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ORIGINAL ARTICLE

Ecological Niche Divergence between *Trapelus ruderatus* (Olivier, 1807) and *T. persicus* (Blanford, 1881) (Sauria: Agamidae) in the Middle East

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Abstract Modeling the potential distribution areas for a given species is important in understanding the relationship between the actual distribution and the most suitable habitat for a species. In this study, we obtained all available records of *Trapelus ruderatus* and *Trapelus persicus* from museums, literature and fieldwork and used them with environmental layers in the Maximum Entropy algorithm to predict highly suitable habitat areas. The distribution model of *T. ruderatus* and *T. persicus* showed excellent performance for both models (*T. ruderatus* AUC = 0.964 ± 0.001 and *T. persicus* AUC = 0.996 ± 0.003), and predicted suitable regions in Iran, Turkey, Iraq and Syria. Niche overlap was measured between the two groups by ENMtools and 13% overlapped. We used a niche identity test to determine differences between the niches of the two species. Finally, by comparing our null hypothesis to the true niche overlap of the two species, we were able to reject our null hypothesis of no difference between the niches. Due to the sympatric distribution pattern of these species, we do not need a background test for niche divergence.

Keywords MaxEnt modeling, habitat suitability, niche differentiation, *Trapelus ruderatus*, *Trapelus persicus*, Middle East

1. Introduction

Ecological niche modeling tries to predict suitable habitats for a particular species based on similarities between occurrence point grids and other potential areas not occupied by the species (Graham *et al*., 2004). Initially, geographic range maps of a given species can be created using museum records (MacArthur, 1972; Guisan and Zimmermann, 2000; Peterson and Vieglais, 2001; Hugall *et al*., 2002).

Species distribution modeling is one of the most important methods used in recent herpetological studies to examine the effects of environmental conditions on species distribution. Recent studies have indicated that bioclimatic layers are very useful in predicting the distribution of reptile species (Litvinchuk *et al*., 2010; Doronin, 2012; Ananjeva and Golynsky, 2013; Bernardes *et al*., 2013; Ficetola *et al*., 2013; Hosseinian Yousefkhani *et al*., 2013; Ananjeva *et al*., 2014; Fattahi *et al*., 2014). Ecological niche divergence between some species is clear, but we must use identity and background tests to investigate the level of this divergence. Due to the sympatric distribution of the two species, the identity test is sufficient and must be employed to confirm ecological niche separation (Warren *et al*., 2010). For allopatric and parapatric species, it is necessary to use the background test for niche divergence as well (Warren *et al*., 2010).

Trapelus ruderatus (Olivier, 1804) and *Trapelus persicus* (Blanford, 1881) are two species of the

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family agamidae that are distributed in the Middle East (Anderson, 1999; Smid *et al.*, 2014). Based on the study of holotypes, Rastegar-Pouyani (2000) placed *T. persicus* in synonymy with *T. ruderatus* due to morphological similarities between the specimens. Later, Ananjeva *et al.* (2013) described the differences between these two taxa (*T. persicus* and *T. ruderatus*) and resurrected *T. persicus* as a valid species. Finally, Ananjeva *et al.* (2013) examined the holotype of *T. lessonae* with *T. ruderatus* and, due to the morphological similarity, considered the holotype of *T. lessonae*, (MZUT R 307) as the neotype of *T. ruderatus.* These species have been rarely studied ecologically and there is little information on distribution modeling and ecological niche differentiation between them (Anderson, 1999; Smid *et al.*, 2014).

In the present study, we employed both occurrence records of the species in the Middle East and environmental layers to predict the potential distribution modeling and compared the results to calculate the level of niche overlap. The main objectives in this study are: 1) to predict highly suitable areas for *T. ruderatus* and *T. persicus* distribution and determine which environmental factors are important for species distribution; and 2) to measure and compare niche divergence between the two species.

