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Habitat suitability and modelling the potential distribution of the Plateau Snake Skink *Ophiomorus nuchalis* (Sauria: Scincidae) on the Iranian Plateau

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Abstract. Species distribution models estimate the relationship between species occurrences and environmental and spatial characteristics. Herein, we used maximum entropy distribution modelling (MaxEnt) for predicting the potential distribution of the Plateau Snake Skink *Ophiomorus nuchalis* on the Iranian Plateau, using a small number of occurrence records (i.e. 10) and environmental variables derived from remote sensing. The MaxEnt model had a high success rate according to test AUC scores (0.912). A remotely sensed enhanced vegetation index (39.1%), and precipitation of the driest month (15.4%) were the most important environmental variables that explained the geographical distribution of *O. nuchalis*. Our results are congruent with previous studies suggesting that suitable habitat of *O. nuchalis* is limited to the central Iranian Plateau, although mountain ranges in western and eastern Iran might be environmentally suitable but not accessible.

Key words: Central Iranian Plateau, habitat, temperature, occurrence records, modelling, MaxEnt.

Introduction

Species distribution models estimate the relationship between environmental characteristics at species occurrences and environmental characteristics within the species' general area of occurrence (Franklin 2009). Hence, predictive models of potential geographic distributions are widely used for a variety of applications in ecology, conservation and biogeography (Graham et al. 2004, Guisan and Thuiller 2005). MaxEnt is one of the algorithms that can be used for the prediction of a species' potential distribution (Phillips et al. 2006). It is a machine-learning approach based on presence-only data, evaluating the likelihood of presence in a given cell on the basis of environmental features in the same cell (Elith et al. 2006, Wisz et al. 2008, Elith et al. 2010, Elith et al. 2011).

As many authors have shown, rare or poorly known species with limited available occurrence records are of particular interest to conservationists. Predictions with small sample sizes may provide useful results for prioritizing conservation of rare species or searching macroecological patterns in poorly known regions or taxa (Raxworthy et al. 2003, Engler et al. 2004, Guisan et al. 2006, Wisz et al. 2007). Based on previous studies, MaxEnt is the method most capable of producing useful results and prediction accuracy for small sample sizes using a jackknife procedure (Hernandez et al. 2006, Wisz et al. 2008, Pearson et al. 2007, Shcheglovitova & Anderson 2013).

The scincid lizard genus *Ophiomorus* comprises 11 species (Anderson & Leviton 1966, Nilson & Andrén 1978, Anderson 1999, Kazemi et al. 2011) which are distributed from the south Balkans of southeastern Europe to the Sindhian deserts of northwestern India (Anderson & Leviton 1966, Sindaco & Jeremčenko 2008). Seven species of *Ophiomorus* have been recorded from Iran: *O. blanfordi* Boulenger, 1887; *O. brevipes* (Blanford, 1874); *O. nuchalis* Nilson and Andrén, 1978; *O. persicus* (Steindachner, 1867); *O. streeti* Anderson and Leviton, 1966; *O. tridactylus* (Blyth, 1853); *O. maranjabensis* Kazemi et al., 2011 (Anderson 1999, Safaei-Mahroo et al. 2015, Kazemi et al. 2011). *Ophiomorus nuchalis* is one of the Iranian endemic species and its type locality is the northern slope of Siah Kooh in the center of the Kavir Protected Region, western portion of Central Plateau of Iran (Nilson & Andrén 1978; Anderson 1999). Its geographic distribution extends into the central part of Iran (Nilson & Andrén 1978, Hosseinzadeh et al. 2016). According to Nilson and Andrén (1978), *O. nuchalis* occupies a rockier habitat than does *O. brevipes*, but recent studies showed that *O. nuchalis* occupies different habitats including low hills with stony or rocky ground, areas near dry rivers with clay topsoil, agricultural farms and sand dunes (Nilson & Andrén 1978, Mozaffari et al. 2011, Farhadi Qomi et al. 2011, Hosseinzadeh et al. 2016). The habitat preferences of *O. nuchalis* are probably associated with morphological differences such as primitive limb morphology (which occurs in the four species which have four digits on the manus and three on the pes) and less specialized sand dwelling habits (Nilson & Andrén 1978).

