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Research Article

Predicted current and future distribution of the fire salamander, *Salamandra infraimmaculata* in Turkey

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Abstract

Although the fire salamander, *Salamandra infraimmaculata*, is relatively distributed in a broad area in the Middle East, it lives in a narrow area in southeast and south Anatolia in Turkey. The habitats of the species have been downgraded day by day, and its IUCN category is listed as "NT, and the population trend is decreasing. Within the scope of this study, a model was created with the existing locality records of the species using ecological niche modeling. As a result of this model, the current and future distribution of the species were compared. The results obtained from the analyzes made within the scope of this study showed that the current probable distribution of the species coincides with the existing locality records. However, for possible climate change scenarios, the possible future distribution of the species will be thought to be negatively affected by the increase in the greenhouse gas effect, the change in the amount of carbon dioxide, and the increase of many harmful gas concentrations in the atmosphere. If all four climate scenarios proposed in this study in the future occur sequentially, the species will have to limit or change its range, and even become will be extinct in some areas. Species conservation action plans should be initiated, and local governments should take necessary measures to prevent this from happening.

Keywords: Climatic change, Ecological niche modeling, Maximum Entropy, Species distribution, Salamandridae, Anatolia

Introduction

The species have been accustomed to living under quite different conditions from past to present in order to make their existence proceed in an ecosystem. They either altered their habitats, according to the changing environmental conditions or tried to adapt themselves to these conditions and survive. Although species with high ecological tolerance can overcome this situation very well, many of the species that cannot adapt to mentioned conditions and unfortunately, either have limited their habitats or have become extinct (Pearson & Dawson, 2003). With the increasing industrial activities starting from the late 19th century, the amount of greenhouse gas emitted into the atmosphere continues to increase in direct proportion. This situation increases the atmospheric temperature over time, causing the earth's climate to change (Krockenberger et al., 2012). The climate diversity of the earth is one of the most important factors that enables many species to live in their natural habitats (Ahsani et al., 2019). Because the slightest change in the climate dynamics can affect these natural environments, can be resulted in a very stressful effect on the species. Nowadays, with the developing species distribution methods, the potential distribution of many vulnerable or endangered species can be calculated, the existence of new suitable habitats for them can be put forth, or in this way, their potential distribution in the future can be predicted and, a conservation plan can be suggested for them (Ahsani et al., 2019). Annual temperature increases with the released greenhouse gas will show the effects of global warming for the current earth conditions and it will contribute to the creation of habitat conditions that may be negative for amphibians (Araújo et al., 2006). This situation may cause amphibians to live in a narrower environment than their habitats and their population size may gradually be reduced (Ahsani et al., 2019).

The fire salamander, *Salamandra infraimmaculata* has been restricted in a narrow distribution area, that covers only the Anatolian Peninsula and upper part of the Arabian Plate (Blank et al., 2013). Moreover, its distribution is limited to southeastern and eastern regions of the Anatolian Peninsula (Olgun et al., 2015), however, three subspecies (*S. i. infraimmaculata*, *S. i. orientalis* and *S. i. semenovi*) were recorded in these regions (Kurnaz, 2020). They prefer to live in hills, mountain areas, under the humid trees and woodlands. They hide under wet soil and stones (Baran et al., 2021). According to IUCN, *S. infraimmaculata* has been classified as NT (near threatened), and its population size tends to decrease gradually (Papenfuss et al., 2009). Although many ecological niche modeling studies on the amphibians and reptiles in Turkey were performed, questioning the climate change studies on amphibian species is quite less (Gül et al., 2018; Kurnaz & Şahin, 2021). The potential distribution of *S. infraimmaculata* was studied in some Iranian populations (Ahsani et al., 2019), in northern Israel (Sinai et al., 2019) and Iraq (Khwarahm et al., 2021), however the study on the potential effects of the climatic change for this species was not performed in Turkey. Here, I have assessed the spatial distribution of fire salamanders in Turkey under present climate conditions, with the goal of understanding and anticipating its potential distribution under future climate scenarios.