2. Material and Methods

2.1 Data collection Distribution records were collected from all literature for *T. ruderatus* (84 records) (Baran *et al.*, 1989; Frynta *et al.*, 1997; Anderson, 1999; Rastegar-Pouyani, 2000; Torki, 2006; Göçmen *et al.*, 2007; Göçmen *et al.*, 2009) and *T. persicus* (23 records) (Frynta *et al.*, 1997; Anderson, 1999; Rastegar-Pouyani, 2000; Fathinia and Rastegar-Pouyani, 2011). Other records were gathered from our original field work in Iran, Syria and Turkey from June 2010 to May 2014 and where we found the species, localities were recorded by GPS. These records cover the whole range of these species in these countries. Some of the records did not have exact coordinates but did have correct localities, so we estimated their coordinates using Google Earth (Figure 1). Additional records were gathered from museums: California Academy of Sciences, San Francisco, California, USA (11 records for *T. ruderatus* and 13 for *T. persicus*), Museum of Vertebrate Zoology, Berkeley, USA (two records for *T. ruderatus*) and Sabzevar University Herpetological Collection, Khorasan Razavi, Iran (10 records for *T. ruderatus*). Finally, 13 records of *T. ruderatus* were obtained from our direct fieldwork in Iran, Syria and Turkey. 120 unique records of *T. ruderatus* and 36 records of *T. persicus* compose the dataset.

2.2 Ecological Niche Modeling To avoid problems with highly correlated variables in analysis, we used environmental information from 500 random points across all parts of the species range (http://www.geomidpoint.com /random/). The correlation matrix was calculated for all 19 bioclimate variables. A Pearson correlation coefficient higher than 0.75 shows highly correlated variables and these were eliminated from the main analysis. Present-day bioclimatic variables (downloaded from www.worldclim.org) in 30 arc-seconds resolution were put as the base for the model predictions. The slope layer was created using ArcGIS 9.2 from the original altitude layer in 30 arc-second resolution.

After collecting the random points, data were imported to the Openmodeller ver. 1.0.7 (Muñoz *et al.*, 2011) and were analyzed with all environmental layers. A matrix of bioclimatic values for 500 random points resulted in Openmodeller and this dataset was imported to statistical software (SPSS 20.0) to obtain bivariate correlation. Variables with a Pearson index higher than 0.75 were distinguished and one variable from a bivariate correlation were eliminated, because another one might uncorrelated with other variables. After removing the correlated variables we used four bioclimatic layers for *T. ruderatus* and seven layers for *T. persicus* in distribution modeling: BIO4=Temperature Seasonality; BIO13= Precipitation of Wettest Month; BIO18= Precipitation of Warmest Quarter and slope steeper for *T. ruderatus* and in addition to the previous layers BIO5= Maximum Temperature of Warmest Month; BIO19= Precipitation of Coldest Quarter; BIO11= Mean Temperature of Coldest Quarter for *T. persicus*. The species potential distribution model was run using maximum entropy method in Maxent 3.3.3e (Phillips *et al.*, 2004; Phillips *et al.*, 2006; Elith *et al.*, 2011) and 25% of data was considered as test samples using a jackknife method to evaluate the informative layer. The robustness of the final model was evaluated based on 10 replications because some point localities did not have precise coordinates and were estimated using GoogleEarth maps directly. The area under receiver operating characteristic curve (AUC) were considered as a measure of accuracy between 0 and 1. A value over 0.5 indicates that the model is better than random and a value closer to 1.0 shows high accuracy of the predicted model (Raes and TerSteege, 2007).

