Modeling Geographic Distribution for the Endangered Yellow Spotted Mountain Newt, *Neurergus microspilotus* (Amphibia: Salamandridae) in Iran and Iraq

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Abstract.—The endangered Yellow Spotted Mountain Newt, *Neurergus microspilotus*, is a poorly known species that has been reported from highland first order streams in western Iran and eastern Iraq. We used a presence-only model to provide potential distribution for the species and identified the variables best explaining the occurrence of the species. Using available information on known localities of *N. microspilotus*, we developed a maximum entropy (MaxEnt) model to predict potential distribution of this species in Iran and Iraq. After the model was validated, we found that low (< 0–20) suitability scores for *N. microspilotus* presence corresponded to 52% of the total area considered (26,572 km²); whereas, high (80-100) suitability scores corresponded to only 2% of this area. Of the total suitable habitat, approximately 67% is located in Iran and 33% in Iraq. The model achieved a 1.8 regularized gain value with contribution of more than 51% provided by precipitation of coldest quarter as the main factor influencing the model performance. With three protected areas in Iraq and one in Iran near or within the predicted distribution, only 2.29% of range for the species was within protected areas. The model indicated high suitability score for considerable area in Iraq that has not been searched for *N. microspilotus*. To preserve the species, we recommend surveys of Iraqi territory in search of *N. microspilotus* and to initiate studies to allocate more reserves with corridors that bridge the otherwise impermeable gaps between the breeding streams.

Key Words.--amphibian; biodiversity; conservation; endangered species; species distribution modeling

INTRODUCTION

Modeling the distribution of a species provides an important tool to identify the key ecological factors determining spatial patterns of occurrence. The application of models for predicting the geographic distribution of a species is becoming important in conservation biology because it provides opportunities to address a wide range of problems (Tsoar et al. 2007). A large number of models are in use that estimate the spatial distribution of plant and animal species (Kumar and Stohlgren 2009; Yang et al. 2013). In recent years, combining ecological data with spatial data have been used for various conservation purposes, including delimiting or defining population distinctiveness of various types (Mota-Vargas and Rojas-Soto 2012), detecting new populations of threatened species (e.g. Rebelo and Jones 2010), mapping suitable habitat for endangered species (Chunco et al. 2013; Groff et al. 2013), selecting re-introduction sites (Martínez-Meyer et al. 2006), restoring native populations in their natural habitat (Khafagi et al. 2012), providing support to species

conservation or reserve planning (Carvalho et al. 2010; Doko et al. 2011), assessing the degree of protection coverage granted by nature reserves (Domíguez-Vega et al. 2012), and designing conservation and management plans (Gebremedhin et al. 2009).

A variety of modeling methods for species distribution are available to predict potential suitable habitat for a species (Guisan and Zimmermann 2000; Wisz et al. 2008). Most modeling methods for species distribution are sensitive to the number of occurrences (Wisz et al. 2008) and may not be able to accurately predict habitat distribution patterns for threatened and endangered species because presence data may not be available for rare and endangered species (Engler et al. 2004). MaxEnt is a general purpose environmental model for predicting the potential distribution of species. The method requires only species presence data and environmental information (Elith and Leathwick 2009). MaxEnt can make use of both continuous and categorical data and incorporate the interactions between the variables (Phillips et al. 2006). Presenceonly modeling methods simply require a set of known

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FIGURE 1. Adult Yellow Spotted Mountain Newt, *Neurergus microspilotus*, in Ghorighala stream in northern Kermanshah Province, Iran. (Photographed by Mozafar Sharifi).

occurrences together with predictor variables, such as topography, climate, soil, and biogeography (Phillips and Dudik 2008).

