern and southern Afghanistan, which corresponds to the Hindu Kush Mountains and northern Syria (Fig. 2). The doubtful records are not congruent with habitat suitable for *S. microlepis* (Fig. 2). The environmental variables with the highest gains for *S. microlepis* are bio18, bio17, bio 12, and bio8 (Fig. 3) as they are those that will decrease the model's gain the most when they are omitted; this means that these variables have a significant amount of information that is not represented by the other variables.

Our results from modelling are highly compatible with the known distribution of *S. microlepis*, with the exception of predicted suitability in Afghanistan and northern Syria where the species obviously is absent. However, the closely related species *S. diadema*, which probably has similar ecological traits and habitat preferences, occurs there. The term niche conservatism is used to describe the tendency of species to have similar ecological needs over evolutionary time-scales (Peterson et al. 1999, Wiens & Graham 2005). According to Acevedo et al. (2014), ecological data suggests that niche conservatism may be explained by the fragmentation in the distribution range of a species' ancestor, which may have been the propellant of the initial stages of divergence, without changes of the environmental niche of the allopatric populations. On the other hand, predicted suitable areas of *S. microlepis* in Afghanistan and Syria are likely not inhabited by the species due to the lack of accessibility in a biogeographical sense. The suitable areas in Zagros Mountains are not connected by suitable habitat to the highlands in Afghanistan and Syria. Therefore, the species could not colonize these areas.

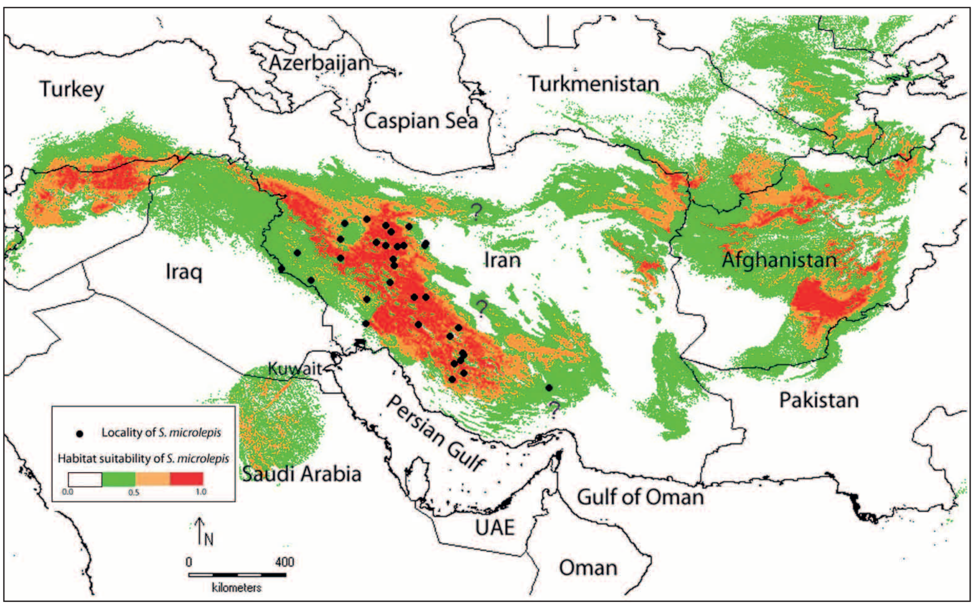

Figure 2. Potential distribution of *Spalerosophis microlepis* resulting from the best-fitting Maxent model. Predicted occurrence from low likelihood (white, 0.0) through green, orange to red (1.0). The question marks refer to doubtful records of *Spalerosophis microlepis.*

