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Original Article

Prediction of climate change impact on the members of *Capoeta damascina* species group in Central Zagros, Iran

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Abstract: The aim of the present study was to predict future distribution change of the Mesopotamian barb species group or *Capoeta damascina* species complex under different climate scenarios in Central Zagros, Iran. By collecting data on the species' presence and applying the Maximum Entropy (MaxEnt) algorithm with the help of R programming language, we were able to create models of the current habitats of the fishes. Then the distribution range shifts in the future were projected in two optimistic and pessimistic scenarios (Representative Concentration Pathways (RCP) 2.6 and 8.5) of 2050 and 2080. The results showed that the accuracy of the implemented model was excellent (i.e. AUC (Area Under Curve) was 0.906. Moreover, the range change of species in all scenarios was negative but in the pessimistic scenario (RCP 8.5), the impact seems to be higher than in the optimistic scenario (RCP 2.6). The results of this study are very important for conservation and management. Knowing the potential impacts of climate change on these fish species in Central Zagros in the present and future can help us make better decisions to protect fish diversity in this important region.

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Introduction

Biological diversity, particularly in fish species, in Iran is at a high level (Esmaeili et al., 2018; Eagderi et al., 2022). However, anthropogenic factors and human pressures, including urbanization, agriculture, industrial development, construction of dams, etc., have been affecting freshwater ecosystems for many years. Consequently, many riverine habitats are under various severe pressures. As a result, the physio-chemical features of aquatic ecosystems are changing, and habitats are degrading. This threatens the aquatic biota and leads to the loss of biodiversity (Coad, 1980; Kiabi et al., 1999; Mostafavi et al., 2014). Mostafavi et al. (2015) pointed out that many fish species have been included in the International Union for Conservation of Nature (IUCN) Red List in recent years, mainly due to human threats; the fish species' distribution in Iran is limited, and their population is decreasing in their main habitats. In the meantime, climate change is turning out to be an extra stress on biodiversity (Radkhah et al., 2022). Climate change is another element that has made freshwater ecosystems undergo considerable changes in recent decades in a way that freshwater biodiversity has declined at a higher pace in comparison to terrestrial lands. It is predicted in some studies that this trend is probable to continue in the future (Dudgeon et al., 2006; Filipe et al., 2013; Morid et al., 2016; Makki et al., 2023) so many species are going to be affected negatively by climate change. Although today the primary cause of species extinction is habitat destruction, Leadley (2010) has suggested that climate change will become the first factor in the next few decades.

The reason for the high vulnerability of freshwater ecosystems is the nature of fragmented habitats of rivers that prohibit the dispersal of aquatic species (Eagderi et al., 2014). Furthermore, the temperature and availability of water are dependent on climate, and the currently existing stresses exposed by humans, contributing factors that have made such ecosystems

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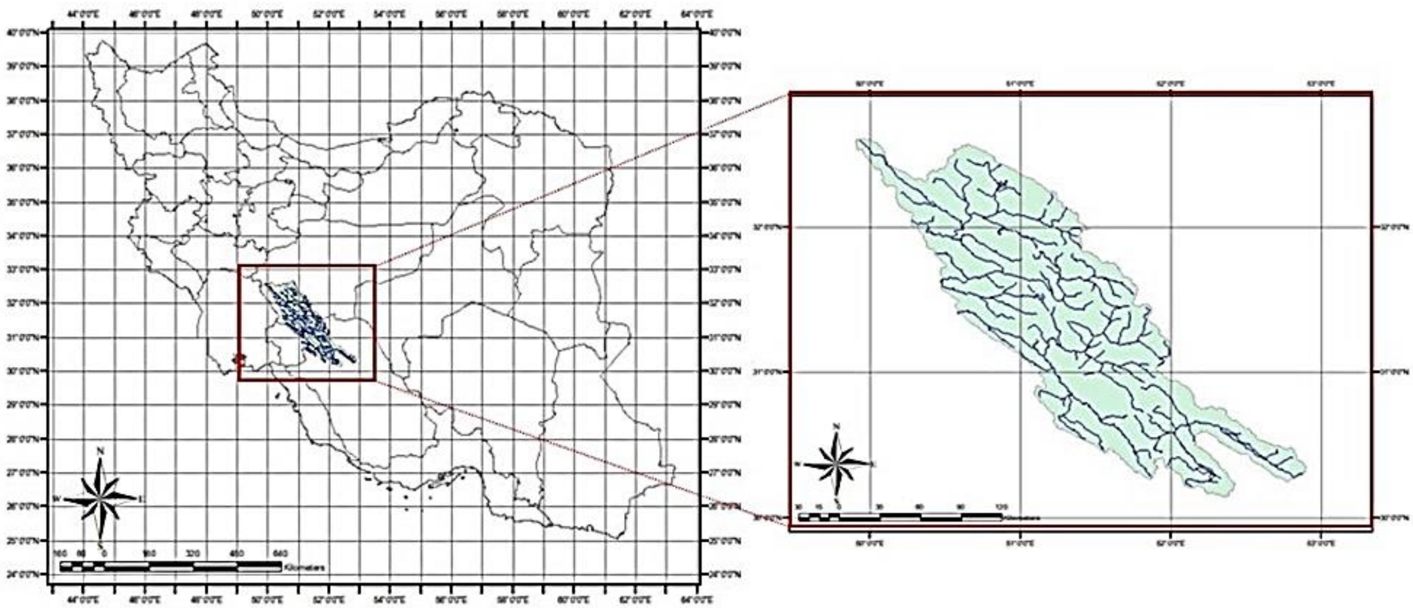

