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Original Article

Forecasting habitat changes of *Vimba persa* (Pallas, 1814) under climate change using machine learning techniques in the southern Caspian Sea basin

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Abstract: The global climate change will decrease species distribution, loss of biodiversity, and decreased food security. The main purpose of this study was to forecast the distribution of *Vimba persa* in the southern Caspian Sea basin under two optimistic and pessimistic scenarios in 2050 and 2080 by the MaxEnt model in R software. Five environmental variables were used for the modeling: annual mean temperature, annual temperature range, annual precipitation, flow accumulation, and slope. The results demonstrated that the model's performance in predicting species distribution was "Good" (0.862) based on the Area Under the Curve criterion. The annual temperature range variable had the greatest impact (61.5) on determining the distribution of the studied species among the environmental variables used in modeling. Moreover, the results indicate that the distribution range of the Caspian vimba is likely to be reduced in 2050 and 2080 under both optimistic and pessimistic climate change scenarios. Hence, the decreasing distribution of this fish, an economic species interested in sport fishing, poses a serious threat to food security and livelihoods for local communities. In conclusion, policymakers should focus on increasing public awareness, implementing correct management practices, taking preventive measures, developing protection plans, allocating more funds for reconstruction and the restoration of aquatic ecosystems, and trying to reduce the accelerating factors of climate change.

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Introduction

The change in the climate system is an event that started with the development of human industrial activities, and now after intensifying, it has affected all aspects of life (Ramanathan, 2020). In other words, along with their progress, humans have also provided the causes for the development of this destructive phenomenon. Therefore, considering that this event will affect all aspects of human life, it will greatly threaten societies' health systems, nutrition, and economy (Xu and Ramanathan, 2017; Liu and Gao, 2020). The global mean surface temperature has risen by 1°C above the pre-industrial period. It is projected to exceed 1.5 and 2°C during this century unless deep reductions in greenhouse gas emissions are made (IPCC, 2022). Additionally, global warming and subsequent changes by removing the availability of favorable habitats will limit the range of distribution of many species (Morid et al., 2016; Schmutz et al., 2018; Mostafavi et al., 2021; Mousavi-Sabet et al., 2023a). In the last year, much evidence from different parts of the world clearly shows the destructive effects of climate change. For example, Chile and Libya experienced flooding, Tropical Storm Idalia hit New York, Iran suffered from drought, fire, and flood, and Canada and other parts of the world were affected by extensive forest fires (Ghasemi et al., 2015; Tabasinezhad et al., 2023).

Currently, one of the most important factors contributing to environmental degradation and species extinction is the events that have occurred following changes in the climate system (Carosi et al., 2019; Makki et al., 2023a). With the continuation of these events, the loss of biodiversity in the world, including freshwater ecosystems, will be one of the unpleasant events facing the Earth (Raven, 2020; Su et al., 2021;

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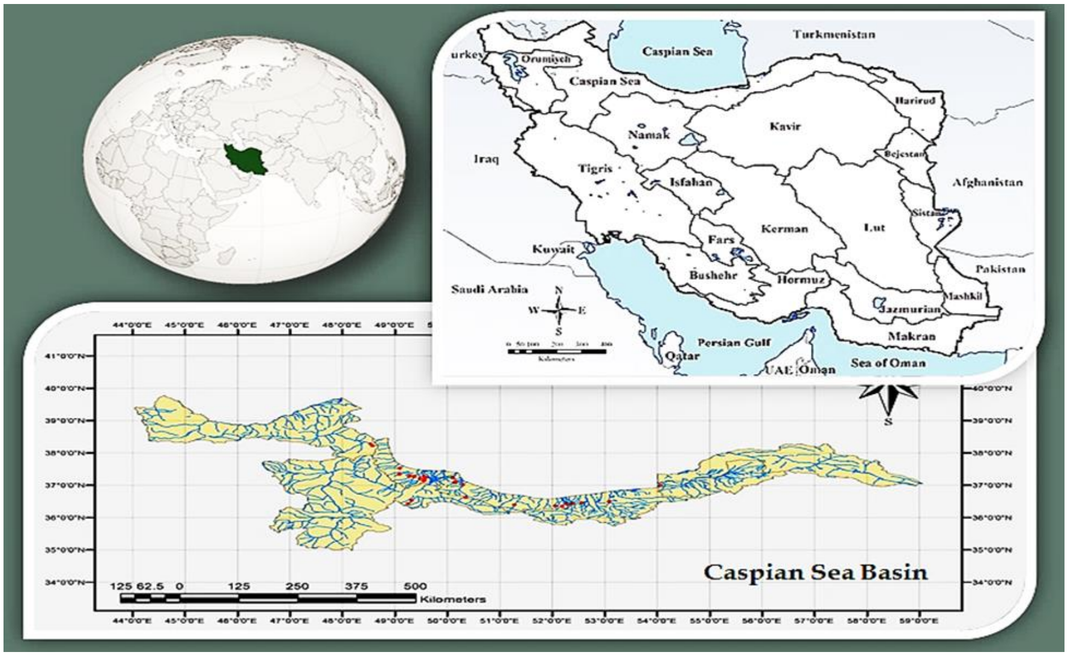

