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Predicting the impact of climate change on the spatial distribution of Euphrates spiny eel *Mastacembelus mastacembelus* (Banks & Solander, 1794) in Iran

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ABSTRACT
The phenomenon of climate change is occurring more rapidly in the global climate due to the role of human factors than in other periods of climate change, and this feature causes the existing ecosystems and species to not have enough time to adapt to this environmental change. The impacts of climate change on the spatial distribution of spiny eel *Mastacembelus mastacembelus* in Iran were investigated using the MaxEnt modeling technique in R software environment under optimistic and pessimistic climate change scenarios of the 2050s and 2080s. Six environmental variables, including annual precipitation, slope, flow accumulation, temperature annual range, annual mean temperature, and upstream drainage area were used. The performance of the model in predicting the species was "good" based on the AUC (area under the curve) criterion. This spatial distribution of species will decrease under optimistic and pessimistic scenarios in 2050 and 2080. These results can be used by the manager in order to plan conservational strategies to protect this species in the future in front of climate change impacts.

Keywords: Spices distribution modeling (SDM), MaxEnt model, Fish diversity, Conservation.
Article type: Research Article.

INTRODUCTION
Due to the complexities of life, climate change affects all aspects of life on Earth, and changes in climate patterns have far-reaching effects. As for the ecological consequences, many environmentalists consider climate change as one of the global threats to biodiversity (Ricciardi & Rasmussen 1999; Heino *et al.* 2009; Rostami *et al.* 2022; Ayada *et al.* 2024). The phenomenon of climate change is occurring more rapidly in the global climate due to the role of human factors than in other periods of climate change, and this feature causes the existing ecosystems and species to not have enough time to adapt to this environmental change. Aquatic ecosystems around the world are among the most important ecosystems that are affected by the consequences of climate change (LeRoy Poff *et al.* 2002) and due to the global climate change trend, this phenomenon will have many effects on the country's ecosystems, especially freshwater river ecosystems. Given that already many factors such as water quality changes, hydrology, morphology, land use, as well as the introduction of non-native species, along with overfishing, threaten the biodiversity of the country's aquatic ecosystems, this phenomenon likely to increase the intensity and speed of the degradation process (Mostafavi *et al.* 2014, 2019; Hajiradkouchak *et al.* 2019; Jaafer Abdullah *et al.* 2022). Freshwater ecosystems are the most endangered ecosystems and habitats in the

world and declines in biodiversity are far greater in freshwaters than in the most affected terrestrial ecosystems and have alarming rates of species extinction (Sala *et al.* 2000; Coates & Grekin 2018). Of the more than 5,000 freshwater fish species assessed by the World Conservation Union (IUCN), over 40% are classified as threatened with extinction (Reid *et al.* 2013). Unpredictable synergies with climate change greatly complicate the impacts of other stressors that threaten many marine and freshwater fishes (Arthington *et al.* 2016). Therefore, by conducting extensive studies, their situation in terms of population, ecology, and protection is carefully investigated and appropriate environmental protection (conservation) and management programs are prepared and implemented for this purpose (Sorensen 1993). In addition, understanding the effects of climate change on species is crucial for correctly estimating their extinction risk and choosing appropriate conservation measures (Butt *et al.* 2016). Species distribution prediction modeling is an important tool in conservation ecology and biology, which can be used in conservation planning, evolution, species management, or resolving the conflict between humans and wildlife, among other things (Hirzel *et al.* 2001). It tries to explain the relationships between the distribution of species and their environmental characteristics (Ebrahimi & Dabbagh 2018). One of the most important methods in modeling the natural environment is species distribution modeling (SDM), which is defined as a tool for examining the relationship between species' geographic distribution data (presence or abundance in known locations) with information about species' environmental characteristics (Elith & Leathwich 2009). The only species of the family Mastacembelidae in Iran is *Mastacembelus mastacembelus*. In this study, we will investigate the effect of climate change on the spatial distribution of this species in south- and south-western Iran, including the basins of Tigris, Persian Gulf (Persis), Hormuz, and Makran under different climate scenarios.

MATERIALS AND METHODS

Study area and species data occurrence

The studied area in this research contains the Tigris, Persian Gulf, Hormuz, and Makran basins in Iran (Figs. 1 and 2). The basins where all are connected to the Persian Gulf and Oman Sea.

