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Modelling the potential distribution of *Mesalina watsonana* (Stoliczka, 1872) (Reptilia: Lacertidae) on the Iranian Plateau

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The Persian Long-tailed Desert Lizard, *Mesalina watsonana*, is one of the most common and most widely distributed lizards on the Iranian Plateau extending from Iran to Pakistan and Afghanistan. The species is frequently encountered in various types of habitats. We collected over 600 distributional records from available literature, museum collections, and our own field work and used bioclimatic and land cover characteristics to develop a model of potential distribution for *M. watsonana*. According to the model, the most important factors limiting the distribution of *M. watsonana* are: precipitation in wettest quarter exceeding 250–300 mm, precipitation in coldest quarter lower than 40 mm and exceeding 250 mm, altitudes above 2500 m and slopes steeper than 10.5°. The model suggests that most of the Iranian Plateau is suitable for the species except for some isolated areas such as the Dasht-e Kavir and Dasht-e Lut deserts in Iran, Helmand basin in Afghanistan, the Karakum Desert in Turkmenistan, the western Chagai-Kharan deserts of Pakistani Balochistan, and Thar and Cholistan deserts in eastern Pakistan. The most important factor in these regions appears to be the extremely low rainfall during coldest quarter of the year. The outer boundary of the distribution of *M. watsonana* follows important biogeographic barriers that are also clearly delimited by climatic conditions.

Keywords: Middle East, Iran, Afghanistan, Pakistan, Maxent, habitat suitability, potential distribution.

Introduction

Mesalina Gray, 1838 is a widespread lacertid genus distributed throughout the Saharo-Sindian desert belt from Morocco in the west to westernmost India in the east. The genus currently contains 14 species, most of which are found in Africa (Schleich, Kästle, & Kabisch, 1996; Sindaco & Jeremčenko, 2008). The Persian Long-tailed Desert Lizard, *Mesalina watsonana* (Stoliczka, 1872), is widely distributed in most of Iran, Pakistan, Afghanistan and westernmost parts of the Indian Thar Desert (Anderson, 1999; Khan, Baig, Masroor, & Arshad, 2008; Sindaco & Jeremčenko, 2008). Marginally it also occurs in Turkmenistan, where it is restricted to clay and crushed stone substrate in the Karakum Desert and northern Kopet Dagh piedmont (Shammakov, 1981; Schammakov, Ataev, & Rustamov, 1993). The range in Afghanistan is limited to the western and southern lowlands (Leviton & Anderson 1963; Clark, Clark, Anderson, &

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Leviton 1969). In Pakistan this species occupies a variety of habitats and is widely distributed (Khan, 1980, 2006; Baig, Masroor, & Arshad, 2008; Masroor, 2012). So far there is no evidence that *M. watsonana* occurs in Iraq (Lahony, pers. comm.). *Mesalina watsonana* is the sole representative of the genus on the Iranian Plateau. Its distribution overlaps only marginally with *M. brevirostris*. Although there are some reports of their syntopic occurrence in western Iran (Anderson, 1999), records from the western slopes of Zagros were shown to be misidentified individuals (Fathinia, Rastegar-Pouyani, Sampour, Bahrami, & Jaafari, 2009). Throughout its range, this lizard inhabits a wide spectrum of habitats ranging from sea level to just under 2500 m of elevation and including open plains with hard soil, alluvial plains with loose substrates, sandy gravel steppes and semideserts with scanty shrubby vegetation, bare areas, and deserts (Smith, 1935; Anderson, 1963, 1968, 1999; Khan, 2006). Based on ecological and distributional data, this species is adaptable to a wide range of habitat types.

As shown recently, *M. watsonana* forms a monophyletic group sister to all other *Mesalina* species (Šmíd & Frynta, 2012). Based on molecular clock calibrations, the split between *M. watsonana* and the remaining taxa is estimated to take place in the mid-Miocene (15.9 Ma). Despite the species is very agile and widespread on the Iranian Plateau, there is remarkably deep phylogeographic structuring at the population level with seven million years old basal radiation (Šmíd & Frynta, 2012).