Figure 1. Study area and sampling sites of the Caspian vimba, in the southern Caspian Sea basin.

Dasgupta, 2021; Radkhah et al., 2022). Freshwater ecosystems contain about 9.5% of all animal species (Çiçek et al., 2018; Reid et al., 2019; Visser et al., 2023), and their existence is necessary for the continuation of human life (Mousavi-Sabet et al., 2023). Especially the role of riverine ecosystems in restoring and regenerating anadromous fishes in natural proliferation is very important (Muhar et al., 2018; Sarpanah et al., 2019; Mousavi-Sabet, 2021). Moreover, rivers are important for having a special fish population, spawning migratory fishes, and feeding estuary fishes (Sarpanah et al., 2019; Abbasi et al., 2023). Currently, anthropogenic activities worldwide have caused drastic modifications to the magnitude, frequency, timing, duration, and rate of change of freshwater flows, which has had a significant impact on the structure and functioning of these ecosystems and the services they provide (Palmer and Ruhi, 2019; Mousavi-Sabet, 2021; Barbarossa et al., 2021; Scherer et al., 2023). Unfortunately, the population of freshwater species declined by 84% between 1970 and 2016, which is higher than the average decline of 68% for all species (WWF, 2020). Therefore, with the intensification of climate change, the destruction of rivers and other water bodies will lead to the destruction of aquatic organisms, including edible fish that have a special place in the food baskets of local communities, and this will threaten their food security due to the lack of these valuable resources (Hejazi et al., 2023; Tabasinezhad et al., 2023). Accordingly, evaluating the condition of water bodies and aquatic animals is necessary to maintain the existing conditions and manage future events. Today, with the progress of science and the use of new techniques, it has become possible to identify and discover many complex environmental phenomena and events that were previously unknown. One of the useful techniques that various researchers have used (Bond et al., 2011; Filipe et al., 2013; Mostafavi et al., 2017; Ellender and Weyl, 2019; Mostafavi and Kambouzia, 2019; Yousefi et al., 2020; Hosseini et al., 2021; Moëzzi et al., 2022; Poorbagher et al., 2022; Makki et al., 2023a, b; Danylchuk et al., 2023; Tabasinezad et al., 2023) for many years is modeling future events under defined scenarios. This technique can be used to inform about the events that will happen in the future and plan to control them.

The Caspian vimba, *Vimba persa* (Pallas, 1814), is a native species distributed in the southern Caspian Sea basin, north of Iran (Eagderi et al., 2022). It is an important economic species in fisheries (Norousta and Mousavi-Sabet, 2013). In the current study, the objective is to predict the effects of climate change on

Table 1. Environmental variables were used for modeling and their estimates of permutation in MaxEnt modeling of Caspian vimba in the southern Caspian Sea basin.

