e-ISSN 1734-9168
http://www.isez.pan.krakow.pl/en/folia-biologica.html

Folia Biologica (Kraków), vol. 69 (2021), No 4
https://doi.org/10.3409/fb_69-4.17

A Contribution to the Biogeography of *Ablepharus anatolicus* and *A. budaki* (Squamata: Scincidae) Using Ecological Niche Modeling in Turkey

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Accepted November 15, 2021 *Published online November 22, 2021* *Issue online December 23, 2021*

Original article

KURNAZ M., HOSSEINIAN YOUSEFKHANI S.S. 2021. A contribution to the biogeography of *Ablepharus anatolicus* and *A. budaki* (Squamata: Scincidae) using ecological niche modeling in Turkey. Folia Biologica (Kraków) **69**: 159-166.

The Anatolian Peninsula is very richly biodiverse in terms of its location and with new studies, this wealth has gradually increased as new taxa of Anatolian origin are added to the literature. *Ablepharus budaki* and *A. anatolicus,* formerly considered to be subspecies of *A. kitaibelli* and *A. budaki* respectively, are spread throughout the southern part of Anatolia. Although recent phylogenetic and morphological studies revealed their species status, no information was given about the relation of the species with each other in terms of ecological niche. In this study, our primary goal was to discover whether the niches of these two taxa were different from each other. Considering the analyses made within the scope of this study, it has been revealed that both *A. anatolicus* and *A. budaki* are different from each other in terms of their ecological niche. However, since these two taxa have very small contact regions, an example of parapatric speciation, and their distribution areas cover almost completely different geographies, we can say that they have different ecological niche requirements, according to the results of this study. As a result, this study supported the findings in literature and the idea that these taxa are two different species

Key words: Biodiversity, geography, distribution area, Anatolian Snake-eyed Skink, Budak's Snake-eyed Skink, Anatolia.

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The genus *Ablepharus* constitutes a small lizard group of the Scincidae family with ten recognized species distributed throughout Eastern Europe and Asia (POULAKAKIS *et al.* 2005; KURNAZ 2020; UETZ *et al.* 2021). In his 1997 study, SCHMIDTLER raised *A. budaki*, which was previously described as a subspecies of *A. kitaibelli* by GÖÇMEN, KUMLUTA & TOSUNOĞLU (1996), to the species level. Recent studies revealed that the anatolicus taxon located in the south of Anatolia, previously considered by SCHMIDTLER (1997) to be a subspecies of *A. budaki*, should also be defined as a phylogenetically different species, *Ablepharus anatolicus* (SKOURTANIOTI *et al*. 2016; BOZKURT & OLGUN 2020).

Although morphology alone is sufficient to describe a new taxon, sometimes it may not be sufficient to accurately determine a taxon's taxonomic location. Looking at the literature, this has been confirmed for many lizard species distributed in Turkey. For example, *Anatololacerta budaki*, *A. pelasgiana*, *Darevkia adjarica*, *Eremias kopetdaghica*, *Lacerta diplochondroles*, *Mediodactylus danilewski*, *M. orientalis*, *Mesalina microlepis*, *Podarcis ionicus*, and *Timon kurdistanucus* are a few species that were firstly described as a subspecies, and all of these lizards have since been raised to the species level as a result of recent phylogenetic studies (AHMADZADEH *et al*. 2012; BELLATI *et al*. 2015; RASTEGAR-POUYANI *et al*. 2015; PSONIS *et al.* 2017; ŠMÍD *et al*. 2017; ARRIBAS *et al.* 2018; KOTSAKIOZI *et al*. 2018; KORNILIOS *et al*. 2020). Similarly, it was thought to raise the *A. anatolicus* taxon to the species level.