Models of potential species distribution of the remarkably rich herpetofauna of Iran have previously focused on species with relatively limited distribution (Ahmadzadeh et al., 2012; Litvinchuk, Mazepa, Kami, & Auer, 2012). For the present study we gathered all available distributional records of *M. watsonana* from throughout its range and added more data from field work carried out in Iran, Afghanistan and Pakistan. The most up-to-date map of the distribution of the species is presented here. The occurrence data were then used to estimate the potential distribution of the species in the region and to identify areas with suitable habitat.

Material and Methods

Data sources. All distribution records of *M. watsonana* from Iran prior to 1999 were summarized by Anderson (1999 – see references therein) including exact localities, all of which are included in our study. Records from Afghanistan, Pakistan, India, Turkmenistan and Iran covering the whole range of the species distribution were obtained from available literature sources (Boulenger, 1889; Alcock & Finn, 1897; Smith, 1935; Leviton, 1959; Leviton & Anderson, 1963, 1970; Mertens, 1965, 1969; Minton, 1966; Anderson & Leviton, 1969; Clark et al., 1969; Král, 1969; Khan, 1972, 1980, 1986, 2006; Shammakov, 1981; Schammakov et al., 1993; Tuniyev, Atayev, & Shammakov, 1998; Baig & Masroor, 2006; Baig et al., 2008; Masroor, 2009; Oraie, Khosravani, Rastegar-Pouyani, & Ghoreishi, 2011, Šmíd & Frynta, 2012). Coordinates of localities given exactly in the literature but missing geographic coordinates were estimated using Google Earth.

Apart from published records, data from the following museum collection catalogues were gathered. The number of specimens used in the current study are in parenthesis: **AMNH** - American Museum of Natural History, New York (5 specimens); **BMNH** - British Museum Natural History, London (37); **CAS** - California Academy of Science, San Francisco (173); **CM** - Carnegie Museum of Natural History, Pittsburgh, USA (4); **FMNH -** Field Museum Natural History, Chicago (14); **MMTT -** National Museum of Natural History, Tehran (14); **MRSN** - Museo Regionale di Scienze Naturali, Torino, Italy (2); **MVZ -** Museum of Vertebrate Zoology, Berkeley, USA (12); **MZUF -** Museo Zoologico, Università, Firenze, Italy (1); **NHMW** - Naturhistorisches Museum Wien, Austria (51); **NMP** – National Museum in Prague, Czech Republic (1); **PMNH -** Pakistan Museum of Natural History, Islamabad, Pakistan (25); **RQP -** Reptiles of Qom project, Department of Environment of Qom, Iran (14); **SMF -** Strategic Missile Forces Museum, Pobuzhskoe, Ukraine (13); **SUHC -** Sabzevar University Herpetological Collection, Khorasan Razavi, Iran (112); **UMMZ -** University of Michigan Museum of Zoology, Michigan(1); **USNM**-United State National Museum, Washington (35). New data were also collected by the authors (SSHY, ERP, RM). The first author conducted 130 days of field surveys on the Iranian Plateau. The final dataset consisted of 591 distribution records. ENMTools 1.3 (Warren, Glor, & Turelli, 2010) was employed to filter out duplicate records which resulted in a dataset of 382 unique distribution records (Figure 1).