Twenty five species of amphibians are known to occur in Iran, including 18 species of anurans and seven species of salamanders (Baloutch and Kami 1995). The Yellow Spotted Mountain Newt, Neurergus microspilotus (Fig. 1), is reported from Iran and Iraq (Afroosheh et al. 2016). This species is listed as Critically Endangered by the International Union for Conservation of Nature (IUCN; Red List criteria: A3cde+4cde; B2ab [iii, iv, v] ver. 3.1) because of its very small area of occupancy in its breeding stream ($< 10 \text{ km}^2$), fragmented habitats, a continuing decline in the extent and quality of its stream habitat, reduced number of subpopulations and individuals associated with habitat degradation, drought, and overcollection of animals for both the national and international pet trade (Sharifi et al. 2009; IUCN 2017). The breeding habitat of N. microspilotus in the Zagros Mountain Range has been degraded recently by water pollution, water extraction, and severe droughts, which have led to the extirpation of some populations (Sharifi and Assadian 2004). Extraction of stream water for use in nearby orchards is also a major threat to this species (Sharifi et al. 2009; IUCN 2017).

Among the main factors responsible for the reduction of *N. microspilotus* population size and geographical range are the loss and fragmentation of original terrestrial habitat associated with development and land use alteration along breeding streams that covered most of the original range of the newt (Afroosheh et al. 2016). In addition to habitat loss and fragmentation, any reduction in population size or local extinction in the breeding streams is difficult to compensate for because of the very small home range and limited dispersal ability in water and over land (Sharifi and Afroosheh 2014). Additionally, the increasing frequency of droughts experienced in highland streams in western Iran associated with climate change may have reduced the reproductive success of *N. microspilotus* because the streams dry before larvae undergo metamorphosis. Climatic conditions are expected to continue to change and it is likely that, similar to other amphibians in western Iran and elsewhere, metamorphosis, development, and growth of *N. microspilotus* will be negatively affected (Vaissi and Sharifi 2016a). Although, the remaining populations of *N. microspilotus* are increasingly threatened by human actions, at present none of the populations have been specifically covered by the Iranian or Iraqi systems of national parks and protected areas, nor have they been included by any kind of public or private effective protection or conservation legislation.

Barabanov and Litvinchuk (2015) have used MaxEnt modeling to predict distribution of various species of the Middle East mountain newts belonging to the genus Neurergus, including Strauch's Spotted Newt (Neurergus strauchi), Lake Urmia Newt (Neurergus crocatus), Kaiser's Mountain Newt (Neurergus kaiseri) and Yellow Spotted Mountain Newt (Neurergus microspilotus). These species occur in southern Zagross Range in Iran, western Zagross in Iran and Iraq, and also in southern Turkey. Barabanov and Litvinchuk (2015) found that four climatic variables associated with temperature and precipitation accounted for 92.1% of the predicted range. However, their study aimed to demonstrate distributional peculiarities of the genus Neurergus as a whole (five taxa) and used 144 known localities of the genera including 26 localities for the Yellow Spotted Mountain Newt. The model had high mean test for the area under the curve (AUC) value (0.977) and showed continual distribution without gaps for all species except for Neurergus kaiseri.

Our primary objective in this study is to predict the distribution of breeding sites of N. *microspilotus* in Iran and Iraq. We also suggest measures to help conserve this species. In this study, we develop a maximum entropy (MaxEnt; Phillips et al. 2006) presence-only distribution model to: (1) carry out the first geographical distribution analysis for N. *microspilotus* and predict distribution of N. *microspilotus* in Iraq where there is not much information about this newt, (2) determine which ecological factors may be limiting the species distribution in the study area, and (3) evaluate the current degree of fragmentation of N. *microspilotus* habitat in Iraq and Iran.

MATERIALS AND METHODS

Study area.—Iran covers an area of approximately 1,600,000 km². Two-thirds of Iran is located in the Iranian Plateau, which is a part of a greater geographic unit extending from east of the Anatolian Plateau to the western edge of the Tibetan Plateau (Noroozi



FIGURE 2. Presence records (circles) along Iran and Iraq border considered for the development of a maximum entropy model (MaxEnt) predicting habitat suitability for the Yellow Spotted Mountain Newt, *Neurergus microspilotus*.

et al. 2007). Extreme topographical relief, diverse climatic conditions, and geographic position of the area between several biogeographic zones have resulted in high biodiversity (Wright et al. 1967). The Zagros Mountain Range acts as a barrier to incoming air masses from the west and receives precipitation based on the elevation and longitude. In general, the northern and western portions of the range receive considerably more precipitation than areas in the south and east. Much of the vegetation cover in the range of N. microspilotus has been converted into agricultural lands (Afroosheh et al. 2016). In southern parts of the distribution of the species in Kurdistan and Kermanshah Provinces. natural vegetative cover ranges from thin scrublands on steep rock outcrops to dense woodlands with diverse tree species. In areas where soil is thick, an open Oakpistachio Woodland may be present. These woodlands are dominated by Brant's Oak (Quercus brantii) and by Common and Khonchic Pistachio (Pistachio vera and P. khonchic). These tree species may play an important role in supporting primary production in the streams by exporting foliage to the benthic community of the highland streams where the macroinvertebrate community is the sole food source for N. microspilotus (Farassat and Sharifi 2014).