Though molecular data is sufficient to distinguish species, it may also provide information to researchers for many factors that support the rise of these groups to the species level and change the genetic structure of species (HOSSEINIAN YOUSEFKHANI *et al.* 2016; KURNAZ *et al.* 2019). For example, geography is very important for the separation of species (KURNAZ & HOSSEINIAN YOUSEFKHANI 2020). Species can use parapatric, sympatric, and allopatric speciation mechanisms. The most important factor here is the geography where species live. Changing structures of the earth over time may result in the isolation of groups of a species, causing their genetic structure to change and to be defined as different species (KURNAZ & HOSSEINIAN YOUSEFKHANI 2020). One of the important elements that help this situation are the different ecological niches of each distinct genetic lineage. The ecological niche species concept is an important phenomenon that differentiates species from each other. Probably, ecological niche conservatism is passed on to future generations from the ancestral species (WIENS & GRAHAM 2005). Therefore, analyzing ecological niche differences among similar species groups can help with both the emergence of new species and with other systematic studies. Ecological niche modeling (ENM) is the primary method for trying to estimate the habitat suitability of species in other potential areas by using the locality records of species and bioclimatic layers (GRAHAM *et al*. 2004; HOSSEINIAN YOUSEFKHANI *et al.* 2016). This method examines the effects of environmental conditions on species distribution, and also there are many studies showing that bioclimatic variables have an effect on the ENM of species (LITVINCHUK *et al.* 2010; DORONIN 2012; FATTAHI *et al*. 2014; HOSSEINIAN YOUSEFKHANI *et al*. 2016; KURNAZ *et al.* 2019; HOSSEINIAN YOUSEFKHANI 2019).

The main purpose of the present study was to I) predict highly suitable areas for *A. anatolicus* and *A. budaki* distribution and determine which environmental factors are important for species distribution, II) measure and compare niche divergence between the two species, and III) to contribute to the literature by contacting on the ecological niche divergence between two taxa which are phylogenetically different species.

Materials and Methods

A total of 94 records were collected from published literature (BIRD 1936; BODENHEIMER 1944; CLARK & CLARK 1973; ANDREN & NILSON 1976; TEYNIE 1991; MULDER 1995; GÖÇMEN *et al.* 1996; SCHMIDTLER 1997; BUDAK *et al.* 1998; UĞURTAŞ *et al*. 2000; KUMLUTAŞ *et al*. 2011, 2015; POULAKAKIS *et al*. 2013; KUCHARZEWSKI 2015, 2016; SKOURTANIOTI *et al.* 2016; SARİKAYA *et al*. 2017; YİLDİZ *et al.* 2019; BOZKURT & OLGUN 2020). Fifty-five of these localities are represented by *A. anatolicus*, thirty-nine by *A. budaki*. A map showing the current distribution of these two species is shown in Figure 1. Geographical coordinates are presented in Supplementary Material.

Nineteen bioclimatic variables were downloaded from Global Climate Data to construct species distri-