Category and Source	Variable	Permutation importance (%)
Bioclimatic variables (www.worldclim.org)	BIO1 (Annual Mean Temperature)	1.6
	BIO7 (Annual Temperature Range)	61.5
	BIO12 (Annual Precipitation)	29.8
Global hydrography datasets (http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/)	Flow Accumulation	1
Topographic variables (www.isric.org www.worldgrids.org)	Slope	6

the spatial distribution of the Caspian vimba in the southern Caspian Sea basin using two optimistic (RSP 2.6) and pessimistic (RCP 8.5) climatic scenarios at two different time scales (2050 and 2080).

Materials and Methods

Study area and data occurrence: The studied area in this research contains rivers in the southern part of the Caspian Sea basin in Iran (Fig. 1). The Caspian Sea basin is one of the most important basins in Iran (Mousavi-Sabet et al., 2023a) with a high level of biodiversity and unique species (Vasil′eva et al., 2015; Abbasi et al., 2023; Coad, 2021). This basin has more than 100 species out of 292 fish species of the inland water ichthyofauna of Iran, including 83 native, 10 exclusive endemic (Eagderi et al., 2022), and 28 exotic species (Mousavi-Sabet et al., 2023b). The species occurrence records were obtained from our fieldwork, previous literature, and experts' personal datasets, which were considered presence points.

Species introduction: *Vimba persa* belongs to the family Leuciscidae and is one of the native species in the Caspian Sea basin (Coad, 2021; Eagderi et al., 2022). In Iran, it is recorded from the Caspian Sea basin and found in rivers, streams, lakes, dams, lagoons, marshes, and brackish environments (Keivany et al., 2016; Coad, 2021). This fish is harvested by local people for food (Taridashti et al., 2017). It is also a sport fishery species in Iran (Abdoli, 2016; Rahmani et al., 2011).

Environmental variables preparation: The environmental layers were extracted from different websites such as worldgrids, worldclim, and Global hydrography datasets. Layers in the scale of Iran with ArcGIS ver. 10.8 were then standardized. Initially, 8 variables were provided. Afterward, co-linearity among environmental variables was tested using Pearson's correlation coefficient (r). Finally, some variables were selected for modeling (Table 1). In addition, if two variables were highly correlated ($r > |0.70|$), one of them was excluded according to our expert judgment (Elith et al., 2011). Seventy percent of occurrence data were used for model training and 30% for testing, and this process was repeated five times using bootstrap sampling from all occurrence data (Franklin et al., 2010). We conducted jack-knife tests of predictor variable importance. To determine variable importance, in each iteration of the training algorithm, the change in regularized gain is added to the contribution of the corresponding variable. For each species, one model was developed at each scale using climate data from the period 1971–2000. This model was then projected to four sets of future climate maps (two GCMs, two emissions scenarios) at each of four scales. The threshold criterion used for analyses where binary maps of suitable vs. unsuitable habitats were required was the threshold where sensitivity equals specificity (Freeman and Moisen, 2008).

Modeling technique: To predict the potential distribution of Caspian vimba, modelling was performed using the "MaxEnt" model (Phillips et al., 2006) in the R package dismo (Hijmans et al., 2017)

Table 2. Quantitative and qualitative classification of model performance based on the AUC index.