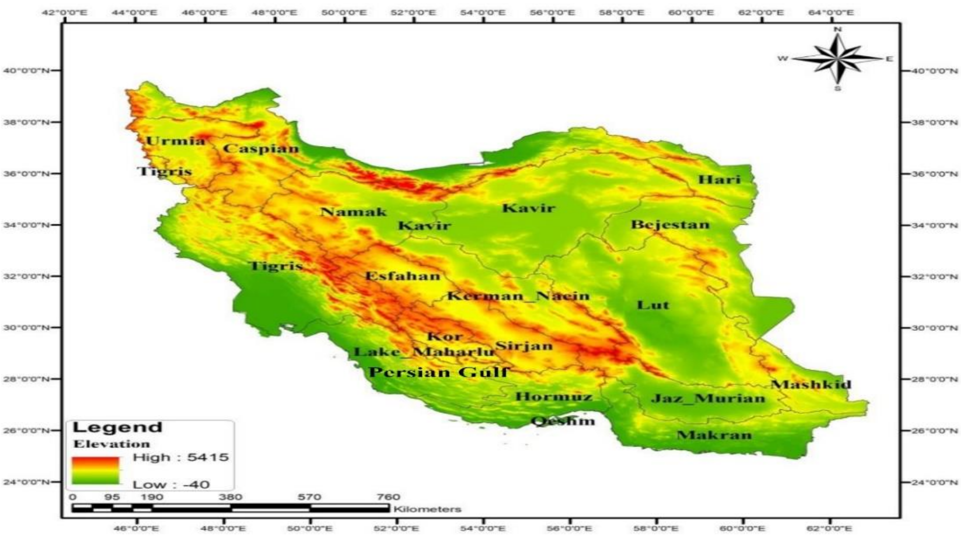


Fig. 1. Major hydrologic units of Iran (Coad 2018).

The spiny eels (Family Mastacembelidae) inhabit the freshwaters from Africa to eastward to Korea and Malaysia and include five genera and 74 species (Froese & Pauly 2004). Mastacembelid species generally are found at high altitudes as well as in low land in both still and running waters (Woo 1995). Among the spiny eel species, *M. mastacembelus* (Fig. 2) is widespread in the south- and southwest of Iran, including the Tigris River, Karoon, and Karkheh and also in the lakes such as Parishan and Zarivar.

The species occurrence was obtained from our fieldwork, previous literature, personal datasets of experts, and museum data with known geographical coordinates, which were considered as presence points.

Environmental variables preparation

Based on the ecological needs of the studied species, a total of eight variables were initially selected (i.e., maximum air temperature, minimum air temperature, BIO1 = annual mean temperature, BIO7 = temperature annual range, BIO12 = annual precipitation, slope, flow accumulation, upstream drainage area; Table 1). Afterward, the co-linearity among environmental variables was tested by Pearson's correlation coefficient (r). If two variables were highly correlated ($r > |0.70|$), one of them was excluded according to our expert judgment (Elith *et al.* 2011). To represent climate change influences, projected future climate variables for 2050 and 2080 with empirically downscaled bioclimatic data were used. The average of 10 general circulation models (GCMs) under optimistic (RCP 2.6) and pessimistic (RCP 8.5) greenhouse gas emissions scenarios was considered. The resolution of environmental variables used in the study was 30 arc-seconds (ca. 1 × 1 km).

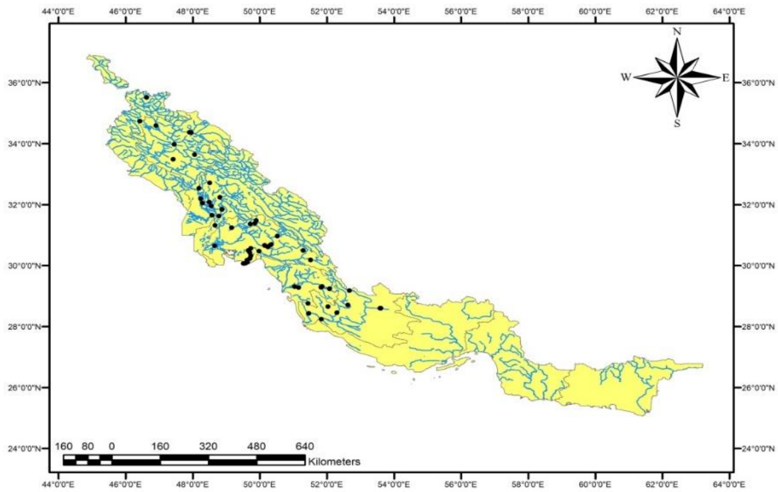


Fig. 2. The current distribution of *Mastacembelus mastacembelus* in Iran.