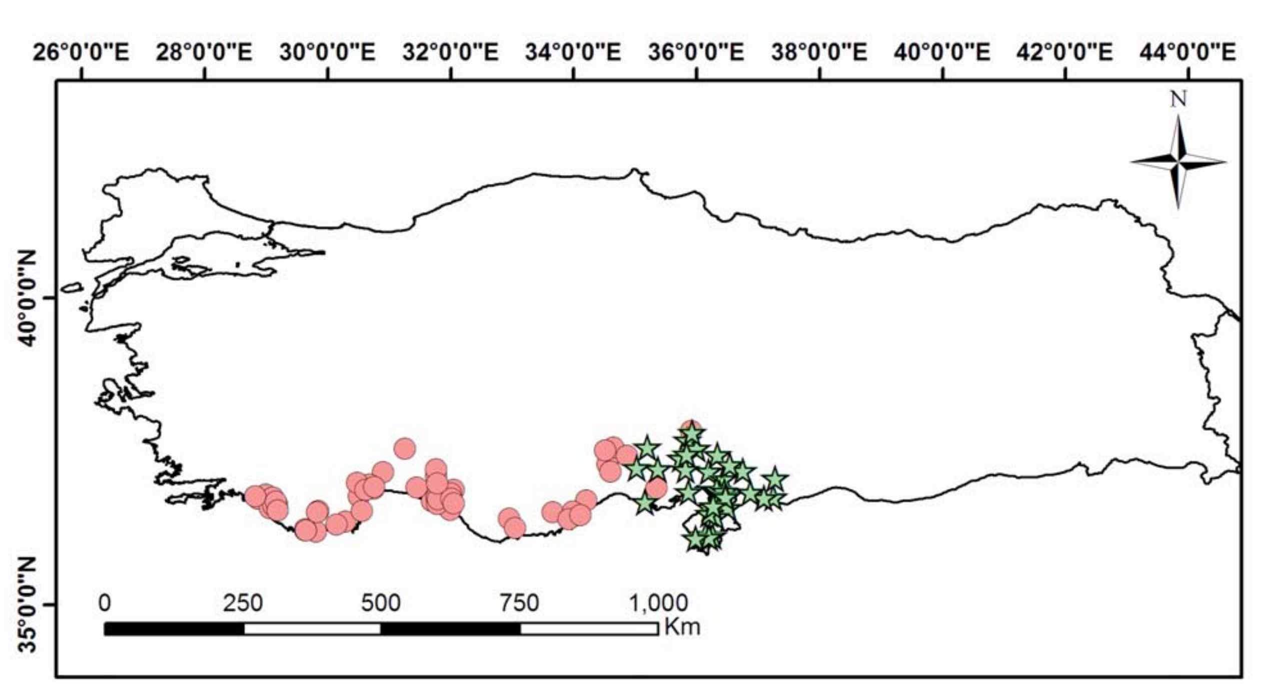

Fig. 1. The current distribution of *Ablepharus anatolicus* (pink circles) and *Ablepharus budaki* (green stars) in Turkey based on occurrence points.

bution modeling (HIJMANS *et al.* 2005; available at www.worldclim.org). These data were generated from global ESRI grids in the highest resolution [30´´ (~1 km)] for current conditions (~1950-2000). Each bioclimatic variable was limited to the land border of Turkey using Arc Toolbox (extract by mask) in ArcGIS software ver. 10.3. All scores of the bioclimatic variables were exported using the Extract by Attiribute section of ArcGIS and later the Pearson correlation coefficient between variables was calculated using SPSS 21 software (IBM Inc.). Highly correlated parameter pairs (r>|0.75|) were excluded from analysis to eliminate adverse consequences from other bioclimatic parameters (Figure 2).

After analyzing correlation, Maxent 3.3.3e (PHILLIPS *et al.* 2006) software was used to perform species distribution modeling (SDM). To develop the model, 94 occurrence data based on literature and field studies were used. A quarter (25%) of the occurrence data were set aside as test points, and 10.000 background points were used to determine the distribution. Additionally, the regularization multiplier = 0.5, maximum iterations = 500, and convergence threshold = 10-5 were chosen in Maxent. In order to test variable importance, the jackknife test of variable importance was chosen in Maxent, and the model was run as ten replicates. Due to recent advances in the modeling process, we not only used the Maxent algorithm but also benefited from the Niche A 3.0 (QIAO *et al.* 2016) and ENMTools 1.3 (WARREN *et al.* 2010) software in evaluating the candidate models; we selected the best model via Akaike Information Criterion corrected (AICc) for small sample sizes (HURVICH & TSAI 1989). In addition to AICc, the power of the model was also determined by the values of the area under the receiver-operator (ROC) curve (AUC) (RAES & TER STEEGE 2007; GALLIEN *et al.* 2012). According to MANEL, WILLIAMS & ORMEROD (2001), model scores are assessed as follows: AUC = 0.5 reflects a performance equivalent to random, AUC> 0.7 reflects a useful performance, AUC> 0.8 reflects a good performance, and AUC ≥ 0.9 reflects an excellent performance. Finally, our model inputs were transformed into binary predictions using a 10-percentile thresholding approach to visualize the "best" model (PERKTAŞ *et al.* 2017).