Niche overlap was calculated using ENMtools v 1.3. The *D* value estimates the local density of a population and allows comparisons between populations. The *I*

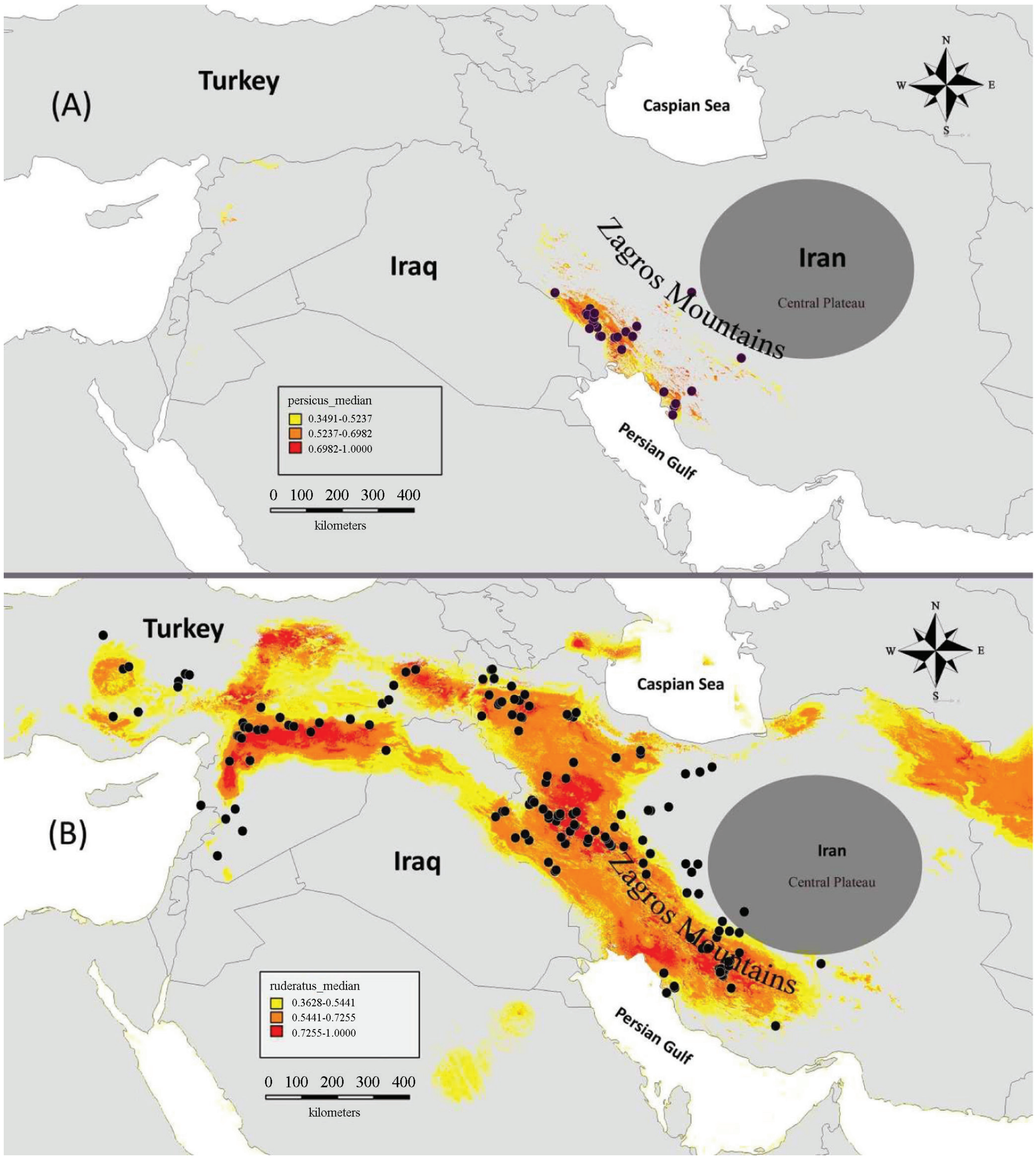

Figure 1 Habitat suitability for *Trapelus persicus* (A) and *Trapelus ruderatus* (B). Three main colors show habitat suitability in the map as mentioned in the map legend. Yellow represents suitability of less than 0.52, orange represents suitability between 0.52 and 0.70, and red color represents suitability greater than 0.70.

value indicates the ability of the model to estimate true suitability of the habitat according to Hellinger distance (Warren *et al.*, 2008; Warren *et al.*, 2010; Kolanowska, 2013). The null hypothesis that the two groups have similar niches is accepted if the niche overlap of both groups is outside of the 95% confidence interval (Warren *et al.*, 2008). When niche overlap between two groups does not fall within the 95% confidence interval and Schoener's *D* and *I* are less than our assumption value, then the groups are separated (Warren *et al.*, 2008). To evaluate this hypothesis statistically, we used a niche identity test between two species.

