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Predicting the impacts of climate change on distribution of the genus *Macrovipera* A.F. Reuss, 1927 in Iran (Reptiles: Squamata)

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Abstract
Climate change is an important growing threat to biodiversity and ecosystems. Previous studies have shown that climate change will negatively influence Iran's biodiversity. Reptiles are among the most vulnerable groups to climate change. Until now, 80 terrestrial snakes have been identified in Iran in which 16 are terrestrial venomous. In the present study, we predicted the impacts of climate change on distribution of the genus *Macrovipera* in Iran. We applied an ensemble approach, using five distribution modeling methods (Generalized Linear Models, Generalized Additive Models, Generalized Boosted Models, Maximum Entropy Modelling and Random Forest) to predict the impacts of climate change on distribution pattern of the genus. We also estimated protected areas coverage for the suitable habitat of the genus under current and future climatic conditions. We found that the genus will lose 11% of its suitable habitat under the worst-case scenario (2071-2100SSP585). Results also showed that only around 8% of the genus suitable habitat is covered by protected areas under current and future climatic conditions. Stable suitable but not protected habitats have high priority for conservation of the genus in Iran.

Keywords: *Macrovipera lebetina, Macrovipera razii*, Distribution, Conservation, Iran.

INTRODUCTION

Reptiles are one of the most diverse groups of vertebrates on earth (Uetz *et al.*, 2023). According to the latest surveys, 12021 species of reptiles (7600 species for Sauria, 4061 species for snakes and 360 species for Testudines) have been identified and described that many of which remains ecologically unknown (Uetz *et al.*, 2023). Considering that many new species are added to the list of reptiles every year, the actual number of reptiles is expected to grow. Venomous snakes are more sensitive to human disturbances and expected to be affected negatively by climate change (Maritz *et al.*, 2016; Pintor *et al.*, 2021). Therefore, it is necessary to investigate the impacts of climate change on this group of snakes. Because without considering the effects of climate change, the implementation of conservation programs will face many problems**.**

Formerly similar studies on venomous snakes showed different results (Ahmadi *et al.*, 2019; Nori *et al.*, 2014; Penman *et al.*, 2010; Yousefi *et al.*, 2015). They show that some species such as

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Hoplocephalus bungaroides in Australia will lose more than 80% of their valuable habitats, or some groups such as members of the genus *Montivipera* in Iran and neighboring countries will lose most of the suitable habitats and inevitably have to move to higher areas along the mountainous habitats (Ahmadi *et al.,* 2019; Yousefi *et al.,* 2015). However, the conditions for some other venomous snakes will be completely different, for example, the venomous snakes in Argentina will increase their suitable habitats under the climate change. suitableThus, more people will be exposed to venomous snakes and the risk of snakebite will increase in the future (Nori *et al.,* 2014).

In Iran also snakes are among the most ecological unknown vertebrates and the conservation status of many of which is not clear due to lack of information (Rajabizadeh, 2018). Currently, 80 terrestrial snakes have been identified in Iran (Rajabizadeh, 2018; Yousefi *et al*., 2023). Among reptiles, venomous snakes have a more critical situation due to the negative attitude of humans and the conflicts they have with rural communities due to their bites (Pintor *et al.,* 2021). Every year, the bites of venomous snakes such as *Macrovipera lebetina*, *Echis carinatus*, *Naja oxiana* and *Pseudocerastes persicus* cause the death and permanent disability of hundreds of people in the country (Dehghani *et al.,* 2014; Yousefi *et al.,* 2020a). This factor makes their conservation more challenging than other species.

Until 2018, all populations of the genus *Macrovipera* in the country were known under the name of *Macrovipera lebetina* (Rajabizadeh, 2018). In fact, until 2018, this species had one of the widest distributions among venomous snakes in Iran (Rajabizadeh, 2018). But some populations of this species were introduced under a new name, *Macrovipera razii* (Oraie *et al.,* 2018). However, the exact distribution of these two species and their boundaries in the country remain unknown and require a detailed study with extensive non-invasive sampling across distribution range of the the genus (Oraie *et al.,* 2018; Oraie 2020). According to the studies conducted in the country, climate change is one of the most important threats to biodiversity (Yousefi *et al*., 2019), as it is predicted that the suitable habitats of many animal species will be lost. The studies conducted show that out of 37 different species studied in the country, 30 species will be affected by the negative effects of climate change (Yousefi *et al.,* 2019). Like other animal groups, climate change is one of the most important threats to venomous snakes (Ahmadi *et al.,* 2019; Yousefi *et al.,* 2015). Therefore, it is necessary to investigate the impact of future climate changes on venomous snakes of the country.