Identity tests are used to test habitat suitability scores for two species to assess significant niche differences generated by ENM (WARREN *et al.* 2010). ENMTools was employed to calculate the niche overlap test between species. Schoener's *D* (WARREN *et al.* 2008) and Hellinger's-based *I* (SCHOENER & GORMAN 1968) are two indices for niche identity and were calculated based on the habitat suitability comparison from ENM. Schoener's *D* calculates the suitable range for a given species based on probability distributions for inhabiting a particular region (cells), calculating niche overlap based upon species abundance in those locations. Hellinger's-based *I* is based purely on probability distributions without the assumptions of Schoener's *D* (WARREN *et al.* 2010; RODDER & ENGLER 2011). Both indices range from 0 (complete divergence/no overlap) to 1 (high similarity/complete overlap). Background tests were performed to evaluate whether the ecological niches of the two species were different from each other beyond expected differences based upon the environmental conditions that they require (WARREN *et al.* 2008). We compared the niche models of potential habitat for each species with a series of 100 pseudoreplicate models generated using data from the others (WARREN *et al.* 2008). The Schoener's *D* and Hellinger's-based *I* of the true calculated niche were compared to the null distribution of 100 replicates (WARREN *et al.* 2008).

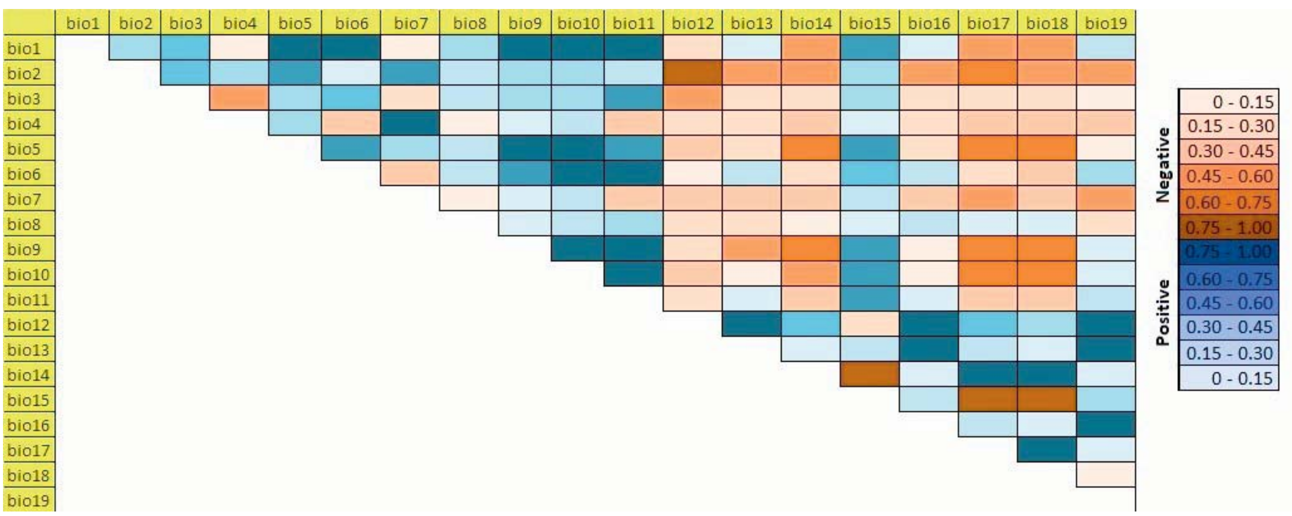

Fig. 2. Correlation matrix among bioclimatic variables used in the present study

Results

According to Pearson's correlation results, we chose a total of 7 variables to use ENM for *A. anatolicus* and *A. budaki*, and these variables were used in the present study. Bio-1 (Annual Mean Temperature), Bio-2 (Mean Diurnal Range), Bio-3 (Isothermality), Bio-4 (Temperature Seasonality), Bio-8 (Mean Temperature of Wettest Quarter), Bio-13 (Precipitation of Wettest Month), and Bio-14 (Precipitation of Driest Month) were chosen for the distribution model. The models were run for ten replicates and the average AUC