In this study, we assess the potential distribution of *O. nuchalis* based on its realized niche. Sampling of the burrowing *Ophiomorus* is more difficult than sampling of other lizards in Iran. Hence, information on its geographic distribution and preferred habitats is also more limited than in other reptile species. We utilized a comprehensive, although small number of occurrence records with environmental layers (bioclimatic, remote sensing and topographic) to predict potential suitable habitats and identify the environmental variables associated with *O. nuchalis*'s potential distribution, with the aid of MaxEnt. Modelling the potential distribution of *O. nuchalis* may shed more light on habitat preferences and suggest further potentially suitable habitats harboring additional populations, undetected so far.

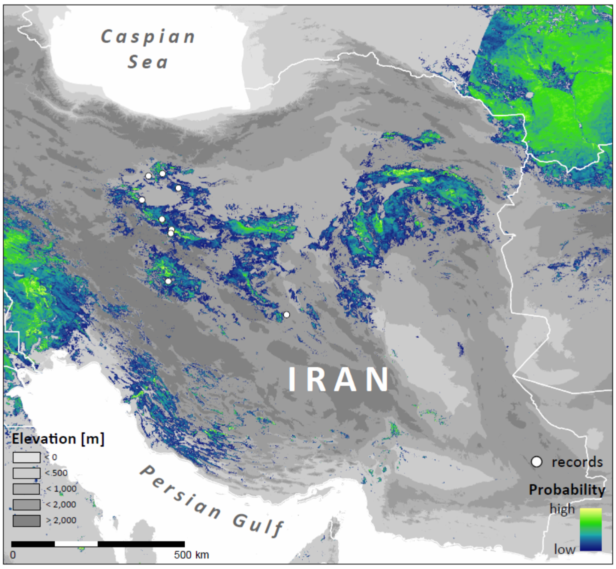

Figure 1. Predicted potential distribution for *O. nuchalis* in the Iranian Plateau.

Material and methods

All occurrence records of *Ophiomorus nuchalis* were compiled from our own field work, online available collections linked to the HerpNet databases (http://www.herpnet.org/) and literature sources (Nilson & Andrén 1978, Mozaffari et al. 2011, Farhadi Qomi et al. 2011, Hosseinzadeh et al. 2016). In total, 10 occurrence records of *O. nuchalis* have been gathered to be used for model building.

The realized environmental space of the taxa was quantified using a set of multi-temporal remote-sensing variables capturing key environmental features, including annual phenology in vegetation coverage and structure, temperature profiles and availability of humidity and insolation. The data set was created based on pre-processed monthly variables over the time period 2001–2005 from MODIS sensors of the two NASA satellites with a spatial resolution of 30 arc seconds provided by the EDENext project (www.edenext.eu; data set MODIS v4). Spectral bands as well as their products include middle infra-red (MIR; quantifying the water content of the surface; Jensen 2007); daytime and night time land surface temperature, normalized difference vegetation index (NDVI, Tucker 1979), and enhanced vegetation index (EVI, Huete et al. 1997); for details see Scharlemann et al. (2008). Annual and seasonal variation of the variables was captured using the *dismo* and *raster* packages (Hijmans 2015, Hijmans et al. 2015) in the R statistical package, version 3.2.2 (R Core Team 2014). As a general strategy, we computed temporal snapshots analogous to the original bioclim variables to capture seasonal temperature, MIR and NDVI changes. For NDVI, we computed the most and least productive vegetation seasons [analogous to mean temperature of the warmest quarter and mean temperature of the coldest quarter (bio10 and bio11), respectively], as three consecutive months to estimate seasonal changes in mean productivity. The complete set of variables describes the seasonal changes in the habitat of the species in terms of temperature, humidity and vegetation structure. In order to include precipitation, the corresponding bioclim variables were used (available through http://www.worldclim.org/, Hijmans et al. 2005). In addition, slope layer was computed in ArcGIS (vers. 10.2.2) by spatial analyst tools in order to approximate ground features such as insolation and topographic complexity.

We quantified correlations between all 50 environmental variables using Spearman's correlation tests. Variables with correlation coefficient greater than 0.75 were discarded in niche modelling (Rissler et al. 2006). For each correlated pair of variables, we tried to keep the putatively biologically most important variable. The procedure led to removing 35 of 50 environmental variables, and therefore, 15 variables were used in this study including slope, bio14 = precipitation of driest month, bio15 = precipitation seasonality, bio16 = precipitation of wettest quarter, bio17 = precipitation of driest quarter, ED1503_bio5 = max NIR of the month with the highest scores, ED1503_bio6 = min NIR of the month with the lowest scores, ED1503_bio7 = NIR annual range, ED1515_bio1 = annual mean EVI, ED1515_bio7 = EVI annual range, ED1515_bio11 = mean EVI of the quarter with the lowest scores, ED150708_bio5 = max EVI of the month with the highest scores, ED150708_bio6 = min temperature of coldest month, ED150708_bio7 = temperature annual range, ED150708_bio10 = mean temperature of warmest quarter.