Table 1. Environmental variables were used in this study.

Category	Variable	Source
Bioclimatic variables	BIO1 = Annual Mean Temperature (°C) BIO7 = Temperature Annual Range (°C) BIO12 = Annual Precipitation (mm)	www.worldclim.org
Topographic variables	Slope (Degree)	www.isric.org / www.worldgrids.org
Global hydrography datasets	Flow Accumulation Upstream Drainage Area	http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/

Modeling technique

The MaxEnt model (Phillips *et al.* 2006) was applied to model the current and future habitat suitability of species. MaxEnt (jar file v3.4.1) was used through the Dismo package v1.1-4 (Hijmans *et al.* 2017) in the R v3.2.3 programming environment (R Core Team 2018). This model is particularly useful when data points are presence-only with a limited number of records (Bosso *et al.* 2013; Fois *et al.* 2018; Vasconcelos *et al.* 2012). The modeling was evaluated using 10-fold cross-validation according to Valavi *et al.* (2019). Permutation importance was also considered in order to define the main environmental variables which influence the potential distribution of the studied species (Abdelaal *et al.* 2019). To assess the accuracy of the modeling results, the area under the curve (AUC; Table 2) of the receiver operating characteristic curve (ROC) was computed (Lobo *et al.* 2008). The AUC score is a powerful tool for measuring model performance because of its independence from threshold selection (Fois *et al.* 2018; Yi *et al.* 2016). AUC shows the power of the model to discriminate presences from random backgrounds (Phillips *et al.* 2009). The AUC ranges between 0 and 1, with 0.5 showing a random prediction performance and value 1 with perfect discrimination. Values under 0.5 indicate models worse than random (Elith *et al.* 2006). To determine the suitable threshold for prediction, the equal training sensitivity and specificity of the MaxEnt report were used according to Liu *et al.* (2018), as it is appropriate for presence data.

Table 2. A quantitative and qualitative classification of model performance based on the AUC index (Tuan *et al.* 2019).

Model performance	**AUC value**
Very Poor	0.6–0.7
Poor	0.7–0.8
Good	0.8–0.9
Excellent	0.9 – 1

RESULTS AND DISCUSSION

After the correlation test, six environmental variables i.e., BIO1 = annual mean temperature, BIO7 = temperature annual range, BIO12 = annual precipitation, slope, flow accumulation, and upstream drainage area were left for modeling (Fig. 3).

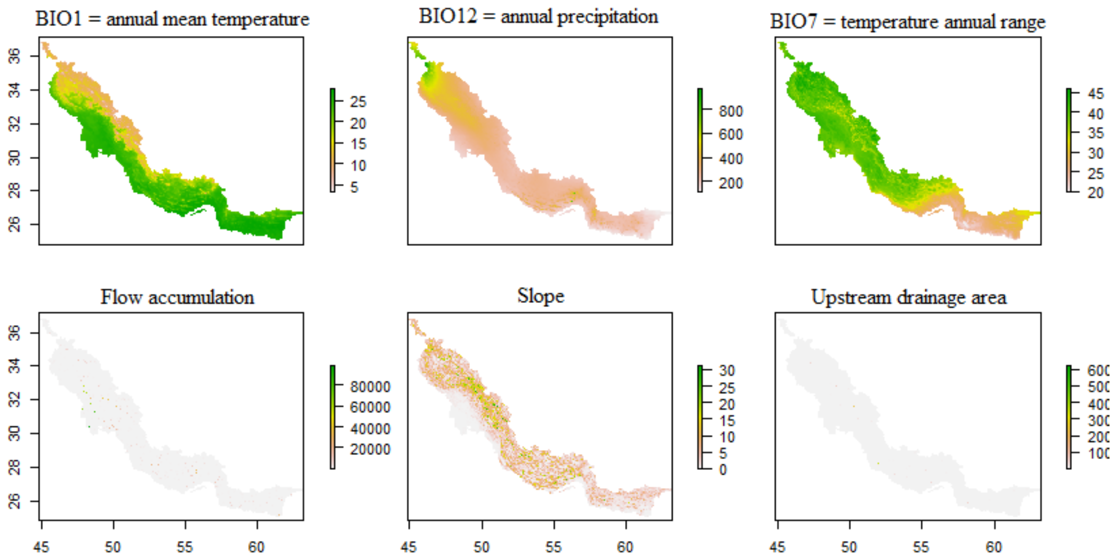


Fig. 3. Six environmental variables are selected in this study.