Considering the importance of knowing how species will be affected by future climate changes, the present study was conducted with the aim of measuring the effects of climate changes on the distribution of the genus *Macrovipera* in Iran. Studies conducted worldwide show that species living in mountainous areas will be more sensitive to climate change and will lose most of their suitable habitats (Hannah, 2015). Vipers of the genus *Macrovipera* are living in the mountainous regions of Iran and are present in the Zagros, Alborz, Kopet Dagh and mountains of central Iran (Oraie *et al.,* 2018; Rajabizadeh, 2018; Oraie 2020). Therefore, it is expected that, like other mountain species, *Monivipera* snakes will lose their suitable habitats under climate change (Yousefi *et al.,* 2015). Therefore, the hypothesis of the present study is that it is expected that the genus *Macrovipera* will lose its suitable range under the climate change and is expected shifts its range to higher elevation habitats. Therefore, the genus future range will be smaller and more limited than their present distribution.

MATERIAL AND METHODS

Occurrence records

The occurrence records were collected during field surveys of Iranian herpetofauna between 2007 and 2021. It was also checked to obtain the occurrence records of online information sources such as GBIF, VertNet, and HerpNet and 187 occurrence points were obtained from all the avobe mentioned sources. Then, the records with a distance of less than 1 km were removed from the set of species occurrence points for modeling. Determining the distance of 1 km records was determined based on the spatial resolution of the climate layers, which in the present study is 1 km. In this way, the number of occurrence records was reduced to 150 points (Figure 1).