Species distribution modelling. To reduce geographical sampling bias in distribution records caused by areas with dense records on the one hand and undersampled regions on the other, Occurrence Thinner 1.04 (Verbruggen, 2012) was employed. The program works with distribution records and a kernel density grid and uses a probability-based procedure, which removes records proportionally based on the density of records in the area defined by the kernel density grid and filters out records from areas with high densities of records and thus produces more even distribution of occurrence points. Occurrence Thinner was run under default settings. The background area used to mask all data layers for model calibration included all countries from which *M. watsonana* has been recorded and neighbouring countries that lie within 200 km from any known record, except that only the north-western part of India was included. A potential distribution model was based on present-day bioclimatic variables (downloaded from the WorldClim database; www.worldclim.org; Hijmans, Cameron, Parra, Jones, & Jarvis, 2005) and global land cover data (downloaded from the ESA - European Space Agency; http://ionia1.esrin.esa.int) at a resolution of 30 arc-seconds. To evaluate the potential effect of slope steepness, a slope layer was created from the original WorldClim altitudinal data using ArcGIS 9.3. Land cover types covering less than 1% of the background area and those without any importance for the species distribution (water bodies, permanent snow) were excluded from the analysis. Closely related land cover types were merged into one character. In order to reduce the effect of collinearity among predictor variables (Heikkinen et al., 2006), correlations between all variables were measured with Pearson's correlation coefficient in ENMTools. We included all variables with correlations lower than 0.75 and variables considered to be ecologically important for *M. watsonana* (Anderson 1999, pers. obs.).

The following climatic and land cover variables were included in the final subset of characters: Altitude; Slope; BIO2 Mean diurnal temperature range; BIO4 Temperature seasonality; BIO5 Maximum temperature of the warmest month; BIO6 Minimum temperature of the coldest month; BIO10 Mean temperature of warmest quarter; BIO15 Precipitation seasonality; BIO16 Precipitation of wettest quarter; BIO17 Precipitation of driest quarter; BIO19 Precipitation of coldest quarter; Irrigated + Rainfed croplands (merged); Mosaic croplands/vegetation + Mosaic vegetation/croplands (merged); Mosaic grassland/forest-shrubland; Closed to open grassland; Sparse vegetation; Bare areas. Potential species distribution models were generated using the maximum entropy approach in Maxent 3.3.3k (Phillips, Anderson, & Schapire, 2006), using 25% of the data as test samples for the model, performing the jackknife procedure for evaluating the importance of each predictor, and random seeding. Convergence threshold and maximum number of iterations were left by default (0.00001, 500 respectively). Other settings were left at default levels. The final model was based on the average of ten replicates of this procedure. Because the data sources we used were likely to have some errors (non-precise or missing coordinates), suitable habitat was defined and displayed using the 10 percentile training presence logistic threshold that includes 90% of the data we used to develop the model and discards 10% of the most outlying data (Pearson, Dawson, Berry, & Harrison, 2002) (Figure 1). The resulting area under the ROC curve (AUC), which ranges from 0 to 1, was taken as a measure of overall model accuracy. A value of 0.5 indicates model accuracy not better than random; the closer to 1, the better is the model performance. The developed model of potential distribution was tested for significance against null models derived from a set of as many localities as used for the species distribution (382) randomly selected from the background area used for model calibration (Raes & Ter Steege, 2007). We created 100 sets of these 382 random distribution records using ENMTools and subsequently developed models of potential distribution with the same Maxent settings as for the tested model (see above) and compared their AUC value with that of the tested species distribution model. The tested model deems statistically significant if it ranks among 5% of the best performing models with highest AUC values.