were obtained as model accuracy for each species separately: the AUC for *A. analoticus* was 0.925 with a standard deviation of 0.047; the AUC for *A. budaki* was 0.965 with a standard deviation of 0.039. The AUC values show the excellent quality of distribution modeling. Based on these results, it was found that Bio 13 (72.2 %) for *A. anatolicus* and Bio 1 (35.5%) for *A. budaki* are the most contributing variables in current climatic conditions. Contribution values of selected variables are given in Table 1. The current distribution of both species is presented in Figure 3 and clearly shows that these are parapatric taxa (southern Turkey). Based on the habitat suitability prediction, *A. anatolicus* has the potential to distribute westward to Adana (Figure 3a). The southern part of Turkey at the edge of the Anatolian diagonal and Turus Mountains provided suitable conditions for an *A. budaki* presence (Figure 3b). Similar to the current distribution range based on records, the habitat suitability prediction suggested to us that both species must be parapatric in their ecological niche space and surely can reflect divergent niches.

Table 1

Contribution values of all layers employed in species distribution modeling. Bold values refer to the highest contributing layer in the prediction model.

Bioclimtic layer	*A. anatolicus*	*A. budaki*
BIO 1	0.2	**35.5**
BIO 2	0.6	7.3
BIO 3	9.4	3
BIO 4	3.7	13.7
BIO 8	1.4	2.1
BIO 13	**72.2**	34
BIO 14	12.7	4.4

To show this divergence, niche overlap and identity tests were done (Figure 4). The niche overlap analyses indicated that there is low overlap between them and show Schoener's *D* 45% and Hellinger's-based *I* 73%. The identity test indicated that the null hypothesis of niche overlap between *A. anatolicus* and *A. budaki* was rejected and that overlap between the two species was significantly different (t-test, df = 99, $p<0.05$) un-

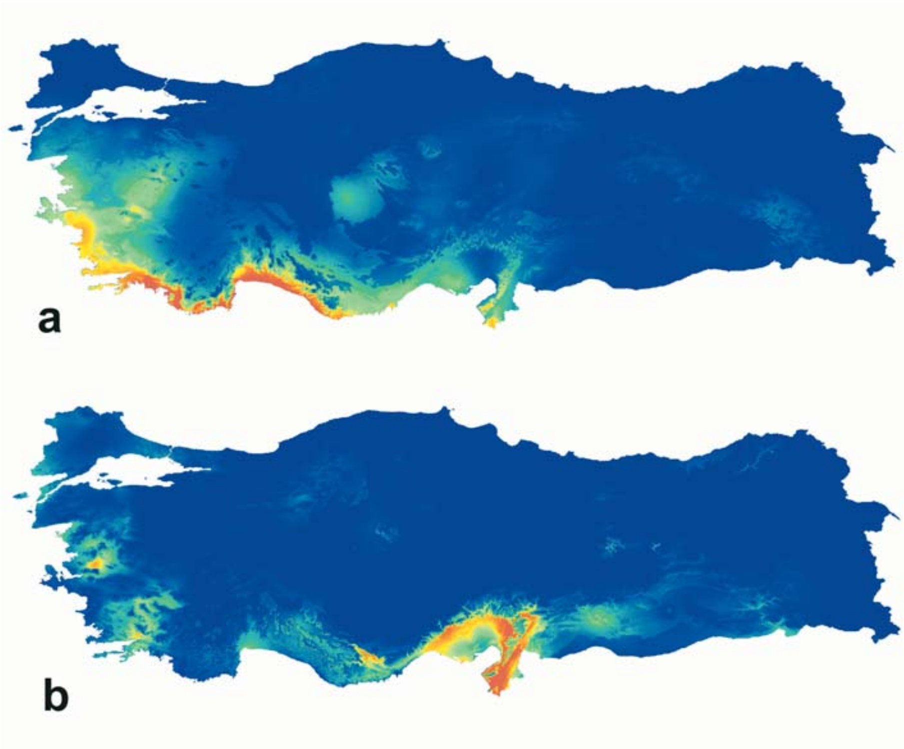

Fig. 3. Habitat suitability prediction based on Maxent models; a – *Ablepharus anatolicus*; b – *Ablepharus budaki*. Warm colors refer to highly suitable regions.