Environmental data.—Distributional records of *N. microspilotus* are limited to 42 specific localities (Fig. 2), which are summarized by Afroosheh et al. (2016). Distributional information was provided by Schmidtler and Schmidtler (1975), who first reported this species from Iran with subsequent studies by Sharifi and Assadian (2004), Najafimajd and Kaya (2010), Schneider and Schneider (2010), Naderi (2012), and Afroosheh et al. (2016). Initially, we calibrated the model using 21 environmental variables, 19 of which were bioclimatic and obtained from the WorldClim

project (downloaded from the WorldClim database; www.worldclim.org). We retrieved vegetation cover data from the global land cover data (downloaded from the ESA-European Space Agency; http://ionia1. esrin.esa.int) and a slope layer was created from the original WorldClim altitudinal data using ArcGIS 9.3. We removed environmental variables that provided no contribution to the preliminary models. Initially, we calculated the correlations among all WorldClim bioclimatic variables and topographic variables for all locations to exclude the highly-correlated ones (r > r)0.75), while keeping variables such as climatic averages and extremes. We included the following climatic and land cover variables in the final subset for calibration: precipitation of coldest quarter, precipitation of warmest quarter, isothermally (BIO2/BIO7) (×100), temperature seasonality (standard deviation×100), temperature annual range (BIO5-BIO6), mean temperature of wettest quarter, mean temperature of driest quarter, and digital elevation mode. We masked all environmental layers, set up the extent and cell size, and exported them as ASCII grids for use in model development. We used maximum number of 10,000 points to determine the background distribution, maximum interactions of 1,000, and a convergence threshold of 0.001.

Modeling procedures .-- To model the geographic distribution of the N. microspilotus, we used Maximum Entropy Species Distribution Modeling (MaxEnt; Phillips et al. 2006) ver.3.3.3k (http://www.cs.princeton. edu/~schapire/maxent). To build the model, we used the 42 presence records of N. microspilotus and nine environmental variables. We selected the logistic output format to generate response curves and Jackknife results. The final map obtained had a logistic format providing the probability of occurrence according to a 0-1 scale. We selected the 20th percentile as the threshold value to define the presence of the species. To evaluate the fit of a model, we used the area under the ROC curve (AUC) and omission rate. The AUC values can range between 0-1, with good models producing AUC values of 0.8-0.9, and models with excellent discriminating ability producing AUC values of 0.9-1.0.

Using the approach proposed by Raes and ter Steege (2007), we also tested the model to check whether it differed significantly from what would be expected by chance. First, we generated null models by randomly drawing 42 localities in the study area (the same number of presence data as used in the distribution models mentioned above). We repeated this procedure 100 times to obtain a frequency histogram of AUC from which it was possible to determine a probability of AUC value other than chance. We also tested our model for environmental bias in presence data. For that, a distribution model using all presence data was tested



FIGURE 3. Maximum entropy model developed for the Yellow Spotted Mountain Newt, *Neurergus microspilotus*, in its known distribution in Iran and Iraq. Percentage probability of occurrence is pooled in five categories and expressed as different shades of grey shown in the legend.

1,000 times against a null model with an equal number of random points for the entire study area. Additionally, we adopted a Jackknife analysis to estimate which variables were most important for model building. During this process, we generated a number of models. First, each Eco-Geographical Variable (EGV) was excluded in turn and a model created with the remaining variables to determine which variable was most informative. Then, we created a model for each individual EGV to determine which variable had the most information that is not present in the others.