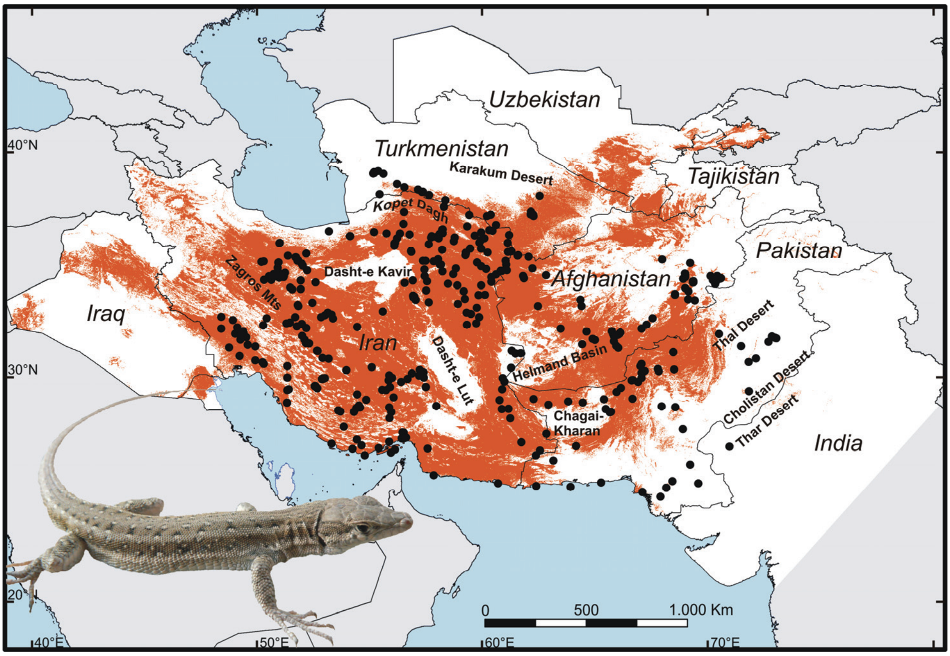

Figure 1. Potential distribution of *Mesalina watsonana* using 10 percentile training presence logistic threshold from the best-fitting Maxent model (orange, dark grey in print). Black dots signify available literature records, data from museum catalogues and new data from the field used for the species distribution modelling; the background area of the model is in white.

Results

The most contributing variables explaining more than 10% of the presence of *M. watsonana* were: BIO16 Precipitation of wettest quarter (18.8%), slope (13.2%), altitude (13%), and BIO19 Precipitation of coldest quarter (11.3%). All other variables had a gradually decreasing contribution from 8.8% downwards. All categorical land cover variables had a minimal effect on the probability of presence of *M. watsonana*; none of them contributed more than 0.5%. The average test AUC value of the model was 0.808±0.0239 and the 10 percentile training presence logistic threshold was 0.3196. The final model performed significantly better than the null models developed from random distribution records (AUC of null models ranging from 0.6 to 0.6725). According to the model developed, suitable habitat for *M. watsonana* is clearly delimited by the environmental factors. The probability of presence is very low in environments with precipitation of wettest quarter (BIO16) exceeding 250–300 mm, precipitation of coldest quarter (BIO19) lower than 40–50 mm and exceeding 250 mm (the Pearson's correlation coefficient between BIO16 and BIO19 = 0.26), on slopes steeper than 10.5°, and at altitudes above 2500 m (Figure 2).

The potential distribution of *M. watsonana* includes most of Iran, a part of the Mesopotamian plain northeast of the Tigris River in Iraq, lowland areas of western and northern Afghanistan, eastern Turkmenistan and Uzbekistan and a territory in Pakistan lying northwest of the Indus River. Isolated areas within these borders without suitable conditions were discovered in central Iran, namely the two largest desert systems –