The result of evaluating the efficiency of the Maxent model using the AUC index (0.850) shows that this model has a great ability in predicting the distribution of *M. mastacembelus* (Fig. 4) . Also, based on the results, the temperature annual range (BIO7) is more important than other variables in determining the distribution of this species. Other variables, including flow accumulation and annual mean temperature, have been effective in its distribution (Fig. 5). The results of modeling the distribution of this species under the influence of climate change indicate that in all the scenarios and time scales studied, the model prediction will show both increase (gain) and decrease (loss). However, the loss is higher than gain and consequently, the range change is negative for all optimistic and pessimistic scenarios (Table 4 and Fig. 6). Moreover, the lowest severity is the pessimistic scenario of 2080 (i.e. -2.68 %). Although in the past there were high ambiguities and uncertainties regarding the severity and extent of climate change by some global experts, it can be stated that today the occurrence of climate change has been universally accepted with high certainty and there is no doubt about the phenomenon of climate change and the extent and intensity of the effects of this phenomenon in the global climate (IPCC 2018).

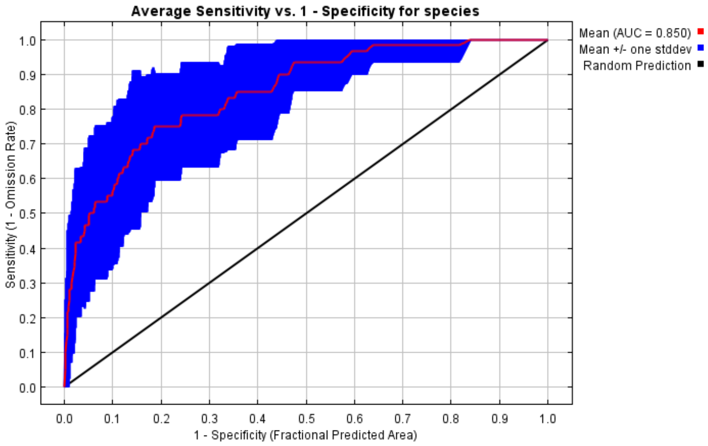


Fig. 4. Receiver operating characteristic (ROC) curve and AUC index.

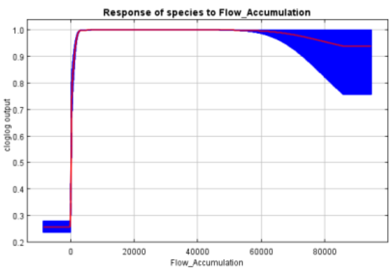
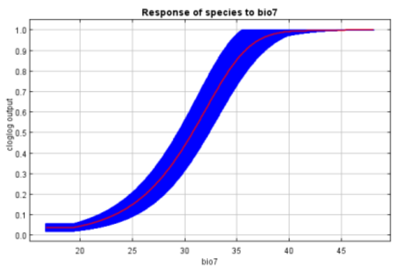
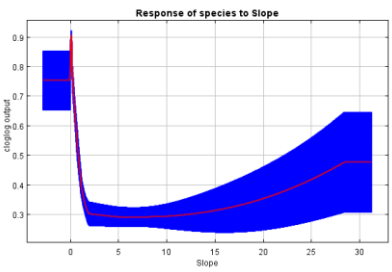
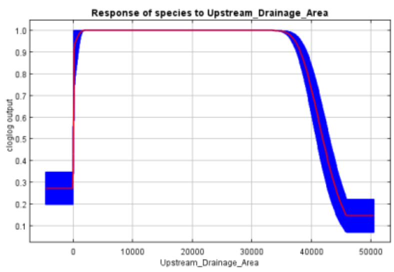
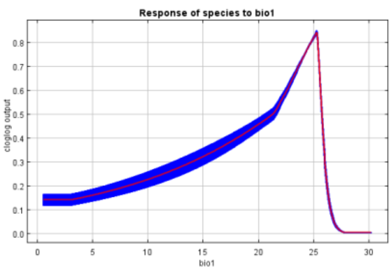
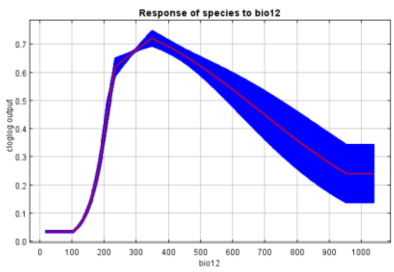
Variable		Permutation importance	Variable		Permutation importance
Flow accumulation		21.7	Temperature annual range		51.2
Slope		6.7	Upstream drainage area		4.1
Annual mean temperature		14.9	Annual precipitation		1.4