Material and methods

This study was performed between 34 - 43º Eastern Longitudes and 35 - 40º Northern Latitudes including the southeast and east parts of the Anatolian Peninsula, Turkey (Fig. 1). A total of 52 occurrence data were gathered from literature (Öz ,1986; Steinfartz et al., 2000; Uğurtaş et al., 2000; Karahisar & Demirsoy, 2012; Coşkun et al., 2013; Olgun et al., 2015; Çiçek et al., 2017; Sarikaya et al., 2017, Akman et al., 2018; Yıldız et al., 2019) (Appendix 1; Figure 1). 19 bioclimatic variables were downloaded in 1 km resolutions for current distribution (30 arc-second) from WorldClim as v. 1.4 (Hijmans et al., 2005; available at www.worldclim.org) (Appendix 2). The Model for Interdisciplinary Research on Climate (MIROC-ESM) was used for future predictions with its following scenarios. These are derived from greenhouse gas emission predictions named Representative Concentration Pathways (RCPs): RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5. RCP 2.6 is a climatic scenario that predicts carbon dioxide concentrations to begin to decline by 2020, and with that to drop to zero by 2100. For this climate scenario, it is predicted that CH_4 concentrations will decrease to approximately half of the average in 2020 and sulfur dioxide (SO_2) emissions will decrease to the level of 1890-1990 (Van Vuren et al., 2007).

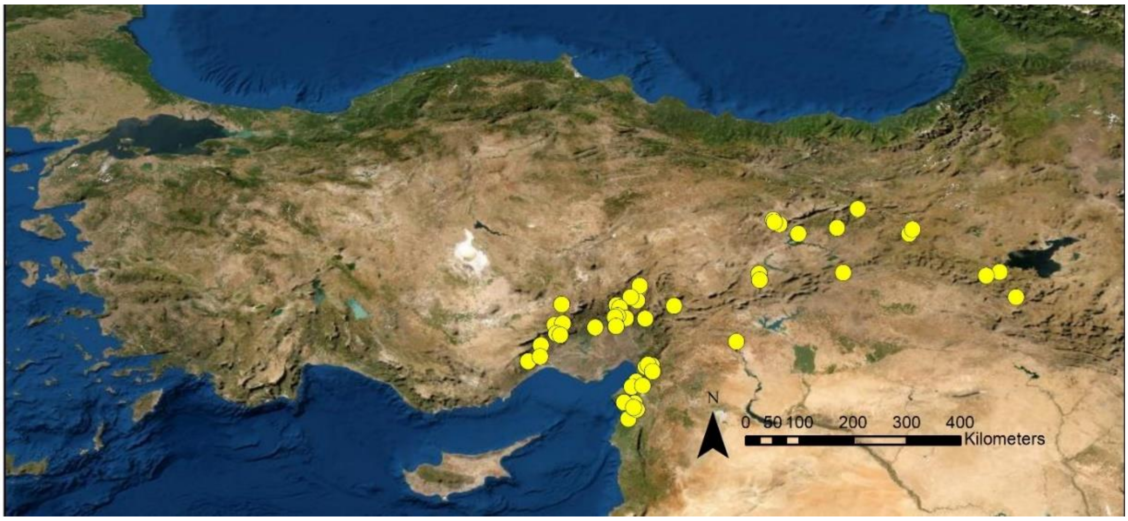

Figure 1. The map shows the current distribution of the *Salamandra infraimmaculata* in Anatolia using occurrence points.

RCP 4.5 is used to describe global greenhouse gas emissions as long-term and short-lived. It explains the land use and land scenarios that stabilize the radiation force per square meter (approximately 650 ppm CO_2-equivalent concentration) in 2100 (Thomson et al., 2011; Harris et al., 2014). The RCP 6.0 is a stabilization scenario where total ative forcing is stabilized the the after 2100 without overshoot by employment of a range of technologies and strategies for reducing greenhouse gas emissions (Fujino et al., 2006; Hijioka et al., 2008). On the other hand, RCP 8.5 represents the path to high greenhouse gas emissions with a high radioactive forcing per square meter at the end of this century. For this scenario, the predicted probable temperature increases for the year 2100 is 2.6-4.8 °C (Riahi et al., 2011; Harris *et al.* 2014). Each bioclimatic parameter was masked to terrestrial zones of study area via Arc Toolbox embedded in ArcGIS ver. 10.3. Pearson Correlation between variables and the coordinates data patterns of the species were calculated in SPSS 21 (IBM Inc®) and highly correlated parametr pairs (r > |0.75|) excluded from analysis for eliminating the adverse consequences from other bioclimatic parameters (Fig. 2).