Figure 1. Permanent and seasonal rivers in Central Zagros water basins.

even more vulnerable (Dudgeon et al., 2006; Woodward et al., 2010). In the future, with this rate of human pressure and climate change, the temperature of the water will increase, and the precipitation, hydrology, and evaporation patterns will also alter; therefore, aquatic species' habitats will be affected severely (Schindler, 2001; Woodward et al., 2010; Filipe et al., 2013).

A proper method to study the relationship between different species and the environment in which they live is Species Distribution Modeling (SDM). It has been applied in many studies in recent years (Guisan and Thuiller, 2005; Zhang et al., 2018; Mostafavi et al., 2019). Using SDM, it is possible to create predictive distribution models for different species for developing management and conservation strategies and decision-making (Phillips and Dud´ık, 2008; Cayuela et al., 2009).

There are 37 valid species in this genus, of which 18 of them occur in Iranian inland waters (Esmaeili et al., 2016; Eagderi et al., 2022). Previous studies based on molecular mitochondrial data recognized three main clades within the genus *Capoeta* i.e. Mesopotamian, Aralo-Caspian, and Anatolian-Iranian clades (Levin et al., 2012; Çiçek et al., 2021a, b). The Mesopotamian group or *C. damascina* species complex is a widespread species group in the Persian Gulf basin, Jordan River drainage, and Orontes basin and includes *C. coadi* (Karun River drainage), *C. ferdowsii* (Zohreh basin), *C. saadi* (Kor, Maharloo, Persis, and Hormozgan basins), and *C. raghazensis* (Hormozgan basin) in the Central Zagros of Iran (Eagderi and Mousavi-Sabet, 2021; Mouludi-Saleh et al., 2022; Eagderi et al., 2022).

In this study, we are trying to predict the effects of climate change on the spatial distribution of *C. damascina* species group in the Central Zagros basins in Iran using two optimistic and pessimistic climatic scenarios (RSP 2.6 and RCP 8.5 respectively) in two different time scales (2050 and 2080).

Materials and Methods

Study area and sampling: The Central Zagros (Fig. 1) is mainly mountainous and is located at a range altitude of 830 to 4416 meters above sea level. Its average elevation is 2332 meters. Its area is about 3,100,000 hectares and most of this area is covered by forests and pastures. About 87% of this area is under the direct supervision of government organizations (Coad, 1980). The particular status of Central Zagros which is located on two main closed endorheic catchments (Kor and Maharloo) and four main open external catchments (Exorheic) named Tigris (Karun), Zohreh (Fahlian), Persis (Mand and Hele) and Hormozgan (Kal and Mehran) provides about 40% of Iran's water resources, so this region has a very good