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

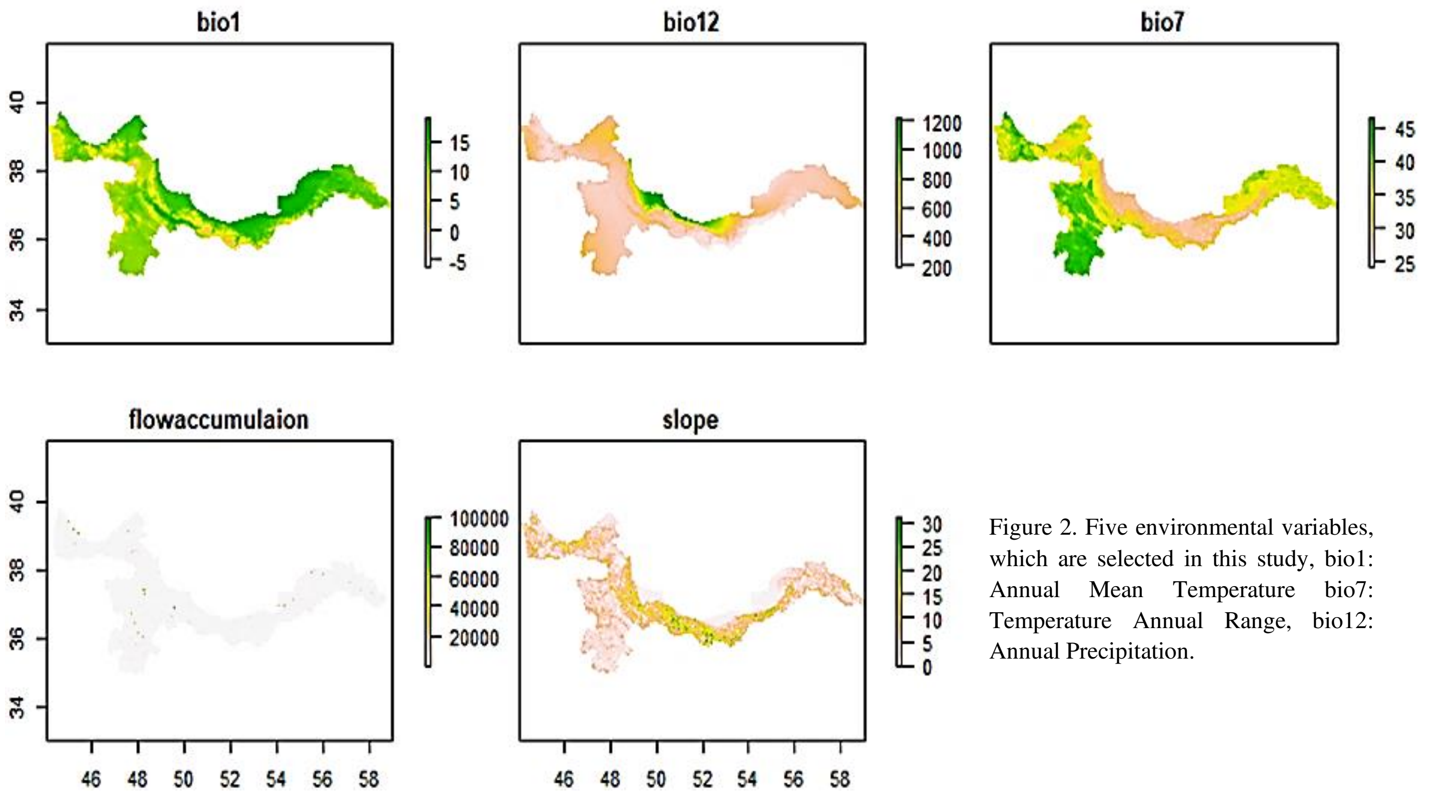

Figure 2. Five environmental variables, which are selected in this study, bio1: Annual Mean Temperature bio7: Temperature Annual Range, bio12: Annual Precipitation.

in R programing (R Core Team, 2018) according to Makki et al. (2023a, b). The MaxEnt model was predominantly used when the data points included presence-only with limited records (Franklin et al., 2013). To represent climate change impacts, projected future climate variables for 2050 and 2080 were used with empirically downscaled bioclimatic data. The average of 10 General Circulation Models (GCMs) under optimistic (RCP 2.6) and pessimistic (RCP 8.5) greenhouse gas emissions scenarios was considered. 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). AUC shows the model's power to discriminate presences from random backgrounds (Filipe et al., 2013). The AUC score is a powerful tool for measuring model performance because of its independence from threshold selection. The AUC ranges between 0 and 1, with 0.5 showing a random prediction performance and 1 showing perfect discrimination. Values under 0.5 indicate models worse than random (Filipe et al., 2013). The “equal training sensitivity and specificity” of the MaxEnt report was used to determine the suitable threshold for prediction (Liu et al., 2013). For Caspian vimba, we calculated the loss and gain of suitable habitats to access the shifts between current and future probabilities of occurrence obtained for each data subset (Pearson et al., 2006).