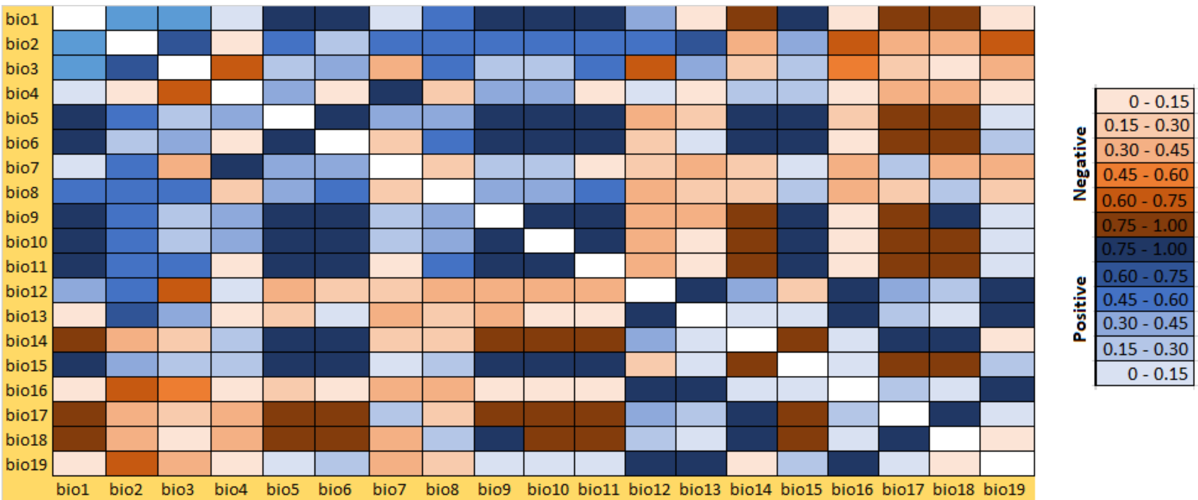

Figure 2. Correlation matrix among bioclimatic variables used in the present study.

The potential climate suitability of the *S. infraimmaculata* was modeled using MaxEnt 3.4.1 (Phillips et al., 2017) with the synthesis of occurrence records and reduced bioclimatic parameters (Elith et al., 2011). These reduced bioclimatic parameters are as follows: Bio 3 (Isothermality), Bio 5 (Max Temperature of Warmest Month), Bio 7 (Temperature Annual Range), Bio 8 (Mean Temperature of Wettest Quarter), and Bio 12 (Annual Precipitation). While studying the entire occurrence data, 75% of them were used for training and the remaining ones for test progress after removing the duplicated presence points. To construct the candidate models, the following settings were applied to MaxEnt: convergence threshold (10000), the maximum number of iterations (500), the regularization multiplier. Moreover, ten bootstrap replicates were run for the studied species. To test the bioclimatic parameter importance, the jackknife test was applied in MaxEnt, which enables us to make beneficial interpretations with the minimum presence records (Elith et al., 2006). Due to the recent advances for modeling process, I not only used the MaxEnt algorithm but also benefited from the NicheA 3.0 (Qiao et al., 2016) and ENMTools 1.4 (Warren et al., 2010) software for evaluating the candidate models; the best model was selected by 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 &and Ter Steege, 2007; Gallien et al., 2012). According to Manel et al. (2002), 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, model inputs were transformed to binary predictions via using a 10-percentile thresholding approach to visualize the “best” model (Perktaş et al., 2017).

Results

In the dissemination analysis made for the *S. infraimmaculata* species under the present bioclimatic conditions, it has been revealed that the distribution of the species is compatible with the habitat requirements (Figure 3). As a result of these analyzes, 4 out of 19 bioclimatic variables (Bio 3, Bio 5, Bio 7, and Bio 12) have a remarkable effect. Among these variables, Bio 5 (34.6%) and Bio 12 (33.4) are the bioclimatic variables that most affect the distribution of the species. This situation constitutes approximately 70% of the distribution (Table 1). The reason that these two variables determine the prevalence of this species, in particular, is because the distribution of the species is affected by the highest temperatures in the warmer months as well as annual precipitation. This situation is characteristic for the south and southeastern Anatolia where the species is spread. Modeling results obtained from AICc scores as decisive criteria for both species showed good distributional predictions (Table 1).