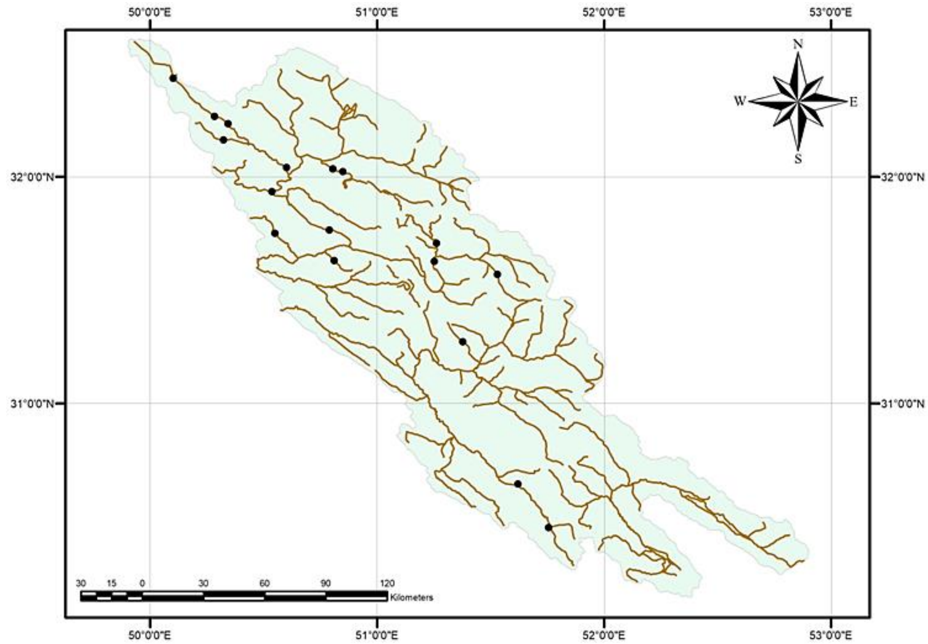

Figure 2. Real distribution of studied in *Capoeta* species group in Central Zagros.

Table 1. Calculation of changes in species distribution.

Percent of loss	Percent of gain	Species range change
(Loss/CD*) × 100	(Gain/CD) × 100	Percent of Gain–Percent of Loss

* NC: Current Distribution for each species.

Table 2. importance of variables for studied species.

Upstream drainage area	**Slope**	**River width**	**Mean diurnal range**	**Land use**	**Elevation**	**Flow accumulation**	**Annual precipitation**	**Annual mean temperature**	**Species**
5.6	2.5	6.0	4.0	1.0	11.4	21.8	46.6	1.2	***Capoeta damascina* species group**

diversity of freshwater fish, some of which have economic value (Coad, 1980).

Biological data: Occurrence data for *C. damascina* species group (Fig. 2) covering several time periods were collected from previous field samplings, from several museums as well as from the literature containing actual and historical information (e.g. Berg, 1949; Saadati, 1977).

Environmental variables: Initially, we downloaded the layers listed in Tables 1 and 2. We performed statistical filters, in other words, Spearman correlation, and omitted one variable in each pair with a high correlation (above 75%). Finally, the number of environmental factors declined to 9 as follows: (1) annual mean temperature, (2) mean diurnal range, (3) annual precipitation, (4) slope, (5) land use, (6) flow accumulation, (7) elevation, (8) river width, and (9) upstream drainage area.

Modeling: In this study, to model the distribution of species we benefitted from the maximum entropy