3. Results

The predicted suitable areas for the two species have high AUC that are 0.964 ± 0.001 for *T. ruderatus* and 0.996 ± 0.003 for *T. persicus* (Figure 1). These high AUC values indicate a good model fit and therefore accurate predictions of the distribution of the species.

The variables that highly contributed to the models are as follows. The four variables that were employed for *T. ruderatus* have important roles in determining species distribution and the relevant contribution levels were: BIO13 Precipitation of wettest month with 34.2%; BIO18 Precipitation of Warmest Quarter with 34%; BIO4 Temperature Seasonality (standard deviation *100) with 18.9%; and slope with 12.8%. For *T. persicus*, the four most important variables were: BIO18 with 33.6%, BIO19 with 26.3%, BIO11 with 19.3% and BIO13 with 10%. Also the jackknife plot is presented (Figure 2) to verifying the relative importance of variables for species prediction.

Niche overlaps were measured and overlap calculated between *T. ruderatus* and *T. persicus* (I = 0.424 and D = 0.135), showing that these species have little overlap in their ecological niche. We ran a niche identity test with both species in a common pool (with shared environmental variables) and the result of this test rejected the null hypothesis. Based on this result, the estimated niche models for both species are D_{H0}= 0.734 ± 0.051 *vs.* D_{H1}= 0.135 and I_{H0}= 0.809 ± 0.025 *vs.* I_{H1}= 0.424 (Figure 3).

4. Discussion

Trapelus ruderatus and *T. persicus* have not been studied ecologically and the ecological niche differences between them are poorly known. The model results confirm the distribution map and also show some potential areas for distribution where the species have not yet been recorded. Two present models resulted in high AUC scores of over 0.9 that indicate good niche prediction based on presence-only occurrence points (Renner and Warton, 2013). *Trapelus persicus* is restricted by the Zagros Mountains and did not expand its range into the Central Plateau (Figure 1). Additionally, the predicted model did not show the suitable regions for this species in central Iran.

Khuzestan in southwestern Iran is the most suitable area for *T. persicus*. The present model of *T. ruderatus* confirmed its current distribution in Iran, Turkey and Syria. According to the model, suitability is highest in southeastern Anatolia, where the most known records are found, according to the literature and the results of our observations (Bird, 1936; Schmidt, 1939; Bodenheimer, 1944; Başoğlu and Hellmich, 1970; Baran *et al.*, 1989;