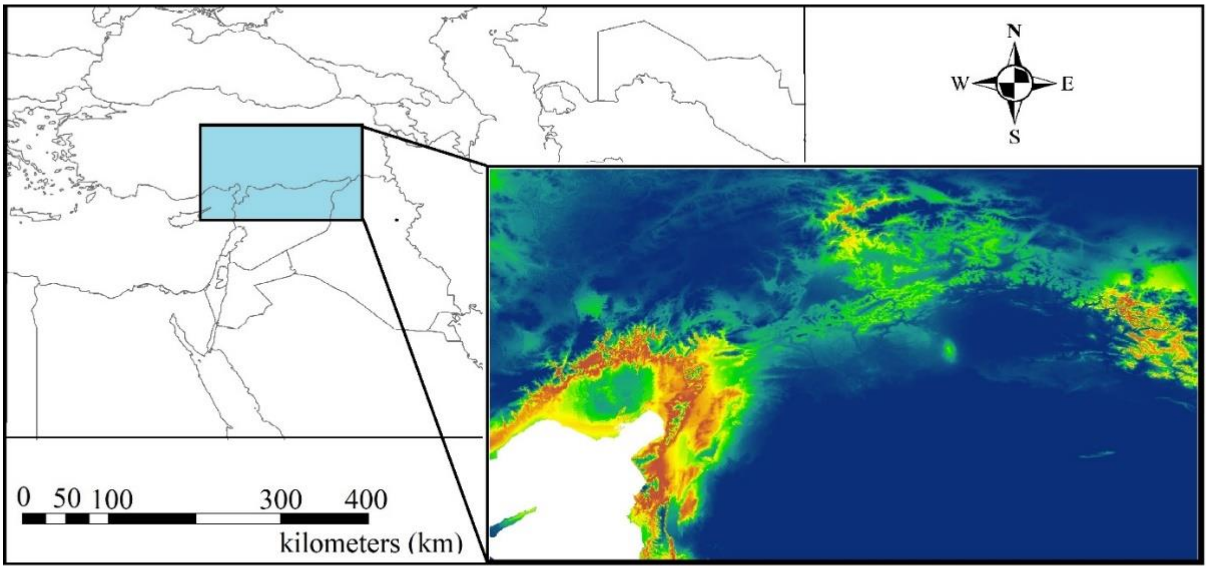

Figure 3. The map shows the range of current climate suitability predicted by the MaxEnt model for *Salamandra infraimmaculata* in the Anatolian Peninsula. Warm colors refer to highly suitable regions.

Table 1. Contribution of low correlated bioclimatic variables and model selection scores in species distribution modeling of *S. infraimmaculata.*

Bioclimatic variables	Current	Future			
		RCP 2.6	RCP 4.5	RCP 6 .0	RCP 8.5
AICc	141.181	145.616	156.903	158.195	149.879
AUC	0.900	0.892	0.900	0.910	0.895
Bio_3 (Isothermality)	3.2	4.4	3.8	2.6	4.3
Bio_5 (Max Temperature of Warmest Month)	34.6	28.8	21.8	27.6	27.5
Bio_7 (Temperature Annual Range)	28.8	29.2	36.6	32.1	34.9
Bio_12 (Annual Precipitation)	33.4	37.6	37.8	37.7	33.3

In the jackknife analysis for distribution, it was revealed that Bio 5 is the most useful variable for the distribution of the species and when used alone can determine the distribution of the species (Figure 4). The result of the receiver operating characteristic (ROC) curve found as a result of the analysis was found to be compatible with the model sensitivity and the value of the area under the curve (AUC) was found to be 0.900 ± 0.060. The fact that this value is very close to 1 show that the geographical distribution of the species is economical with the analysis. It also shows that current bioclimatic variables and geographic variables have the most appropriate effect on the distribution of the species.

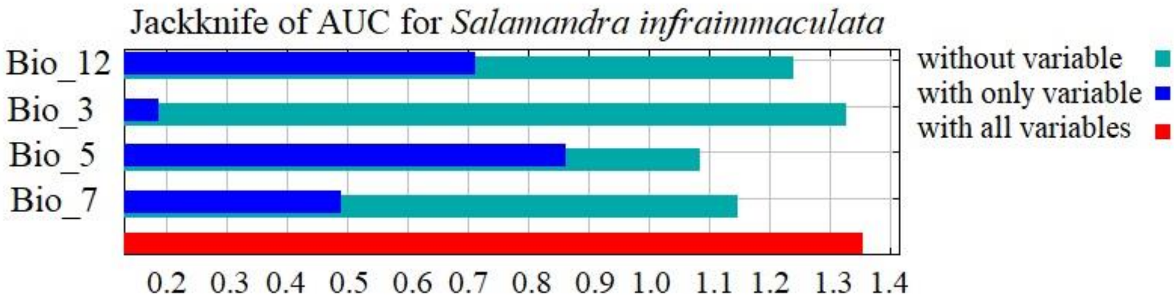

Figure 4. The relative predictive power of the four bioclimatic variables predicted by the jackknife of regularized training gain in the MaxEnt model for the species.