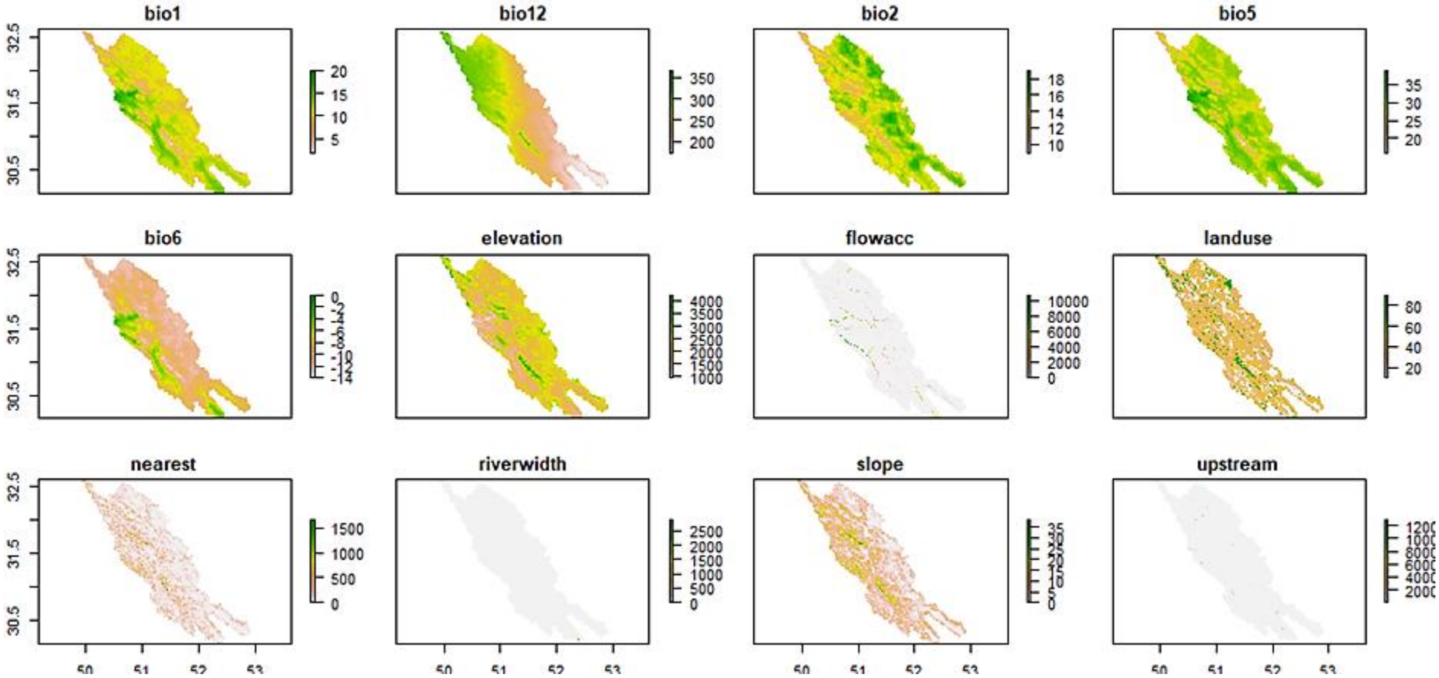

Figure 3. Environmental variables applied for modelling before the correlation test.

(MaxEnt) method using R programming language. MaxEnt is a common machine learning method. It originates from the concept of maximum entropy which is the second law of thermodynamics (Phillips et al., 2006). In the end, we used the AUC metric (area under the ROC (Receiver operating characteristic curve) curve) metric to evaluate the accuracy of each model. As a matter of fact, the higher the value of this metric is the higher accuracy it points out. AUC values above 0.7 are reported as valid and we can categorize the valid models into three groups: 0.7-0.8 as average, 0.8-0.9 as good models, and above 0.9 which indicates excellent models (Tuan et al., 2019).

Then, we used the model to project the distribution range of each species for the future. We extracted climatic data in two General Circulation Models (GCMs) of greenhouse gas emission for 2050 and 2080 from http://www.ccafs-climate.org. We used two RCPs to reduce the uncertainty resulting from the future climate models. In this study, RCP 2.6 is the optimistic, and RCP 8.5 is the pessimistic climate scenario in terms of greenhouse gas emission.

Distribution shift measurement: We calculated the projected shift in the potential habitat for every species in the future. We measured it by counting the number of lost, gained, or stable suitable pixels in each model (Table 1).

Results

Accuracy of models: According to the AUC value, the model performance was at an excellent level (AUC = 0.906) (Fig. 4).

Variable importance: The importance of each variable was also calculated by the MaxEnt algorithm (Table 2). We realized that annual precipitation, flow accumulation, and elevation are the most important variables for this species in choosing the suitable habitat respectively.

Habitat transformation: According to Tables 3 and 4, and Figure 5, the studied species group shows expansion and reduction in all scenarios of 2050 and 2080. However, in both scenarios, the range change will be reduced in the future and the impact of the pessimistic scenario is more than that of the optimistic scenario of 2050 and 2080.

Discussions

The SDMs and predictions built in this study for the Mesopotamian barb species group are particularly valuable for developing new research suggestions and planning effective conservation and management actions. Managers may initiate plans to protect current