Results

After the correlation test, five environmental variables, i.e., BIO1 = Annual mean temperature, BIO7 = Annual temperature range, BIO12 = Annual precipitation, Flow accumulation, and Slope, were used for modeling (Fig. 2). The result of evaluating the

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

Scenarios	Optimistic (RCP 2.6)		Pessimistic (RCP 8.5)	
Time	2050	2080	2050	2080
Gain	2.69	4.41	1.24	0.66
Loss	36.08	34.58	50.84	60.18
Range change	-33.39	-30.16	-49.61	59.52

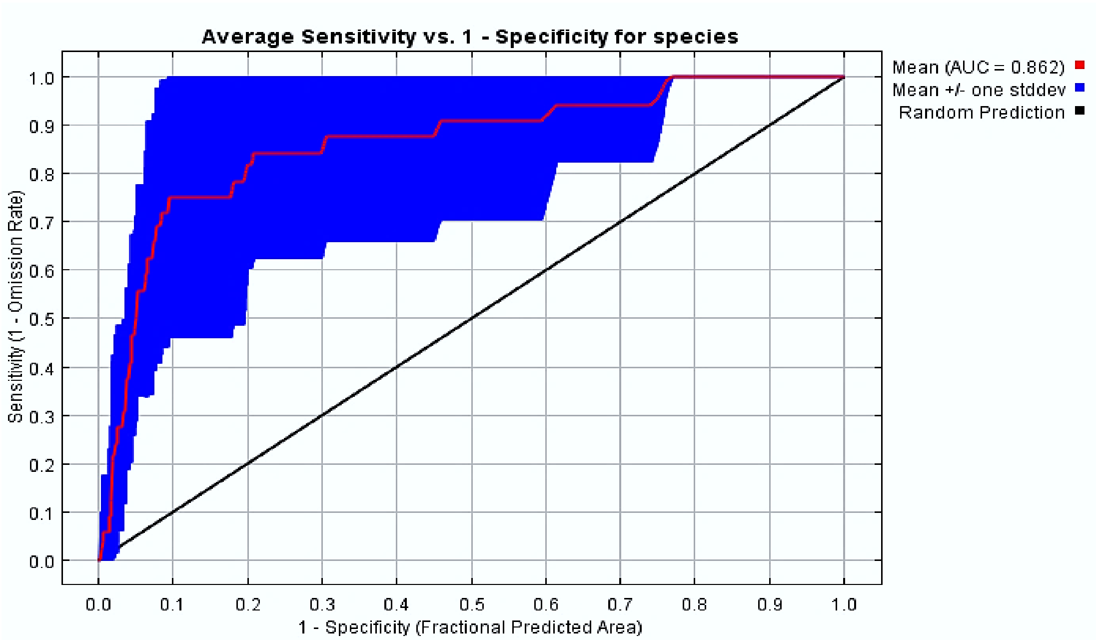

Figure 3. Five environmental variables are selected in this study: bio1: Annual Mean Temperature, bio7: Temperature Annual Range, and bio12: Annual Precipitation.

efficiency of the MaxEnt model using the AUC index (i.e. 0.862) shows that this model has a great ability in predicting the distribution of Caspian vimba (Fig. 3). Based on the results, the annual temperature range is the most important variable than the other variables in determining the distribution of this species (Fig. 4).
Both expansion (gain) and reduction (loss) are observed for the future distribution of Caspian vimba under both optimistic (RCP 2.6) and pessimistic (RCP 8.5) scenarios in 2050 and 2080. However, the percentage of loss is considerably more than gain. Moreover, the percentage of loss under a pessimistic scenario of 2050 and 2080 is remarkably more than the optimist scenario of 2050 and 2080 (Table 3, Fig. 5).