The future distribution of the species is narrower than under current bioclimatic conditions in all future climatic scenarios. The projected future distribution maps for *S. infraimmaculata* are shown in figure 5. Towards the end of the century, it is expected that the increase in carbon dioxide levels, radiation rates, and greenhouse gases could possibly lead to a relatively small shrinkage of the potential distributional range of the species. While the species is compared under these future estimation scenarios, it might be speculated that the *S. infraimmaculata* (Fig. 5a) would be more vulnerable to the effects of global climate change. Due to the RCP 2.6 climatic scenario, *S. infraimmaculata* is predicted to change its dispersal significantly towards the end of the 21st century.

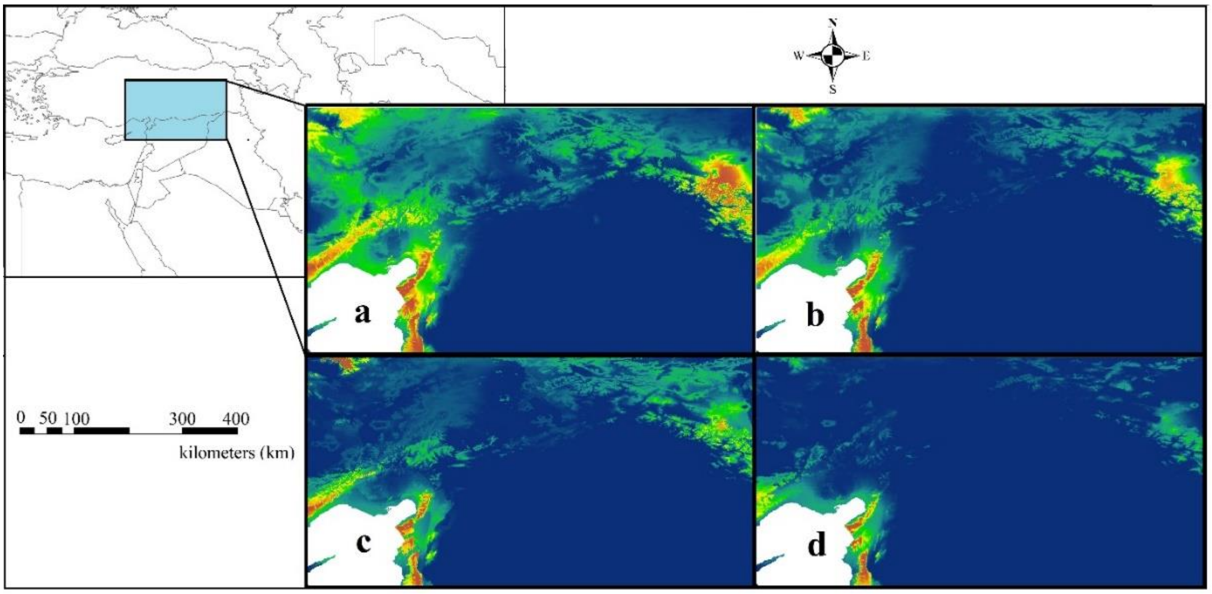

Figure 5. The map shows the range of future climate suitability predicted with HADGEM (**a:** RCP 2.6; **b:** RCP 4.5; **c:** RCP 6.0 and **d:** RCP 8.5) by MaxEnt for *Salamandra infraimmaculata* in the Anatolian Peninsula. Warm colors refer to highly suitable regions.