Maximum entropy modelling was used to assess the species' potential distribution using MaxEnt v3.3.3k (Phillips et al. 2006). Environmental background was randomly drawn within an area enclosed by a radial buffer of 200 km around the presence locations. Testing is required to assess the predictive performance of the model. Subsampling has been the most commonly used method to partition the data randomly into a 'training' and 'test' sets, thus creating quasi-independent data for model testing (Fielding & Bell 1997, Guisan & Hofer 2003). However, this approach may not work with a small sample size, because the 'training' and 'test' datasets would be very small. Therefore, we followed Pearson et al. (2007) and used a jackknife (also named 'leave-one-out') procedure by 100 times randomly omitting one single record from the training set to assess the predictive performance of the model using the area under the curve (AUC) of the receiver operating characteristic (ROC) plot (Swets 1988). We used the 'lowest presence threshold' (LPT, equal to the lowest probability at the species presence locations) that can be interpreted ecologically as assessment pixels predicted as being at least as suitable as those where a species presence has been recorded, identifying the minimum predicted area possible, whereas maintaining zero omission error in the training data set. Within the projection area of the model, we identified those areas characterized by environmental conditions exceeding the training range using multivariate environmental similarity surfaces (MESS) (Elith et al. 2010). Projections beyond the training range of the model were discarded.

Results

The MaxEnt model predicted potential suitable habitat for *O. nuchalis* with high success rates ($AUC_{training}$ = 0.944, AUC_{test} = 0.912).

The potential distribution model of *O. nuchalis*, as suggested by the MaxEnt SDM, highlights the central mountain ranges in Iran as potentially suitable habitats, as well as some geographically isolated mountain ranges in western and eastern Iran and adjacent Turkmenistan (Figure 1). The most highly contributing variables were ED1515_bio11 (39.1%), bio14 (15.4%), bio17 (9.4%), ED170708_bio10 (8.3%), ED1503_bio7 (6.2%), bio16 (5.5%), and bio15 (5.3%). The remaining variables contributed less than 5% to the final model.

Average variable contributions across 100 MaxEnt models were: bio14 = precipitation of driest month (15.4%), bio15 = precipitation seasonality (5.3%), bio16 = precipitation of wettest quarter (5.5%), bio17 = precipitation of driest quarter (9.4%), ED1503_bio5 = max NIR of the month with the highest scores (0%), ED1503_bio6 = min NIR of the month with the lowest scores (2.6%), ED1503_bio7 = NIR annual range (6.2%), ED1515_bio1 = annual mean EVI (1.5%), ED1515_bio7 = EVI annual range (2.2%), ED1515_bio11 = mean EVI of the quarter with the lowest scores (39.1%), ED150708_bio5 = max EVI of the month with the highest scores (0.1%), ED150708_bio6 = min temperature of coldest month (1.3%), ED150708_bio7 = temperature annual range (0.3%), ED150708_bio10 = mean temperature of warmest quarter (8.3%) and slope (2.9%).

Discussion

Among the 15 environmental variables used in this study, the most important factors were the mean EVI of the quarter with the lowest scores (ED1515_bio11), indicating minimum vegetation coverage, and precipitation of driest month (bio 14), with contribution of 39.1% and 15.4%, respectively. Reptiles and amphibians are ectothermic and completely dependent on ambient warmth to raise their body temperature and become active, thus they often have limited climatic tolerance and are strongly dependent on climatic conditions (Luo et al. 2012, Buckley et al. 2010, Ficetola et al. 2013, Hosseinzadeh et al. 2014). The known distribution of the species (i.e. central Iran) has a warm and arid climate with high temperature in summer that may reach 50°C, and low temperature in winter, may reach -15°C. As the species is fossorial, it shows reasonable adaptation with desert ground which has remarkable temperature differences between summer and winter, and between day and night. According to Ahmadzadeh et al. (2016), climatic variables such as temperature seasonality can have an important role in niche divergence among species.