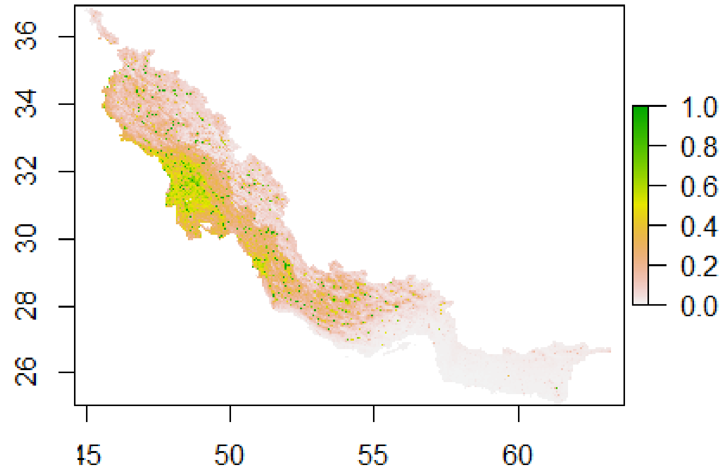
Fig. 5. Variable importance for distribution of *Mastacembelus mastacembelus*.

Predicting the consequences of climate change on organisms' geographical distribution, and consequently, on their biodiversity, is a complex and monumental task, but one which is necessary (Warren *et al.* 2018). SDMs allowed the selection of the most appropriate geographical extent or accessible area (Acevedo *et al.* 2017). The present study showed that by the occurrence of climate changes in the future, the distribution range of *M. mastacembelus* will decrease according to the RCP2.6 and RCP8.5 climate scenarios, in two-time scales of 2050 and 2080.

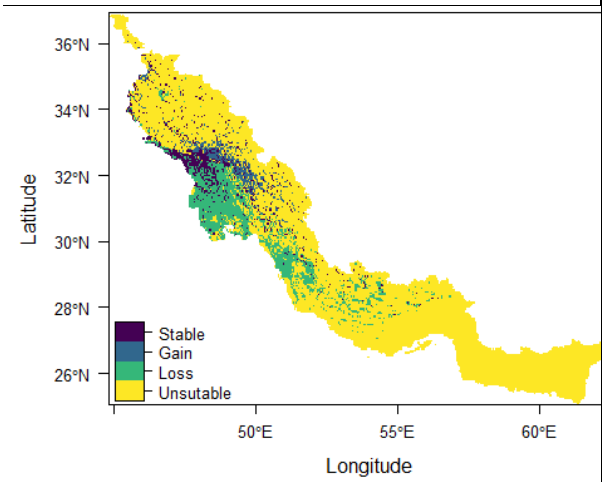
Table 3. Percentage of gain, loss, and range change of species under scenarios for 2050 and 2080.

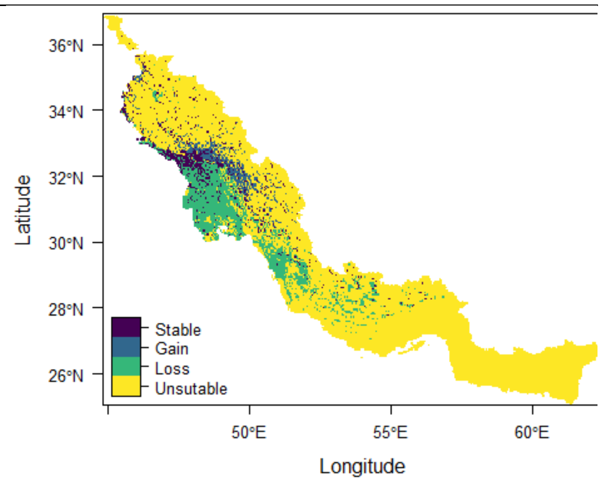
Species	Time – Scenarios						Optimistic/ Pessimistic
	Rcp 2050			Rcp 2080			
	Gain	Loss	Range change	Gain	Loss	Range change	
M. mastacembelus	17.52	71.30	-53.78	18.07	72.76	-54.70	Optimistic
	33.26	78.04	-44.79	79.61	82.29	-2.68	Pessimistic