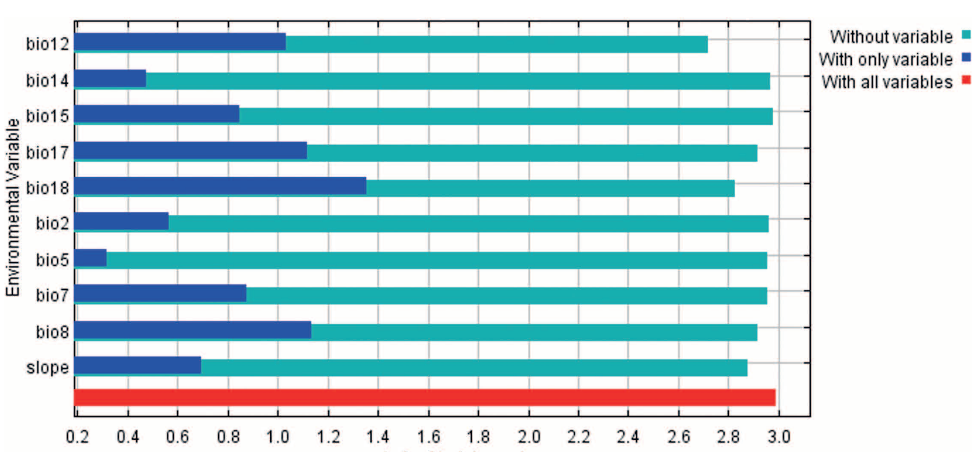

Figure 3. Results of Jackknife evaluations of importance of the variables used for our *Spalerosophis microlepis* Maxent model.

The model obtained suggests suitability for occupation to be the highest along the Zagros Mountains in western Iran, where most records originate. As already mentioned, doubtful records such as Semnan, western Yazd, and northern Hormozgan probably do not refer to *S. microlepis* and probably are based on misidentified *S. diadema*. In addition, the results of Maxent modelling did not show highly suitable habitat for *S. microlepis* in Iraq, but isolated populations of *S. microlepis* probably are located in the mountainous areas of the Kurdistan region, northwestern Iraq, which are considered part of the Zagros Mountains and known to harbour many species of reptiles and amphibians also present in the Iranian part of the Zagros. A recent study confirms the occurrence of an isolated population of the species in northwestern Iraq (Afrasiab & Mohamad 2014). Topographically, the Zagros Mountains form a barrier between the central plateau and the Mesopotamian lowlands and a corridor for the southward distribution of northern faunal elements (Fisher 1968). The mountains host the highest number of endemics on the Iranian Plateau and also are considered part of the 20th global hotspot region, the so-called Irano-Anatolian biodiversity hotspot (Mittermeier et al. 2004, Gholamifard 2011). Iran is home to ten endemic species of snakes and seven of these occur in the Zagros Mountains: *Xerotyphlops wilsoni, Hierophis andreanus, Eirenis rechingeri, Spalerosophis microlepis, Telescopus tesselatus, Pseudocerastes urarachnoides,* and *Eirenis (Pediophis) punctatolineatus condoni*. Consequently, the Zagros Mountains play a major role in the separation, isolation, and speciation of the Iranian herpetofauna (e.g., Anderson 1968, Rastegar-Pouyani et al. 2010, Hosseinzadeh et al. 2014).

Amongst the ten environmental variables that were used in this study, the most important factors were precipitation in the coldest quarter (bio18) and annual precipitation (bio12), as these variables contributed 40 and 20%, respectively. On the other hand, the AUC value of the full model was excellent and the standard deviation (SD) of the model was also very low, which implied a good performance of the model (Manel et al. 2001). Therefore, the results of our modelling indicated a trend for *S. microlepis* of preferably selecting relatively humid habitats (mountainous regions: Zagros Mountains, Hindu Kush Mountains). However, for *S. microlepis*, precipitation in the coldest quarter (bio18), annual precipitation (bio12), and mean temperature in the wettest quarter (bio8) were the three factors that were more significantly associated with its distribution. Commonly, environmental variables such as precipitation or temperature are responsible for the distribution patterns exhibited by many reptile species (e.g., Real et al. 1997, Brito et al. 1999, Guisan & Hofer 2003, Rodríguez et al. 2005, Hosseinzadeh et al. 2014). As has already been shown by many authors, reptiles and amphibians are ectotherms and absolutely depend on ambient warmth to raise their body temperature and then become active, so that they often have limited climatic tolerances and are strongly dependent on climatic conditions (Buckley et al. 2010, Luo et al. 2012, Hosseinzadeh et al. 2014).

We conclude that precipitation, temperature, and slope play the most important roles in predicting the distribution of *S. microlepis* as these factors contributed about 85% of the environmental factors to the full model. More fieldwork is needed throughout Iran and Iraq to shed more light on the remaining ambiguities of the distribution of *S. microlepis*.

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