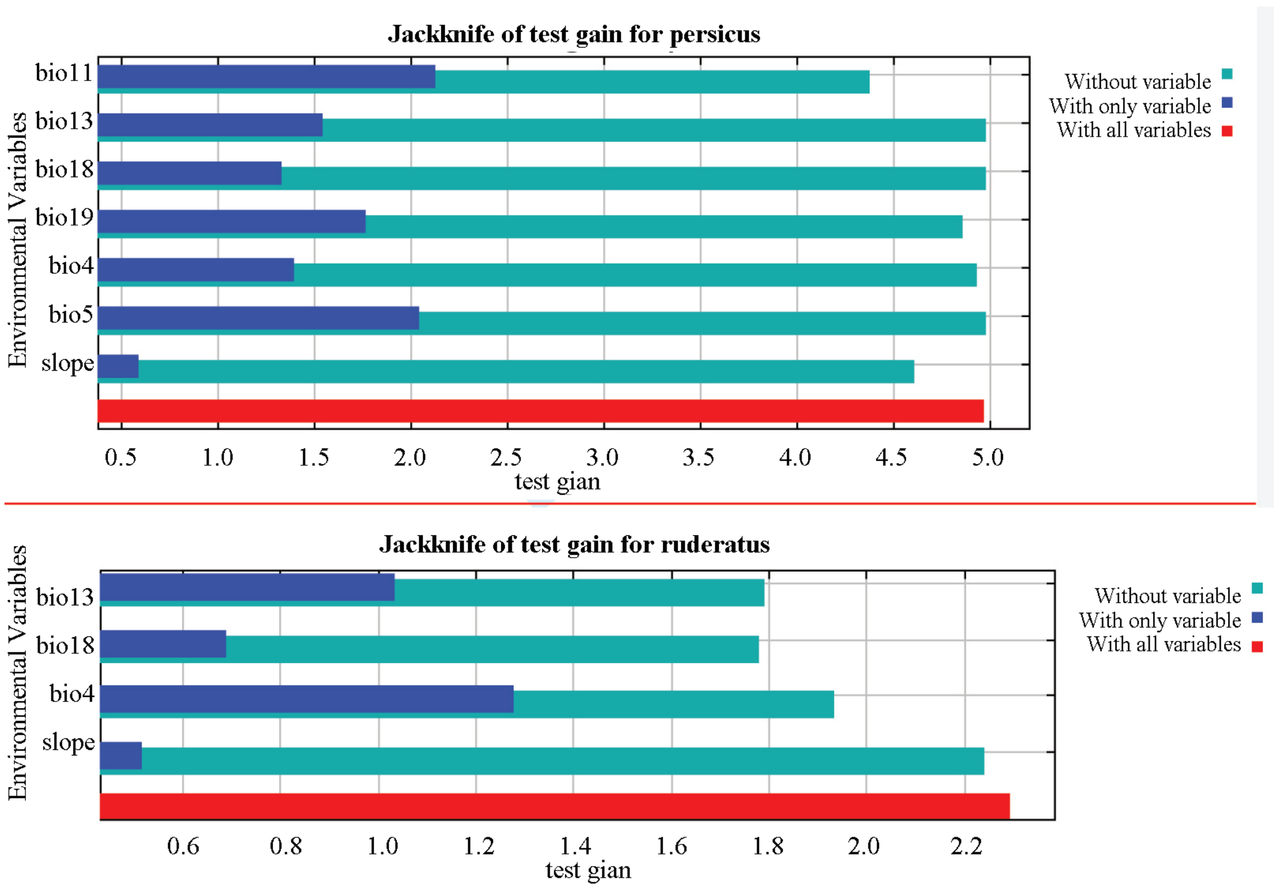

Figure 2 The results of jackknife test of relative importance variables for both species. The upper plot is for *T. persicus* and the lower plot for *T. ruderatus*.