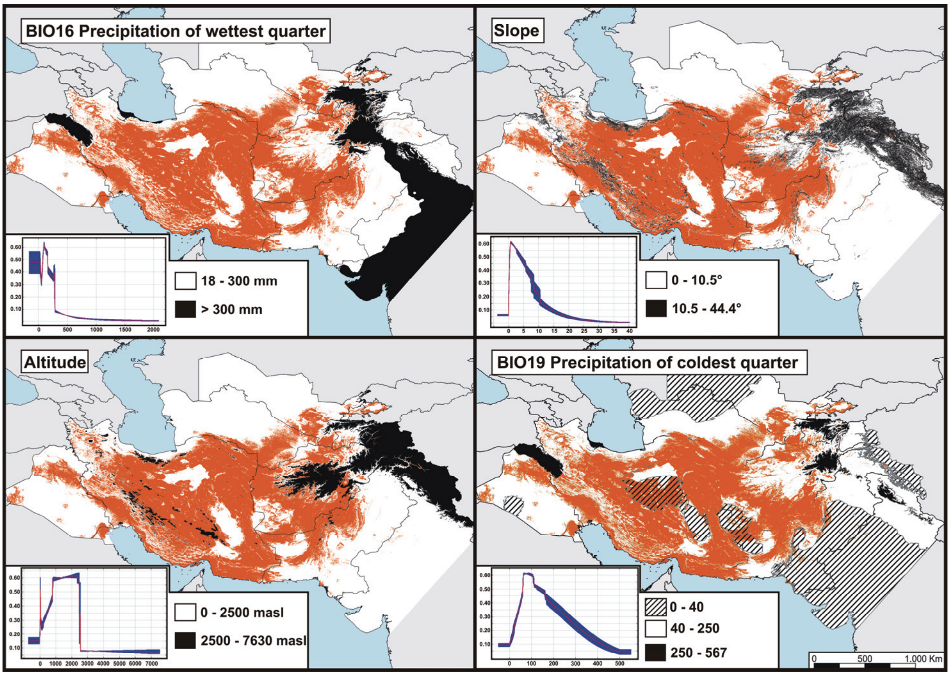

Figure 2. Four environmental variables contributing more than 10% to the final model and delimiting the distribution of *M. watsonana*: BIO16 Precipitation of wettest quarter (18.8%), slope (13.2%), altitude (13%), and BIO19 Precipitation of coldest quarter (11.3%). Only the background area used to develop the model is depicted. Potential distribution is in orange (dark grey in print). Areas of low probability of the species presence as depending on individual predictors are in black and dashed. The inset graphs show the response curves for each variable (y-axis represents the probability of species presence, x-axis values of individual variables).

Dasht-e Lut and Dasht-e Kavir; in Chagai-Kharan, Thar and Cholistan deserts in Pakistan and in the Helmand basin on the Iran/Afghanistan boundary (Figure 1). Apart from the extremely low precipitation of coldest quarter (BIO19), the most important factors limiting the distribution further in the southeast direction to Pakistan and India are, despite their lower contribution to the model, the land cover characteristics. The border region between Sindh (Pakistan) and Rajasthan (India) with mosaic forest-shrubland/ grassland coverage (glob_120) and most of northern India and the Indus valley in Pakistan that are typical for irrigated and rainfed croplands (merged glob_11 and glob_14 layers) were not predicted to be suitable (probability of presence in mosaic grassland/ forest-shrubland = 0.51, elsewhere = 0.24; in irrigated/ rainfed croplands = 0.34, elsewhere = 0.51). Although there are some distributional records from inland Turkmenistan, there is a remarkably straight boundary in the potential distribution of *M. watsonana* running along the western border between Iran and Turkmenistan, rendering most of the plains of Turkmenistan unsuitable.

Discussion

The present study provides the first results of species distribution modelling for a broadly distributed and ecologically tolerant reptile species on the Iranian plateau. As has been shown before, predictions of generalist species that occupy a wide variety of habitats tend to be less accurate compared to predictions of rare or specialized species with strict ecological requirements (Elith et al., 2006; Tsoar, Allouche, Steinitz, Rotem, & Kadmon, 2007; Jiménez-Valverde, Lobo, & Hortal, 2008). In spite of the limitations of museum collections data and records from publications (which often lack desired precision: models derived from such records perform worse than models developed from precise GPS data, see e.g. Graham, Ferrier, Huettman, Moritz, & Townsend Peterson, 2004; Kaliontzopoulou, Brito, Carretero, Larbes, & Harris, 2008; Beukema et al., 2010), they are still the primary and frequently the only source of information about species distribution and should be utilised for species distribution modelling (Ponder, Carter, Flemons, & Chapman, 2001; Elith & Leathwick, 2007).