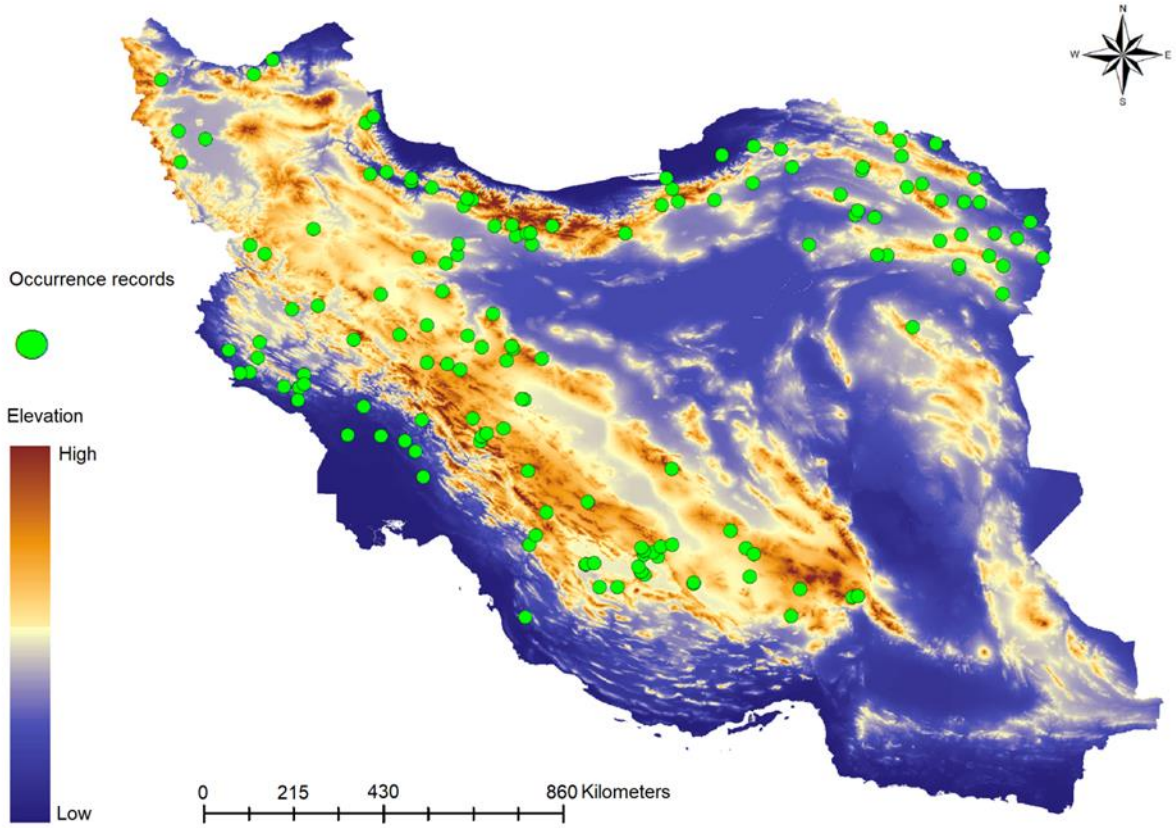

FIGURE 1. Distribution map of the genus *Macrovipera* on the Digital Elevation Model (DEM) of Iran.

Environmental variables.

To predict the impacts of climate change on the distribution of the genus *Macrovipera* in Iran, the climatic variables of the CHELSA database were used (Karger *et al.*, 2017). Current and future climate variables (years 2041-2070 and 2071-2100) from five global circulation models (GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MR-ESM2-0, UKESM1-0) -LL) was extracted. The reason for using several climate change models is that each of these models is associated with uncertainties, so by interpolating several models, uncertainties can be reduced to a certain extent and reliable results can be obtained. Two scenarios (SSP126 and SSP585) were considered for each model. These two future climate change scenarios provide optimistic conditions (SSP126) and pessimistic conditions (SSP585). The environmental variables used for habitat suitability modeling include four climatic variables, i.e. cumulative heat units during the growing season above 10 degrees Celsius (GDD), seasonal temperature changes (Bio4), annual precipitation (Bio12), precipitation in the driest season of the year (Bio17) and slope are topographic variables. To consider the topographical conditions in the models, the slope variable was used that was prepared using SRTM elevation digital model (Jarvis *et al.*, 2008). Variance Inflation Factor (VIF) (Quinn & Keough, 2002) was used to ensure the absence of collinearity between climate variables. Based on the results, the mentioned variables had a variance inflation index of less than 10, so they can be used for modeling.

Climate change modelling

Modeling the effects of climate change on the distribution of the genus *Macrovipera* in Iran was done using an ensemble approach of five different algorithms (Araújo & New, 2007; Guisan *et al.*, 2017). The use of an ensemble approach makes it possible to consider the results of different algorithms simultaneously, and it is also possible to reduce the uncertainty resulting from single algorithms (Araújo & New, 2007; Guisan *et al.*, 2017). Ensemble model was created using GLMs (base R-package; R

environment), GAMs (gam R-package version 1.20.1), GBMs (gbm R-packge version 2.1.8), RandomForests (randomForest R-package version 2.1.8) and Maxent (dismo R-package version 1.3-5) in the R software environment (R Core Team, 2020). In the present study, to measure the effectiveness of the models, 70% of the points were considered as training data and 30% as tests, and modeling was done with 10 repetitions. The the area under the receiver operating characteristic curve (AUC) was used to measure the performance of the models (Fielding & Bell, 1997). Based on this metric, models with AUC higher than 0.9 have excellent performance, 0.7 to 0.9 have good performance, and less than 0.7 have low performance.

Coverage of protected areas

After developing the distribution models of the genus *Macrovipera*, these models were overlapped with the map of protected areas of Iran in ArcMap 10.3 to determine the coverage of suitable habitats by protected areas of the country (Kafash *et al.*, 2021). For this purpose, in the first step, continuous habitat desirability models were divided into two suitable/unsuitable classes using the maximum sensitivity plus specificity threshold. In the next step, the area of suitable habitats within the protected areas calculated in ArcGIS 10.5.

RESULTS

Based on the AUC metric, the models made for the genus *Macrovipera* have high performance (AUC GLM=0.83, GAM=0.83, GBM=0.84, RF=0.84 and Maxent=0.84) and are therefore reliable (AUC ensemble = 0.85). According to the current distribution model, 614,126 square kilometers of the area of Iran (about 37% of the total area of Iran) are suitable for this species. Alborz, Zagros and Kopet Dagh Mountains have the most suitable habitat for the species of this genus (Figure 2).