Discussions

With the increase in climate changes and the subsequent reduction of water resources and destruction of rivers, it is not far from expected that more and more types of aquatic species will be destroyed (Mostafavi et al., 2019; Shi et al., 2019; Kovach et al., 2020). Hence, decision-makers in this field must focus and put more effort into protecting rivers and aquatic animals. The future ecological and physiological consequences of climate change on rivers and fishes largely depend on the speed and magnitude of changes (temperature and water flow) related to the intensity of climate action (Pletterbauer et al., 2018; Liu and Gao, 2020). Importantly, metabolic and molecular impairments in fish due to extreme temperature events will affect growth, immunity, and disease resistance (Islam et al., 2022). For example, when environmental conditions such as water temperature, pH, or salinity approach a species' tolerance levels, it can cause physiological

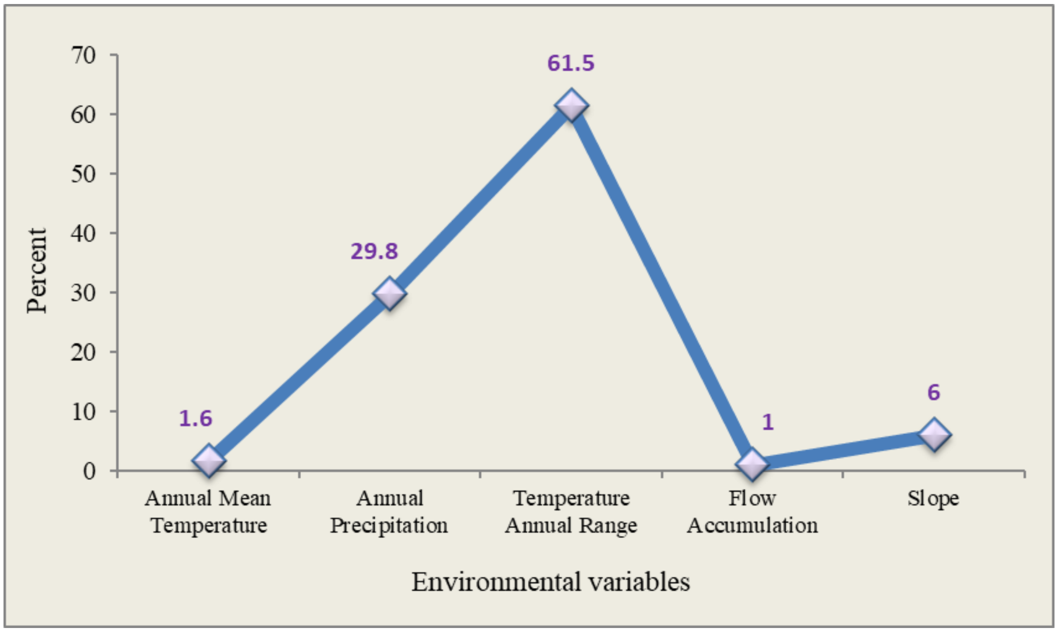

Figure 4. Variable importance for distribution of Caspian vimba in the southern Caspian Sea basin.