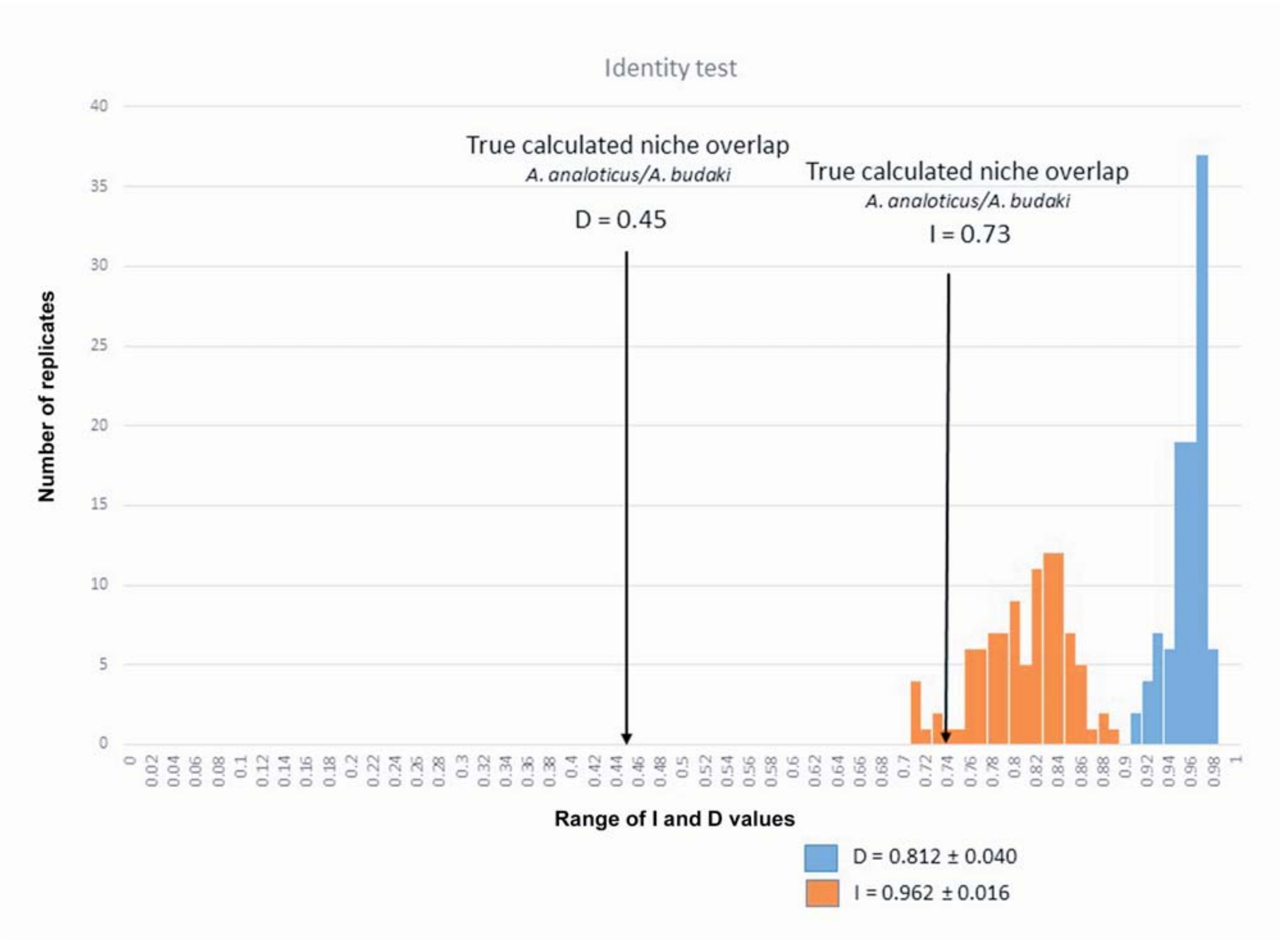

Fig. 4. The result of an identity test that showed a significant differentiation between the two species.