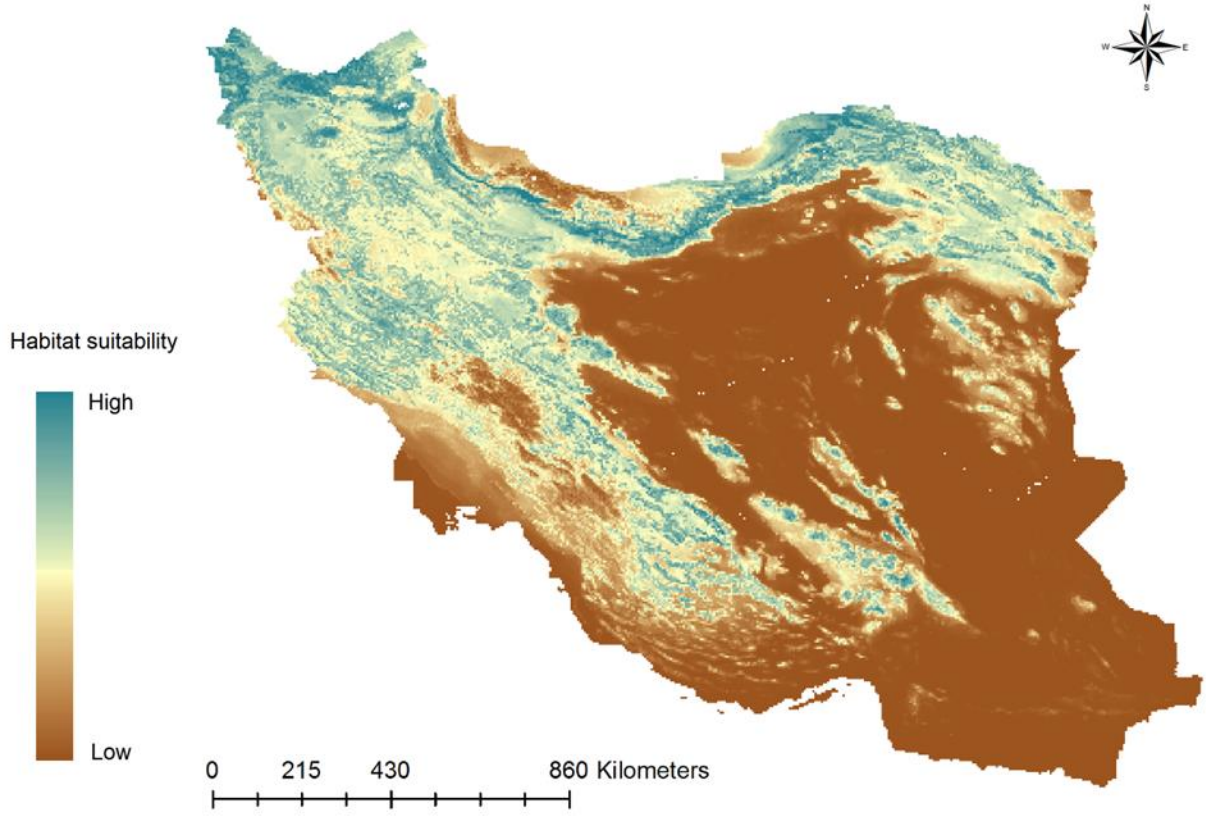

FIGURE 2. *Macrovipera* distribution model in Iran under current climate conditions based on ensemble model.

Future distribution of the genus *Macrovipera*

Based on the future distribution model of the genus *Macrovipera*, suitable habitat of this genus will decrease slightly in the future. Under pessimistic scenarios for the years 2071-2100, about 11% of the suitable habitats will decrease in Iran (Table 1). In other words, the area of suitable habitats will decrease from 614,126 to 548,197 (Figure 3).

TABLE 1. Area and percentage of suitable habitats of the genus *Macrovipera* in Iran under the current and future climate.

Year and Scenario	Present (2010)	2041-2070 ssp126	2041-2070 ssp585	2071-2100 ssp126	2071-2100 ssp585
Area (km^2)	614126	613888	586128	608993	548197
Percent of area reduction	0	-0.04	-4.56	-0.84	-10.74