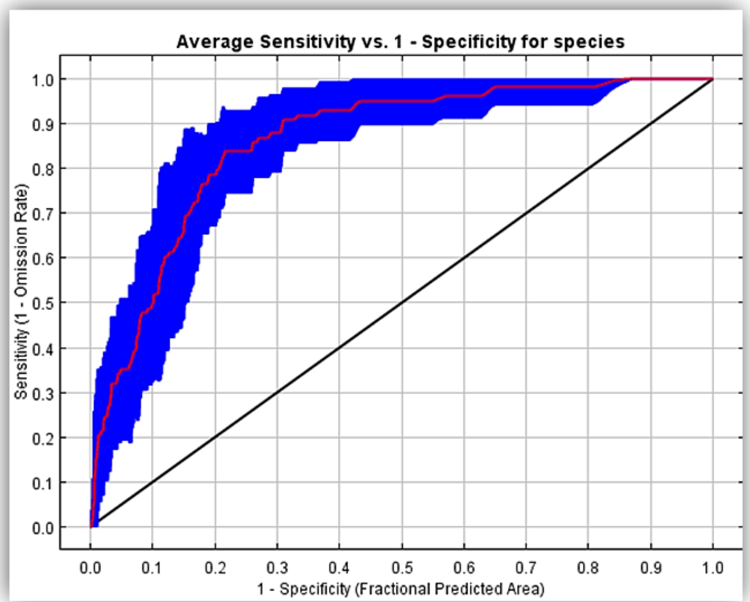

Figure 4. The accuracy of the model according to the AUC value (0.906).

Table 3. Amount of habitat shifts for studied species under optimistic scenario 2.6 in 2050 and 2080.

Species	Time – Scenario					
	2.6-2050			2.6-2080		
	Gain	Loss	Change	Gain	Loss	Change
Capoeta damascina species group in Central Zagros	17.48	36.11	-18.63	11.87	37.43	-25.56

Table 4. amount of habitat shifts for studied species under pessimistic scenario 8.5 in 2050 and 2080.

Species	Time – Scenario					
	8.5-2050			8.5-2080		
	Gain	Loss	Change	Gain	Loss	Change
Capoeta damascina species group in Central Zagros	13.27	39.32	-26.05	6.60	54.33	-47.73

and future habitats where these species are likely to occur based on our forecasts (Moss et al., 2009; Filipe et al., 2013). Improving environments for adaptation by protecting critical habitats is better than releasing maladapted captive-bred animals – a common practice in commercially exploited freshwater species (Lovejoy and Hannah, 2005). Usually, species can respond to climate change in several ways i.e. move to track climatic conditions, stay in place, and adapt to the new climate, or they become extinct (Berteaux et al., 2004; Lovejoy and Hannah, 2006). These changes in potential distribution can be different for each species due to their specific ecological characteristics, their needs, as well as the variation in the climatic scenarios (Moëzzi et al., 2022). There are several studies that have proven that fish species are going to face the risk of losing their habitat. For example, it was predicted that eight fish species in Europe will lose the whole extent of their habitat by 2050 as a result of climate change (Markovic et al., 2014). Also, Mostafavi and Kambouzia (2019) showed that brown trout in Iran are prone to lose some parts of their habitat. Furthermore, in France, cold-water fish species are to be affected negatively as their geographical range will decline (Buisson et al., 2008). However, climate change has a positive impact on