Validation of predictive models.—We also tested the model to check whether it differed significantly from what would be expected by chance using the approach proposed by Raes and ter Steege (2007). First, we generated null models by randomly drawing 42 localities in the study area (the same number of presence data as used in the distribution models mentioned above). We repeated this procedure 100 times to obtain a frequency histogram of AUC from which it was possible to determine a probability of AUC value other than chance. Subsequently, we also tested the model for environmental bias in presence data. For that, we tested a distribution model using all presence data 1,000 times against a null model with an equal number of random points for the entire study area. Additionally, we used a Jackknife analysis to estimate which variables were most important for model building.

We conducted testing or validation by dividing the data randomly into Training and Test sets, thus creating quasi-independent data for model testing (Fielding and Bell 1997). We followed Pearson et al. (2007) and used a Jackknife (also called leave-one-out) procedure, in which model performance was assessed based on its ability to predict the single locality that is excluded from the Training dataset (Pearson et al. 2007). Fortyone different predictions were thus made with one of the occurrence records excluded in each prediction and the final potential habitat map was generated using all records. The jackknife validation test required the use of a threshold to define suitable and unsuitable areas. To assess the degree of protection granted to N. microspilotus by the present protected areas in Iran and Iraq, we overlaid the MaxEnt presence/absence map with the shape files containing the boundaries of three Iraqi protected regions (Qara Dagh, Peramagroon Mountain, Sakran Protected Area) and one Iranian protected region (Bozinmarakhil Protected Area). We retrieved data for the protected region from http://www.minambiente.it/.

RESULTS

Assessment of probability of N. microspilotus presence.—Although the study area at the conjunction of the western Iranian Plateau and the northern Mesopotamian Plain in western Iran and eastern Iraq is highly heterogeneous topographically, the MaxEnt model identified substantially uninterrupted areas of geographic distribution (Fig. 3). In the remaining area, we detected only very limited and scattered sites with low suitability. We also detected some areas characterized by a high presence likelihood where records for the species were lacking (Fig. 3). This is particularly well pronounced in Iraqi territory at the middle of the distribution range. The model also predicted that *N. microspilotus* does not occur in Turkey.

We tested the predictive ability of the model with receiver operated characteristics (ROC). The area under curve (AUC) of the ROC analysis provides a single measure of model performance (Fielding and Bell 1997) and ranges from 0.5 (randomness) to 1 (perfect discrimination). In present study, the AUC value was 0.92. The model achieved a 1.8 regularized gain value indicating a good fit to the presence data. Eight variables contributed for 70% of model prediction. The analysis of single variable contribution (Fig. 4) showed that precipitation of coldest quarter (51.1%), mean temperature of driest quarter (11%), temperature seasonality (10.5%), isothermality (8.4%), precipitation of warmest quarter (7.2%), mean temperature of wettest



FIGURE 4. Representation of the contribution provided by the eight environmental variables considered to develop the MaxEnt model for the Yellow Spotted Mountain Newt, *Neurergus microspilotus*. Black bars show the percentage contribution of each variable to the model and corresponding values are given on the left axis. Jack knife results for the model (values on the right axis) are also shown for single variables (white), for all variables except the one selected (grey) and for all variables (diagonal shade).

quarter (5.1%), temperature annual range (4.9%), and digital elevation model (1.7%) were the main factors influencing model performance (Fig 4).

Iran and Iraq.—Our model predicted a total distribution area for *N. microspilotus* of 26,572 km². Of this, 13,975 km² (52%) has a low (0–20%) probability of presence. The area classified as very high (80–100%) presence probability was found only in 267 km², corresponding to 1% of the total area. Only 3,174 km² (12%) obtained a species presence score > 60%. Of the total distribution area for *N. microspilotus*, 68% is located in the Iranian territory and 32% in Iraq (Table 1).

TABLE 1. Extent of different habitat suitability classes for the Yellow Spotted Mountain Newt, *Neurergus microspilotus*, as a whole and in the Iranian and Iraqi territories. Suitable areas were extracted from the 20th percentile threshold binary map of the MaxEnt model.