The results of this scenario show that while the species distribution in the eastern part of its distribution will enlarge a little more, its distribution in the western part will decrease significantly. Therefore, there will not have a distribution area between these two regions in future climate scenarios for the species. In addition to that, it is predicted that the distribution area of the species in the western part will shift a little further to the upper northern latitudes. RCP 4.5 predicts the presence of a narrower area than RCP 2.6 as the distribution (Figure 5b). It seems that such greenhouse gases starting to increase by the end of the century, and significant changes in the radiation rate will greatly affect the future distribution of this species. In this model, the species' spreading areas in both the western and eastern become very narrow and it predicts that an almost limited area will remain. According to the RCP 2.6 model, the spreading area in the northern part has narrowed considerably compared to this model. The RCP 6.0 climate change model shows almost the same distribution as the RCP 4.5 model (Figure 5c). However, according to the RCP 6.0 model, the distribution of the species in the eastern part predicts that it will shrink further than the RCP 4.5 model. The last climatic change scenario with RCP 8.5 displays the most drastic spillover contraction will be exhibited. If this pattern happens, there is almost no suitable distribution for the species. According to this model, the distribution of the species will only constitute a very small area in the east (Figure 5d). It represents a very narrow area, almost as 5% of the species' range today. The result of the receiver operating characteristic (ROC) curve found as a result of the analysis was found to be compatible with the model sensitivity and the value of the area under the curve (AUC) was given in Table 1.

The estimated future distribution areas for studied *S. infraimmaculata* taxon are given in Figure 5. Although the bioclimatic factors, which have a crucial role in the distribution of the species are the same, the bioclimatic envelopes are different. In order to understand future distribution patterns of the species in four climatic scenarios, the most contributing variables are given as follows: Bio 12 (Precipitation of Wettest Month) and Bio 7 (Temperature Annual Range) are the most contributing variables, with 66.8% for RCP 2.6, 74.4% for RCP 4.5, 69.7% for RCP 6.0 and 66.8% for RCP 8.5, respectively (Table 1). Although Bio 8 (Mean Temperature of Wettest Quarter) did not correlate with the other parameters, it was not included in the analysis, due to odd spatial anomalies in the form of discontinuities between neighboring pixels in the absence of environmental gradients on the ground (Ashraf *et al*. 2017; Behroozian *et al.* 2020).

Discussion

Salamandra infraimmaculata is distributed in a large area including Asia and Europe with its closest relative, *S. salamandra*, until 13 million years ago (Steinfartz et al., 2000). However, changing conditions caused the two lineages to diverge over time. Therefore, *S. infraimmaculata* has limited its distribution in a relatively narrow area in the Middle East and Asia Minor. The separation of these two major lineages approximately corresponds to the middle of the Miocene period (Steinfartz et al., 2000). Although the slow global cooling led to glaciations late of Miocene, the climate on the Miocene is moderately warm. Glaciation likely caused *S. infraimmaculata* to break away from the main population and adapt to living in a narrow range in the Middle East as a result of climatic change in time.

Although many variables (biotic and abiotic) have been influential from past to present to shape the distribution boundaries of *S. infraimmaculata* biogeographically, only bioclimatic variables have been used in this study to estimate the future distribution of the habitats of this species. *S. infraimmaculata*, which has currently NT status in the IUCN red list of endangered species (Papenfuss et al., 2009), will probably have a limited distribution towards the end of this century with the effect of global warming. This will further sensitize the species and possibly increase its conservation status to an even more important level. Future distribution modeling analyzes have also shown that the greenhouse gas effect emitted has a significant impact on the distribution of this species.

The current potential distribution results in the present study showed that the distribution of the species in three unconnected populations in southeast Anatolia was more appropriate. Up to date, there are very few studies involving the distribution modeling of amphibian species distributed in Anatolia (Hosseinian-Yousefkhani et al., 2016; Gül et al., 2018; Kurnaz & Şahin, 2021). Of these studies, Hosseinian-Yousefkhani et al. (2016) examined the effect of bioclimatic variables on the current distribution modeling of three different tree frogs (*Hyla*) and explained that the distribution of tree frogs is sensitive to moisture deficiency and extreme temperatures. Moreover, Gül et al. (2018) examined a distribution model of the Caucasian salamander, *Mertensiella caucasica* on current and future climatic scenarios and predicted that in the future the Caucasian salamander will limit its distribution in the Caucasus in a more limited area than today. Finally, Kurnaz and Şahin (2021) examined two *Neurergus* species in terms of their current and future distribution, as well as ecological niche differences. With the results of this study, they reported that the two *Neurergus* species are different from each other in terms of ecological niches and that the distribution area of these two species in the future will narrow more than today. Similarly, in this study, it was revealed that the distribution of the fire salamander in Anatolia was significantly dependent on annual precipitation and temperature changes. In addition, the wide distribution of this salamander species in the current conditions will probably narrow with the change of climatic factors in the future, and even disappear completely in some regions. The suitability of the model is also supported by the high AUC value. Because the high AUC value also increases the accuracy and fidelity of the analysis (Manel et al., 2002).