Current Prediction



26.2050 | **26.2080**





85.2050 | **85.2080**

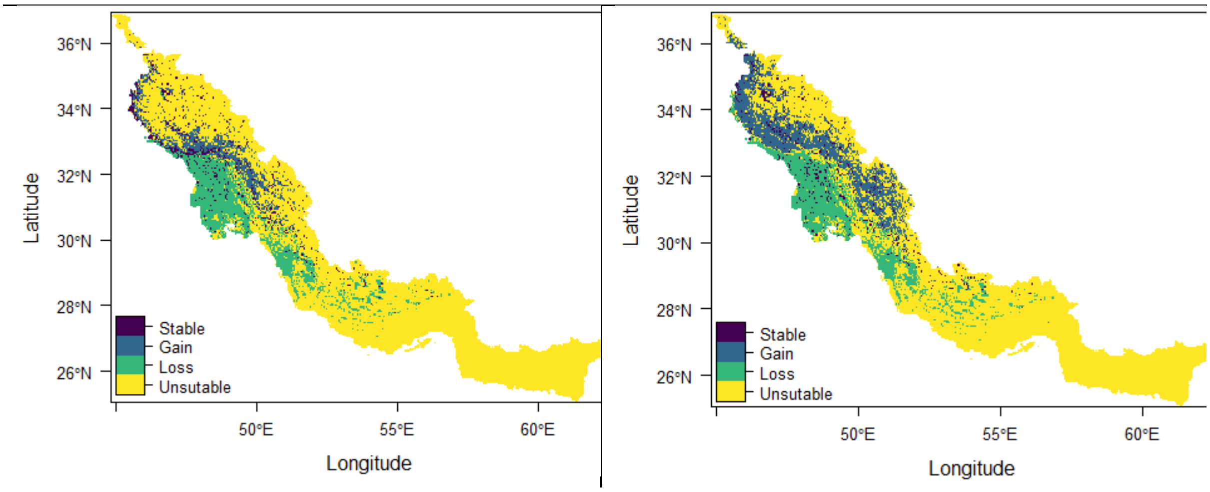


Fig. 6. Distribution of species under different climate change scenarios for 2050 and 2080.

Freshwater fishes are ectothermic animals and particularly sensitive to temperature. It has been documented that temperature is one of the main factors determining the spatial distribution of stream fishes (Buisson *et al.* 2008; Herlihy *et al.* 2019). Temperature fluctuations affect the metabolism, breeding, development, and growth of fish (Mann 1996). Moreover, since streams and rivers are relatively shallow, turbulent and well-mixed, they easily exchange heat with the atmosphere. Consequently, annual (mean and range) air temperatures were used as a surrogate of water temperature. In the present study, mean air temperature was found to be an important variable affecting fish species distributions. This outcome has already been documented by previous studies (e.g., Buisson *et al.* 2008; Abdoli & Naderi Jolodar 2009; Mostafavi *et al.* 2014, 2015). In general, organisms respond to climate change in several ways i.e., move to track climatic conditions, stay in place and adapt to the new climate, or become extinct (Berteaux *et al.* 2004). The analysis in our study indicated that the distribution of *M. mastacembelus* will become reduced in the future in all tested scenarios. Mostafavi & Kambouzia (2019), and Mostafavi *et al.* (2018), predicted a reduction in the distribution range of *Salmo trutta* and *Alburnus filippii* under optimistic and pessimistic climate-change scenarios (RCP 2.6 and RCP 8.5) in 2050 and 2080 based on their database. Moreover, under climate change, some cold-water fish species in French streams would experience high reductions in their distributions (Buisson *et al.* 2008). As mentioned above, climate change probably impacts most species negatively. However, some species may benefit from climate change, since the amount of suitable habitat might be increased (Yousefi *et al.* 2020). Filipe *et al.* (2013) modeled that brown trout distribution also will be decreased due to climate change effects in the future. In conclusion, concerning the results of this study and the evaluation of the models performance, it can be concluded that SDMs are successful in modeling the fish species distribution, including the studied species. Therefore, it could be used in conservation measures of fish species in an area with large climatic variability such as Iran. Moreover, this study provides valuable information to managers and researchers in the field of biodiversity management and protection, since conservation, restoring, and managing biodiversity are important strategies against climate change and its effects (Levin & Lubchenco 2008; Hodgson *et al.* 2009; McClure *et al.* 2013).

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