Suitability classes	Total (km ²)	Iran (km²)	Iraq (km²)
0–20 (%)	13,975.74	9,174.15	4,801.58
20-40 (%)	3,134.43	2,068.90	1,065.53
40-60 (%)	6,287.66	4,276.06	2,011.59
60-80 (%)	2,907.49	2,239.83	667.66
80–100 (%)	267.37	264.71	2.66

Present model predicted that 74% of the total study area has a low (<0.5) probability of presence. More than 52% of the total area was classified as of very low (< 0.2) presence probability; whereas, only 12% obtained a species presence score > 0.6. Areas with probability of presence values of 0.8–1 accounted for 1% of the total area (Fig. 5). Presence records mainly (83% of total sample) corresponded to sites whose probability of presence was > 0.6 (Fig. 5).

Protected areas.—The overlay between the existing system of conservation areas in Iran (Bozinmarakhil Protected Area) and Iraq (Qara Dagh, Peramagroon Mountain, Sakran Protected Area) and the MaxEnt map (Fig. 6) indicated that approximately 66.93% of potential habitat in Iran and 30.08% of potential habitat for N. microspilotus in Iraq is unprotected (Fig. 6). The entire protected area in three Iraqi reserves (553.59 km²) protects only about 2.08% of potential habitat. However, 0.01% of these areas have low suitability scores (< 20). Similar value for low suitability score in the single Iranian reserve is 1.10% (Table 2). The analysis based on recorded presence obtained from published records (Afroosheh et al. 2016) indicate that the Iranian reserve (Bozinmarakhil protected Area) contains only 0.89% of presence points represented in the existing conservation areas (Fig. 6).



FIGURE 5. Percentage classification of study area (black) and presence records (white) according to 20% habitat suitability intervals derived from the maximum entropy model developed for the Yellow Spotted Mountain Newt, *Neurergus microspilotus*.

DISCUSSION

We succeeded in developing a species distribution model (MaxEnt) able to detect a set of environmental variables, in a relatively small but topographically diverse area, that explain a non-random pattern of geographic distribution. Also, assuming models with predictive values greater than AUC > 0.75 are regarded as reliable (Elith 2002), our model with an AUC > 0.92demonstrates an especially high predictive power. Our model also identifies locations inside Iraqi territory lacking records of occurrence for N. microspilotus that have high probabilities of occurrence. Although encouraging, there is not much opportunity to search for newts in this region because of war. Thus, the present model provides a better understanding of the potential distribution of N. microspilotus and is satisfactorily validated; however, we are aware that some limitations may arise from the absence of important predicting factors, such as biotic interaction, effect of climate change, and human impact.

Our model provides opportunities to examine the influence of various factors, such as climatic variables, on distribution of N. *microspilotus* in areas where there is little opportunity to conduct field studies. Our study provides important information on a broad scale



FIGURE 6. Overlay between suitable areas for the Yellow Spotted Mountain Newt, *Neurergus microspilotus*, and boundaries of the Bozinmarakhil (Iran) and Qra Dagh, Peramagroon and Sakran Mountain (Iraq).

that complements what is known about local patterns of habitat selection of N. microspilotus. The model achieved a 1.8 regularised gain value indicating a good fit to the presence data. The variables contributing most to the model prediction include precipitation of coldest quarter (51.1%), mean temperature of driest quarter (11%) and temperature seasonality (10.5%). The terrestrial habitat encompassing the breeding streams are Oak-pistachio Woodland and are located at relatively high elevation; consequently, the entire distribution of N. microspilotus is an elevation belt (630 and 2,057 m above sea level [asl]) that is most likely to be affected by high fluctuations of eco-geographical variables, such as mean temperature of driest quarter and temperature seasonality.

TABLE 2. Extent of different habitat suitability classes for the Yellow Spotted Mountain Newt, *Neurergus microspilotus*, within protected areas in Iran and Iraq. Suitable areas were extracted from the 20th percentile threshold binary map of the MaxEnt model.