der the present climatic conditions. According to the identity test, the overlap between the two species was significantly different. In addition, because the model demonstrated that the estimated niches for the two taxa were completely separated under present climatic conditions, we can say that these taxa are separate species.

Discussion

The determination of ecological niche is a fundamental phenomenon that differentiates species from each other and occurs as a result of the differentiation of many factors such as morphology, molecular differences, caryology, and allozyme among populations (Kurnaz *et al.* 2019). This is also very important in determining the species status of taxa (Sokal & Crovello 1970; Wiley 1978; Mayr 1999). Many new parameters are being used to evaluate the concept of ecological niche, to calculate differences between populations, and to investigate whether there is niche overlap between populations (Kozak & Wiens 2010; Warren *et al.* 2010). This process is calculated with many abiotic and biotic variables that affect populations found in special geographies, by determining these parameters according to the similarity and difference between the populations (Kozak & Wiens 2010; Shipley *et al.* 2013). This is the first study to measure the niche difference between two lizard species belonging to the *Ablepharus* genus using abiotic variables in the distribution range of these species and is very important in this respect.

Ablepharus anatolicus and *A. budaki* are two scincid species. Within the scope of this study, the following issues were evaluated: the species distribution models of these two lizards, the estimation of ecologically suitable new habitats and criteria such as niche overlap and identity test (Kurnaz & Hosseinian Yousefkhani 2020; Kurnaz & Şahin 2021; Şahin *et al*. 2021). We found that the niches of the two studied species do not overlap inside Turkey. In addition, our distribution analysis revealed that the two species are spread out in relatively different geographies. While *A. anatolicus* generally prefers the southern part of the eastern Taurus Mountains as its distribution, *A. budaki* prefers the eastern part. These different geographic selections have contributed significantly to the differentiation of these two species, both in morphology and genetics, and this has led to the differentiation of the ecological niche of the two taxa. In other words, the Taurus Mountains play an important role in the spread of these two taxa and in the formation of their ecological requirements. It can be said that this makes a great contribution to the determination of the speciation processes that distinguish the two species from each other.

According to our analysis, it can be said that the niche overlap between the two taxa is less than 0.5, so they may be different in terms of niche (HEIDARI 2021). An identity test was used to compare the observed and expected niche gaps of the two taxa (KOZAK & WIENS 2010) and the results showed that the ecological niches of the two species were significantly different from each other. Although this alone explains an important criterion, it is very important that molecular and morphological markers support this as well as geography for the differentiation of the two taxa on species concept. It was first proposed by SCHMIDTLER (1997) that *A. budaki* and *A. anatolicus* were morphologically different taxa, and later in extensive phylogenetic studies including the taxa, it was suggested that the they could be different species (SKOURTANIOTI *et al.* 2016; BOZKURT & OLGUN 2020). In addition, it has been revealed that they are different from each other in terms of morphology at the species level (BOZKURT & OLGUN 2020). As a result, the overlap of our results of niche distinction obtained within the scope of this study with the results of morphological and molecular studies in the literature strengthens the necessity of considering these two taxa at the species level.

Author Contributions

Research concept and design: M.K.; Collection and/or assembly of data: M.K.; Data analysis and interpretation: S.S.H.Y.; Writing the article: M.K.; Critical revision of the article: S.S.H.Y.; Final approval of article: S.S.H.Y.

Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary Material to this article can be found online at:

http://www.isez.pan.krakow.pl/en/folia-biologica.html

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