In addition, a study showing the distribution of the fire salamander in a small area in Iran has suggested that the distribution of the species is unlikely in regions with extreme conditions (Ahsani et al., 2018). On the other hand, temperature and precipitation are important factors in shaping the Zagros flora (Noroosi et al., 2008) and determining the distribution of animal and plant species (Tews et al., 2004). Since the southeast of Anatolia is an area that interacts with Zagros Mountain, it also affects the possible distribution of the fire salamander (especially for the *semenovi* subspecies). Besides, in the distribution analysis performed on populations of the fire salamanders in a small area in the north of Israel, it was observed that precipitation and temperature were significantly effective in determining the distribution area of the species (Sinai et al., 2019). The findings obtained from this study also show that temperature changes and precipitation dynamics are important factors in the distribution of the species in Anatolia. It also reveals that these factors will shape the distribution of the species today and in the future.

Climatic conditions are the most important factors that will affect the distribution of all species and determine their distribution boundaries (Cahill et al., 2013). *S. infraimmaculata* is a species that is distributed in the Middle East and is represented by three subspecies (Blank et al., 2013; Olgun et al., 2015). Distribution constitutes an important part of Turkey's territory and it is available in three subspecies in Turkey (Olgun et al., 2015; Kurnaz, 2020). *S. i. infraimmaculata*, one of the subspecies, constitutes the westernmost of the distribution area, while *S. i. semenovi* shows its most eastern distribution. Moreover, *S. i. orientalis* subspecies is endemic to Turkey and is located between the eastern and western distribution areas (Olgun et al., 2015). It is predicted that *S. infraimmaculata*, which is spread over a relatively wide area in the projected current climatic scenario, will pose a threat to the current distribution of *S. i. orientalis* and *S. i. semenovi* subspecies, depending on the number of greenhouse gases for future climatic scenarios. The results obtained in this study showed that climate scenarios ranging from RCP 2.6 to RCP 8.5 are highly effective against the *S. i. orientalis* subspecies and will have an effect at the level of extinction. It is also predicted that the RCP 8.5 climate scenario will have a destructive effect for the *S. i. semenovi* subspecies. Similar to the present study, in Iraq populations, Future distribution of the *S.*

infraimmaculata demonstrated that under the RCP 2.6 2070 and RCP 8.5 2070 climate change scenarios, the habitat distribution ranges for *S. infraimmaculata* would reduce from current to future (Khwarahm et al., 2021).

The results of the of dispersion analysis have shown that annual precipitation, minimum temperatures in cold months, and annual temperature changes are highly effective on this species. Increasing greenhouse gases and possibly changes in atmospheric temperature will cause all three factors to change over time, affecting the breed's breeding, feeding, and behavioral biology. Increasing greenhouse gas will likely cause lower precipitation and unchanged summer and winter temperatures. For this reason, evaporation will increase, and humidity will decrease. Since amphibian species are sensitive to water sources and moisture and are sensitive to temperature, over time these factors will limit the current distribution of the fire salamander and if this situation continues continuously, the existence of the species will be endangered.

Conclusion

In a conclusion, changing climatic conditions will negatively affect the distribution of the fire salamander in the future, as in many species. Habitat losses will probably have an effective role in this consequence. As it is known, the habitats where the species live are not only shelters but also places where their feeding, reproduction, and many behaviors occur. The deterioration of habitats means the inability to do these activities and sustain the continuity of the life for the species (Benton et al., 2003). Fire salamanders generally prefer humid mountainous and forested areas to live in (Baran et al., 2021). The reduction in the size and number of forested areas worldwide is one of the biggest problems facing amphibians (Pounds et al., 2006). This limits the habitats of amphibians. Many anthropogenic factors such as forest fires, cutting down trees, and agricultural activities have a significant impact on the decrease in the habitats of amphibian species (Ahsani et al., 2018). It can be thought that the possible future distribution of the fire salamander, which is the subject of this study, may be caused not only by climatic changes but also by human-induced effects. Therefore, they should take their own measures to protect the species in Turkey, with sustainable species protection action plans that should reveal all amphibian and reptile species of national conservation status. Otherwise, it will cause the extinction of many species or limit their distribution due to both climatic changes and anthropogenic effects in the future.

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