Protected area	0–20 (km ²)	20–40 (km ²)	40–60 (km ²)	60–80 (km ²)	80–100 (km ²)	Extent (km ²)
Bouzinmarakhyl	2.94	16.47	61.74	106.13	48.86	236.14
Qara Dagh	109.28	31.87	48.68	-	-	189.83
Peramagroon Mountain	65.85	34.50	19.25	-	-	119.6
Sakran Mountain	230.79	13.33	-	-	-	244.12
Total	408.87	96.19	129.68	106.13	49.86	789.69

That precipitation during winter and early spring contributed to more than 50% of the model prediction, which may be explained by snow accumulation in the highlands that supports water discharge and longer hydroperiod in breeding streams (Sharifi et al. 2009). Such accumulation of snow may also prevent late spring water stress, especially in lower elevations where a warmer climate could exacerbate a reduction Field observations and laboratory in hydroperiod. experiments have shown that longer hydroperiods favor late spawning and larval growth (Farassat and Sharifi 2014) and provide longer periods of time for larval growth and development, and that larvae complete metamorphosis at a larger body size (Vaissi and Sharifi 2016a). Mean temperature of driest quarter can provide a significant contribution to model performance, addressing the importance of high temperature in turning a small stream to a desiccated stream during a dry season. Developmental rates of N. microspilotus are affected by temperature (Vaissi and Sharifi 2016a) and may even mediate cannibalism (Vaissi and Sharifi 2016b).

Data on other climatic parameters obtained from Worldclim, such as temperature seasonality and temperature annual range, signify variation in summer temperature (Elith and Leathwick 2009) and are most likely to contribute to a warmer spring temperatures. A laboratory experiment with N. microspilotus has shown that warmer water temperature influence the final stage of larval development leading to larger body size and lower survival rate (Vaissi and Sharifi 2016a). Warmer temperatures also are associated with shorter hydroperiods in the breeding streams, and during very warm summer the streams may dry up completely (Sharifi et al. 2009). The thermal requirement highlighted in our model may indicate microclimatic preferences in conjunction with other factors, such as the amount of shading provided by riverine vegetation.

Although our model describes potential distribution of N. microspilotus at a large scale, it is also important to remark that on a habitat scale, this newt often selects large streams with well-developed benthic macro-invertebrate communities (Farassat and Sharifi 2014). Therefore, environmental factors alone do not indicate suitable habitat. All reported localities with N. microspilotus are breeding streams at elevations up to 2,000 m asl, where oak open-woodland and other vegetation, such as Deciduous Dwarf-scrublands, Amygdales Scrublands, and Cushion Shrub Land, potentially grow (Khalyani et al. 2012). However, the Zagros forests of western Iran have a long history of use and human exploitation, in addition to cycles of forest expansion and contraction as the result of fluctuating climate during the Pleistocene (Farasat et al. 2016). These factors have resulted in dramatic changes in both

the amount and structure of forest cover, and in many places the entire forest community has been converted to agricultural land (Khalyani et al. 2012). The Zagros Oak Forests in western Iran have been used for livestock breeding, grazing, and agriculture since the beginning of the 5th Millennium BP (Wright et al. 1967; Djamali et al. 2009). Traditional livestock grazing and disturbance coupled with recent population growth are the driving factors that have led to deforestation or changes in the vertical structure, composition, and configuration of forests in the Zagros Mountain Range (Metzger et al. 2005). There are various habitat types that can be considered as the remnants of formerly widespread and open woodlands that are currently present only in the southern part of the geographic range of N. microspilotus. The few remaining populations of N. microspilotus in the northern part of its distribution are located in areas that presumably lost their natural vegetation cover decades ago, including flooding meadows, agricultural lands, rangelands, and orchards.

Our model indicates that the reported distribution of N. microspilotus (Afroosheh et al. 2016), which is based on locations of known breeding streams, may be an underestimation of actual distribution of the species. However, this species is in jeopardy because of many factors that affect breeding streams and terrestrial habitats. Aquatic habitats used by this species vary greatly in terms of water discharge and hydroperiod (Sharifi and Assadian 2004). The larger streams are targeted by farmers who redirect water flow to their crops, and more water is needed as additional land is added into cultivation. In addition to conservation efforts on the small scale, such as applying more sustainable management practices on agricultural land, we suggest that large-spatial scale conservation measures also should be adopted. Specifically, we suggest that open woodland corridors should be created or restored that will connect fragmented habitat and support gene flow. Present protected areas in Iraq and Iran close to or within the geographic distribution of N. microspilotus as predicted by the model should be surveyed extensively to see if they either support, or are capable of supporting, the newt.

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