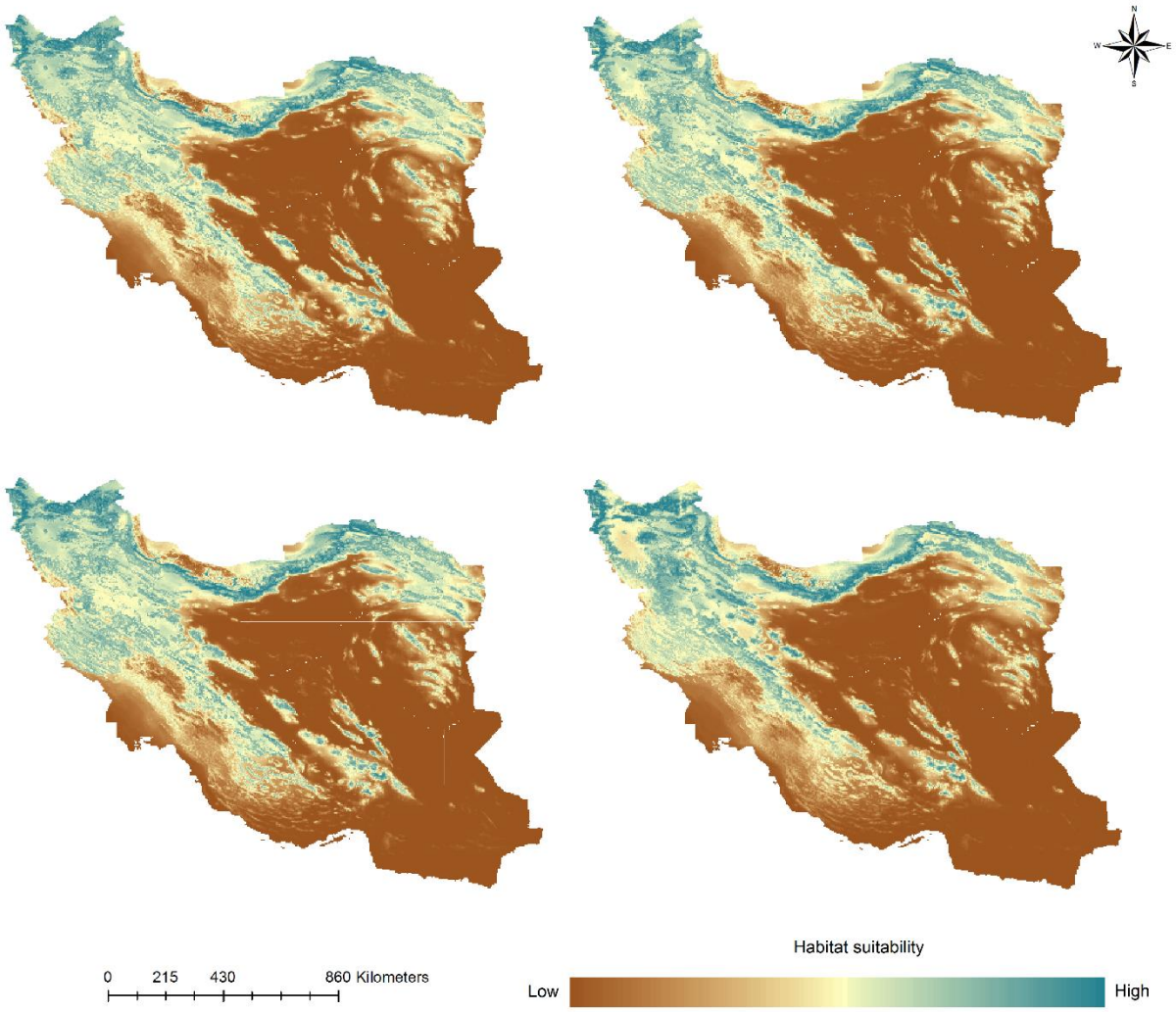

FIGURE 3. Future distribution models of the genus *Macrovipera* in Iran.

Coverage of protected areas

The measurement of the coverage of the protected areas for the suitable habitats of the genus showed that only about eight percent of the suitable habitats of the species are covered by the protected areas (Table 2). Determining the extent of suitable habitats in different categories of protected areas showed that 3,500 square kilometers of protected habitats are located in the national parks, 12,050 square kilometers in the wildlife refuges, and 34,580 square kilometers in the protected areas. In the future, the extent of suitable habitats in protected areas will remain almost the same.

TABLE 2. Area and percentage of protected suitable habitats of the genus *Macrovipera* in Iran.