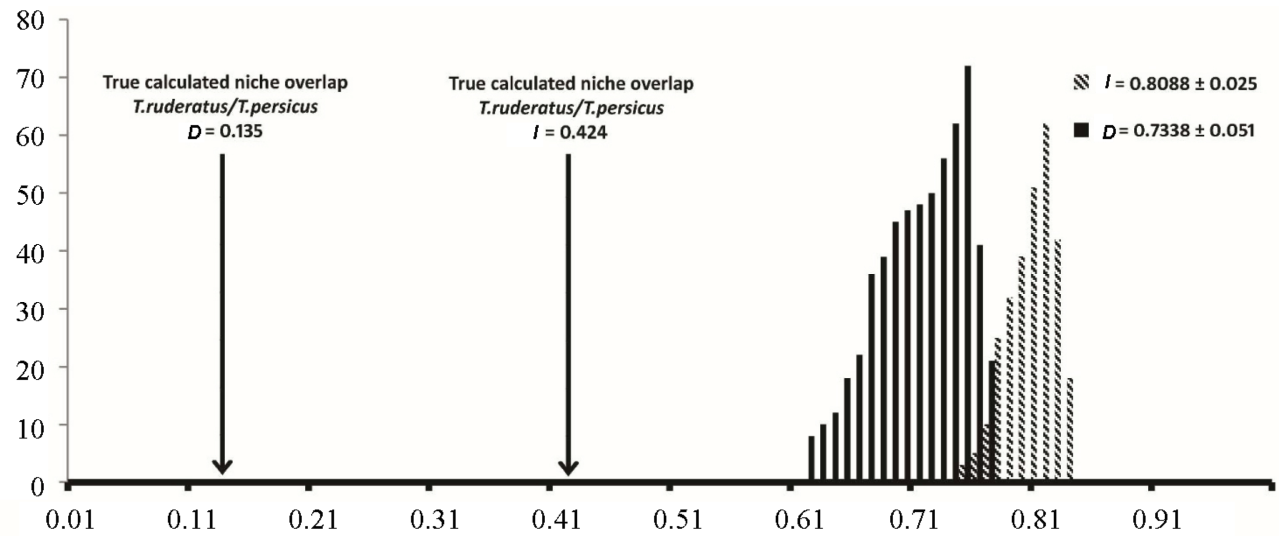

Figure 3 The results of the identity test performed using ENMTools. Black arrows refer to the true calculated niche overlap by ENMTools (*D* and *I*). The solid and hachured columns are calculated by replicates with identity test mode.

Baran and Atatür, 1998; Baran *et al.*, 2012).

In this study, we tried to determine importance of variables that are involved in determining species distribution (Table 1). Precipitation is a very important variable for both species' distributions. The warmest quarter precipitation is important variable for *T. persicus* and the precipitation of the wettest month are the most important variables for *T. ruderatus*. The highest contribution of these variables indicated that these species are not phytophagous (Ananjeva *et al.*, 2014). Precipitation in the warmest quarter is associated with water availability in arid regions of southern Iran and, according to the model species presence is highly related to this condition. On the other hand, precipitation in the wettest month is the variable with the highest contribution for *T. ruderatus* and water availability in this month is highly associated with shrub and plant growth. The results of the model show us that increasing the precipitation in the wettest month has a direct impact on species presence and species presence probability will be increased. Water availability in the wettest month is an important factor for growing shrubs, preparing shelters, and for resources needed for insect aggregation.

Warren *et al.* (2010) established a new method for identifying ecological niches using the ENMTools package and comparing ecological niches belonging to two species using background and identity tests. ASCii files that are resulted from MaxEnt analysis were employed to calculate niche overlap using ENMTools package and showed that 0.13 and 0.42 niches of two populations are overlapped in *D* and *I* indexes respectively. As both species are sympatrically distributed in southern Iran, then it is sufficient to run the identity test. When two studied species are distributed parapatrically or allopatrically, it is necessary to calculate the background test as an additional analysis (Warren *et al.*, 2010). According to our test, the true calculated niche overlap of both species (*D*= 0.13 and *I*=0.42) is outside of the 95% confidence interval of the null hypothesis (Figure 2) and confirms the separation between them.

Our results suggest that *T. ruderatus* and *T. persicus* have high separation in their own ecological niches, unless they are distributed sympatrically. Distribution range of *T. persicus* is restricted to a small area, on the other hand, IUCN status of the species is marked as LC (Least Concern) but the niche modeling suggests that the environmental requirements for the species is limited. Niche modeling studies can aid in conservation

Table 1 Level contribution of variables used in Maxent model for two species of the genus *Trapelus*.

Variables	Description of variables	*T. ruderatus*	*T. persicus*
BIO4	Temperature Seasonality (standard deviation * 100)	18.9	1.1
BIO5	Maximum Temperature of Warmest Month		0.7
BIO11	Mean Temperature of Coldest Quarter		19.3
BIO13	Precipitation of Wettest Month	34.2	10
BIO18	Precipitation of Warmest Quarter	34	33.6
BIO19	Precipitation of Coldest Quarter		26.3
Slope	Slope steeper	12.8	8.9

assessment, because the model highlights the areas of unknown occurrence as the high suitable area without relying on confirmed species presence. More field studies will help us to know about the factual distribution range of the species and shape its status clearly than present time.

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