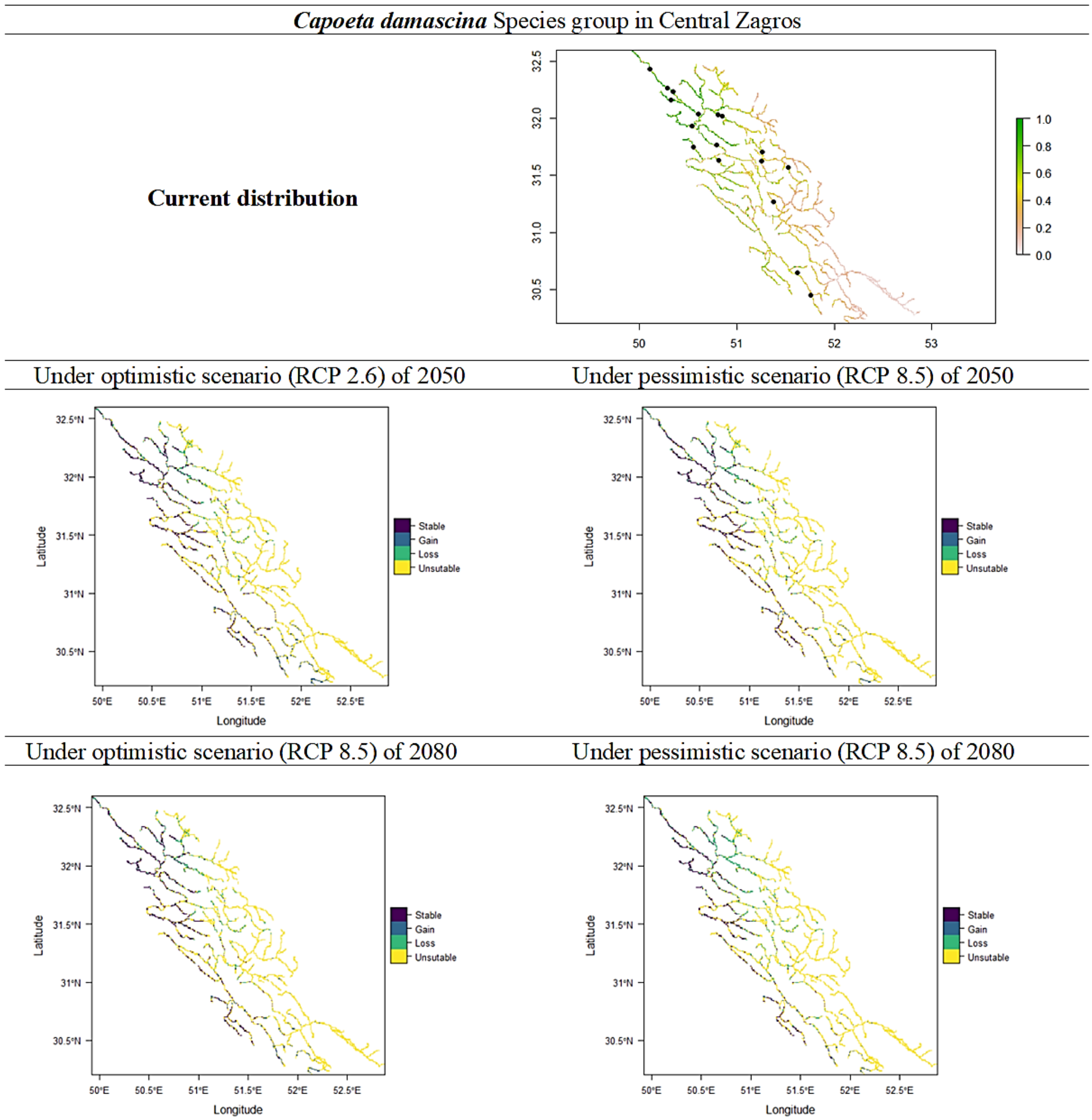

Figure 5. Prediction of current and future (under different scenarios of 2050 and 2080) distribution of studied *Capoeta* species in Central Zagros.

some species and can make the potential habitat of many species grow in extent (e.g., Muths et al., 2017; Kafash et al., 2018; Yousefi et al., 2020). Yousefi et al. (2020) studied 15 freshwater fish species in Iran. Their results demonstrated that the potential habitat for 10 species will increase due to climate change.

It has to be indicated that for those species whose habitats are predicted to increase under climate change scenarios, two facts can be ascertained. The first is that some of these new appropriate regions belong to basins where there is no connection between them or even belong to the same basin but there is no connection due to natural/artificial barriers. Therefore, other possible options such as translocation of species to new locations should be investigated (Markovic et al., 2014). More research, however, must be done to prospect this opportunity and other parameters should be checked to ensure that any new habitats are suitable. Because translocation of a species may also lead to catastrophic consequences in many situations, i.e. species might be able to adapt to the new conditions but may also be a potential competitor of other species, especially the native species of the target basins (Bittner, 2011; IPCC, 2014). The second fact is that for those species that are able to migrate through a basin, it should also be checked whether the predicted habitats would be affected by human development in the future (i.e. changes in land use, river connectivity by construction of dams, hydrology, morphology, water quality, introduction of exotic species, etc. According to Mostafavi et al. (2014), regarding *Alburnus zagrosensis*, now the junior synonym of *A. sellal* (Eagderi et al., 2019), Potentially suitable habitats in the Tigris basin are a considerable distance from its current territory. If these habitats face any human threats in the future or even currently, they should be addressed, and planners should work to remove or mitigate potential problems in order to implement a successful strategy for conservation. Species must have adaption and migration strategies when facing climate change and ultimately, there will be a high probability of extinction if these obstacles are not overcome (Parmesan, 2006; Aitken et al., 2008; Munday et al., 2017).

Conclusion

The results of this study are important in management and conservation. Knowing how climate affects the fish species, we can develop management strategies and prioritize potential areas for conservation. We suggest further studies about the potential future distribution of other species and biodiversity in this important region.

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