Year and scenario	Present (2010)	2041-2070 ssp126	2041-2070 ssp585	2071-2100 ssp126	2071-2100 ssp585
Area of protected habitat (km^2)	50130	51054	47057	49433	44774
Percent of protected habitat	8.16	8.32	8.03	8.12	8.17

DISCUSSION

In the present study, the impact of future climate changes on the genus *Macrovipera* in Iran was investigated. The results show that climate changes will not have a major impact on the distribution of this genus, so that under the pessimistic scenarios for the years 2071-2100, about 11% of the suitable habitats of this genus in Iran will be reduced.

The result of the present study is in line with the studies conducted on other venomous snakes in Iran as well as venomous snakes in other countries, which show that venomous snakes will lose their suitable habitats under climate change (Ahmadi *et al.,* 2019; Penman *et al.,* 2010; Yousefi *et al.,* 2015; Yousefi *et al.,* 2019). The studies carried out in Iran on how the genus *Montivipera* is affected by future climate changes have shown that the suitable habitats for the genus *Montivipera* in the mountainous regions of the country will decrease sharply and the members of this genus will move to higher altitudes to find suitable habitats. (Yousefi *et al.,* 2019). Therefore, it can be concluded that both genus will be negatively affected by climate change, but the severity of climate change will be different on each genus.

Penman *et al.* (2010) predicted the impacts of climate change on a snake in Australia and showed the future distribution of the species was constructed for the years 2030 and 2070. Their results also showed that the range of presence of the species will decrease in the future. According to the pessimistic scenario, only 14% of the currently known populations of the species will survive in the future, and other populations will either adapt to rapidly changing conditions or undergo local extinctions (Penman *et al.,* 2010). Although the rate of loss of suitable habitats of this species is much higher than that of *Macrovipera* in Iran, the status of suitable habitats in both studies is decreasing due to climate change.

Climate changes will change species interactions and cause competition between different species by changing the distribution pattern of species (Hannah, 2015). The distribution of members of the two genera *Macrovipera* and *Montivipera* is separated from each other in terms of elevation (Rajabizadeh, 2018). The genus *Montivipera* lives in high elevation habitats, while the members of the genus *Macrovipera* live at lower elevations (Rajabizadeh, 2018). Based on the results of the present study, the suitable climatic of the genus *Macrovipera* will decrease in low elevation areas and move to higher elevation areas. This pattern of moving species to higher habitats in response to climate change is also predicted for other reptile species (Vaissi, 2022; Yousefi *et al.,* 2015). As a result, it is expected that the populations of the genus *Macrovipera* will move to higher areas than their current habitat. However, as mentioned, in major parts of the Zagros and Alborz mountain ranges, higher elevation habitats are already occupied by members of the genus *Montivipera* (Rajabizadeh, 2018; Yousefi *et al.,* 2019). Therefore, there will be a possibility of competition between the two genera to occupy the suitable habitats. One other possibility is that the genus *Macrovipera* can adapt to the new climatic conditions in low elevation habitats.

Species distribution models are practical tools for measuring the coverage of protected areas for suitable habitats of species (Guisan *et al.*, 2017). In the present study, it was determined that currently eight percent of the suitable habitats of *Macrovipera* vipers are under legal protection. Although the suitable protected habitats will not decrease under the climate change, but considering that the coverage of the protected areas for the suitable habitats of this genus is generally limited, there is a need for protected areas development programs to protected suitable but not unprotected habitats of the genus. Determining the extent of suitable habitats in different categories of protected areas showed that national parks have the lowest percentage of protected habitats of the genus *Macrovipera* and the largest extent of suitable habitats is in the category of protected areas.

Although the results of the present study showed that the genus *Macrovipera* will lose a small part of its suitable habitats and will not be significantly affected by the climate change, but the studies conducted on other reptiles (Hosseinian Yousefkhani *et al.*, 2017; Kafash *et al.*, 2018; Vaissi, 2022), amphibians (Kafash *et al.*, 2018; Vaissi, 2021), freshwater fish (Esmaeili *et al.*, 2018; Yousefi *et al.*, 2020b), birds (Sheykhi Ilanloo *et al.*, 2021) and mammals (Malekian & Sadeghi, 2020; Malakoutikhah *et al.*, 2020; Ebrahimi *et al.*, 2021) show that many species will be influenced by climate changes and they will lose a significant part of their suitable habitats (Yousefi *et al.*, 2019). Therefore, climate change will continue to be a major challenge for biodiversity conservation in Iran.

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