As suggested before, *M. watsonana* probably diverged from the rest of the genus after the uplift of the Zagros massif in the mid-Miocene (Šmíd & Frynta, 2012). The fact that the species does not inhabit high altitudes suggests that it has limited ability to cross continuous mountain ranges and thus supports the hypothesis of the Zagros uplift as a crucial biogeographic barrier. Absence of *M. watsonana* in the Mesopotamian plain in Iraq, where the suitable habitat exists, may be a result of interspecific competition with ecologically equivalent *M. brevirostris* (Haas & Werner, 1969; Anderson, 1999). The distribution of these two species is parapatric with a very limited overlap in the contact zone (e.g. Kalabagh area and Thal Desert, Pakistan). Expanding the model predictors by the distribution of an ecologically similar but allopatric species would probably help to enhance the model accuracy and filter out areas potentially suitable for both competing species. This may also apply for the potentially suitable areas in eastern Uzbekistan and extreme northern Afghanistan from where there are no known records of *M. watsonana* but where several ecologically similar species of *Eremias* abound (Leviton & Anderson, 1970). Absence in the plains of Turkmenistan can be explained by unsuitability of environment caused by temperature seasonality (BIO4, contribution 8.8%) with high fluctuations of temperatures, which is higher in northern latitudes and may confine the distribution of Saharo-Sindian species to the south. It has been shown before that environmental conditions change abruptly on the Iran/Turkmenistan border beyond the Kopet Dagh range and species inhabiting only one side of this boundary have restricted potential to occur on the other side of the massif (Gavashelishvili & Lukarevskiy, 2008; Graham, Oláh-Hemmings, & Fet, 2012). The Kopet Dagh mountain range therefore represents not only physical barrier, but also a boundary dividing thermally fluctuating Turkmenistan from more climatically stable and extremely arid Iran (Breckle, 1983; Anderson, 1968).

Two factors contribute most to the south-eastern limits of the potential distribution of *M. watsonana* – extreme dryness in coldest quarter and, although only marginally, high precipitation of wettest quarter (Figure 2) which coincides with the western termination of the influence of the Indian monsoon (Anderson, 1968; Krishnamurthy & Kinter, 2002). Records from lowland Pakistan from the Indus River basin lying within the cropland habitat outside the predicted distribution can probably be explained by fragmentation of the croplands and presence of transitional habitats. The vast river drainage system provided by extensive canalization in Punjab and partly in Sindh for irrigation purposes has fragmented the habitats, which in turn offers climatic conditions suitable for the species to occur in diversified habitats. The extreme temperatures in the deserts of Cholistan, Thar and Thal are somewhat neutralized by the effect of habitat fragmentation and the availability of shrub cover.

As mentioned before, the absence of suitable habitat for *M. watsonana* in the desert areas on the Iranian Plateau – the Dasht-e Lut, Dasht-e Kavir deserts in Iran and the Chagai-Kharan deserts in western Pakistan – may be caused by the extremely dry conditions with very low total annual rainfall and almost no rainfall during coldest quarter of the year (Figure 2). The fact that *M. watsonana* has never been collected or observed here only confirms its predicted absence in these places. Contrary to the importance of precipitation, temperatures do not seem to limit *M. watsonana* in its potential distribution. Even areas with extremely high temperatures like the Mesopotamian plain support potential presence of this species.

Our study is the first to use species distribution modelling on a widely distributed lizard species for the whole Iranian Plateau. The model of suitable habitat suggests that despite the obviously wide ecological tolerance of *M. watsonana* there are areas of unsuitable conditions lying within its distribution on the Iranian Plateau. The absence of distributional records from such regions is therefore not an artefact caused by a lack of collecting effort, but apparently a natural hiatus in the species distribution. Whether the same conditions contribute to exclusion of other widespread reptile taxa from Iranian deserts remains to be studied.

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