The model showed central parts of Iran as suitable habitat for *O. nuchalis,* part of which overlaps with the habitat of *O. brevipes*. According to Anderson and Leviton (1966), the species of *Ophiomorus* may be divided into western and eastern groups: the western group includes *O. latastii, O. persicus* and *O. punctatissimus,* and the eastern one comprises *O. blanfordi, O. brevipes, O. chernovi, O. raithmai, O. streeti, O. tridactylus and O. nuchalis*. In another study, Greer and Wilson (2001) confirmed the monophyly of the eastern group, but not of the western group, which is paraphyletic. Few authors have reported the close relationship between *O. nuchalis* and *O. brevipes* as members of the eastern group (Nilson & Andrén 1978, Greer & Wilson 2001). As mentioned above, the model suggests that southwestern Iran, which is occupied by another *Ophiomorus* species, *O. persicus* (placed in the western group), is suitable for this species. The distribution range of *O. persicus* is separated from that of *O. nuchalis* by the Zagros Mountains. Interestingly, the models indicated that the northeast of Iran, where *O. chernovi* is distributed, is also a suitable habitat, within which the Alborz Mountains act as a geographic barrier.

Predicting the geographic range of one species by projecting a model trained with a close relative species may indicate some degree of niche conservatism which is often related to a geographic mode of speciation (e.g. Warren et al. 2014). Anderson and Leviton (1966) discussed geographical isolation for species of *Ophiomorus* living in sand habitats. They suggested that different populations are isolated from one another by physical barriers. These sandy habitats may act as islands on which the populations probably have remained remarkably genetically and phenotypically stable. Hence it is likely that geological factors had a strong influence on the geographic range of *O. nuchalis*, as it has been suggested that the uplifting Zagros Mountains acted as a geological barrier that has had a major role in the diversification of the Iranian herpetofauna (Wischuf & Fritz 1996, Feldman & Parham 2004, Hrbek & Meyer 2003, Rastegar-Pouyani et al. 2010, Šmíd & Frynta 2012). Because of the presence of the Zagros Mountains, the east and southwest of Iran are considered as richness hotspots for reptiles, and the Iranian Plateau probably harbors a higher species richness than currently known (Ficetola et al. 2013).

In this contribution, we have delimited the potential distribution of *O. nuchalis* and compared it with the realized ranges of the other *Ophiomorus* species. We assessed the ecological separation in habitat preferences of *O. nuchalis* and its sister taxon, *O. brevipes*, and compared the results also with some *Ophiomorus* species from the eastern group, including *O. chernovi*. Based on our modeling results, *O. nuchalis* and its closely related species, *O. brevipes*, occupy the similar habitats. Our findings suggest that the potential distribution of *O. nuchalis* equals those of the other members of the eastern group. Moreover, northeastern parts of Iran are indicated as suitable habitat for *O. chernovi*, which is currently known from Turkmenistan. Probably the Alborz Mountains act as a geographic barrier. Besides, the distribution range of *O. persicus*, a member of the western group overlaps with the potential distribution of *O. nuchalis*. The findings support the hypothesis of a separation of *Ophiomorus* species by vicariance and geological events, wherein niches remained conserved. Niche conservatism is tendency of lineages for retaining their ancestral ecological traits leading to closely related species occupying similar niches. The role of niche conservatism in speciation can be very clear especially in vicariance, when niches remain stable when the distribution range of a species' ancestor becomes fragmented (Peterson et al. 1999, Wiens 2004, Wiens & Graham 2005, Ahmadzadeh et al. 2016).

The most obvious finding to emerge from this study was that *O. nuchalis* was found in different habitats, not only in rocky ones which was mentioned by Nilson and Andrén (1978) for the first time. Its distribution probably extends to the foothills of the Zagros Mountains. Moreover, species of *Ophiomorus* were delimited using morphological characters by some researchers and then further research is required to explore the taxonomic status between *O. nuchalis* and the other species of the eastern group, especially *O. brevipes*, using molecular data. In addition, molecular studies covering all species of the genus are required to validate the systematic status of eastern and western groups and their members. Furthermore, more field surveys are necessary to explore the microhabitat preferences of the species. The variable ecological conditions within this diverse range of potential habitats provide very divergent local micro-habitats, depending on ground structure comprising salt flats, stony or gravelly hills, sand dunes, rocky mountain slopes and brackish springs.

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