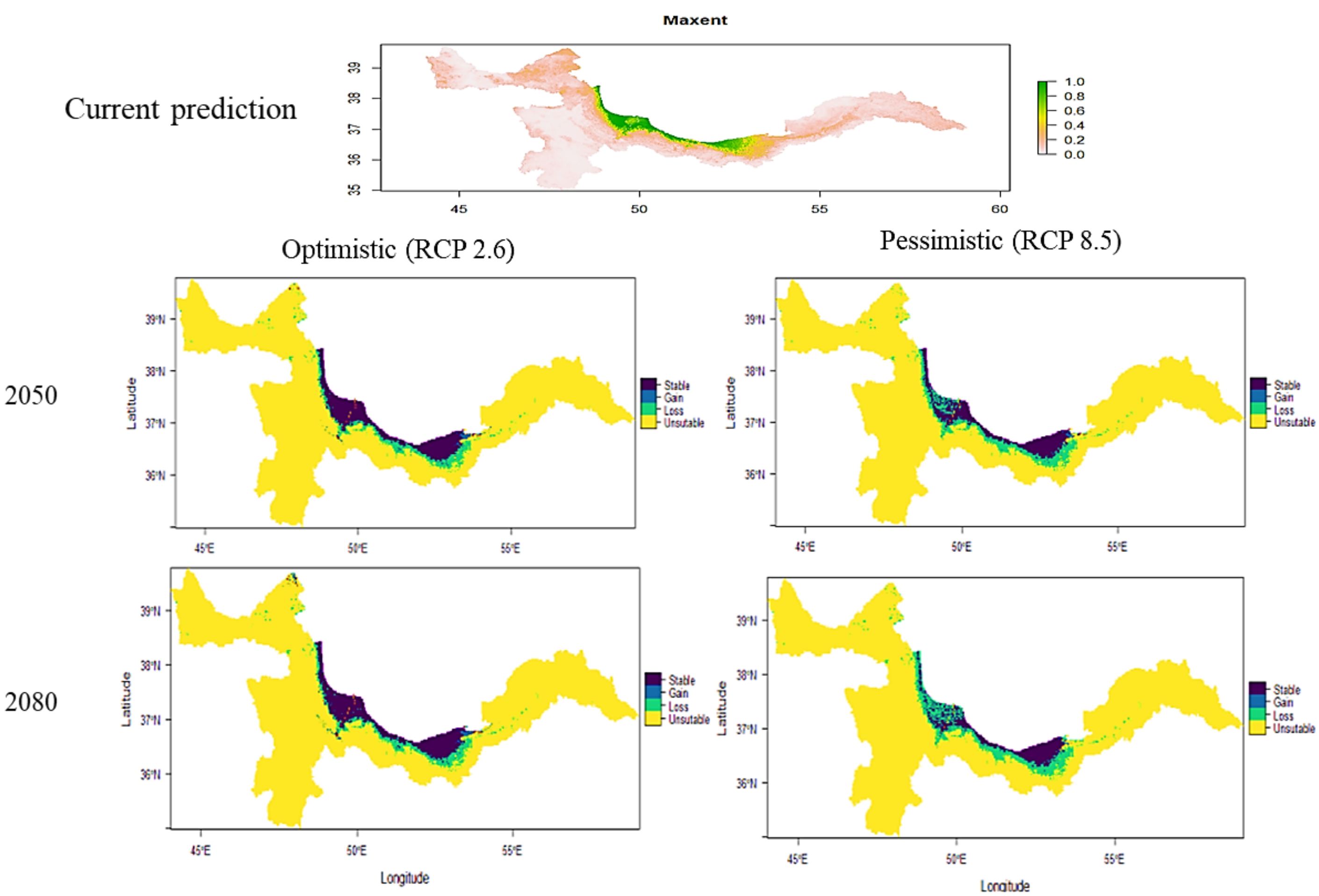

Figure 5. Distribution of Caspian vimba in the southern Caspian Sea basin under different climate change scenarios for 2050 and 2080.

disturbances and trigger a glucocorticoid stress response (Shi et al., 2019; Kovach et al., 2020; Danylchuk et al., 2023) and by analyzing tissue samples such as blood, muscle, and liver with biochemical assays, it is possible to determine how fish respond to environmental challenges and stressors

(Sopinka et al., 2016). In addition, flow alterations can cause a variety of effects, including changes in hydrology, sediment deposition and erosion in floodplains, primary production, nutrient cycling, metabolic activity (Schmutz et al., 2018; Muhar et al., 2018; Mousavi-Sabet, 2021), life history, trophic structure, spatial ecology of streams and watersheds (Mostafavi et al., 2022; Khob et al., 2023).

The results of the current study indicate that the distribution range of Caspian vimba is likely to be reduced in 2050 and 2080 under both optimistic (RCP2.6) and pessimistic (RCP8.5) climate scenarios. Our results are in line with previous studies which predicted the impacts of climate change in Iran. Previous studies predicted range reductions (Mostafavi et al., 2014; Esmaeili et al., 2018; Yousefi et al., 2020; Mostafavi and Kambosia, 2019; Makki et al., 2021; Makki et al., 2023a; Tabasinezhad et al., 2023) for various fishes in the country. Already, several studies have been conducted on Caspian vimba, such as determining the occurrence and intensity of the parasite in Caspian vimba by Sattari (2004), the hematological study by Norousta and Mousavi-Sabet (2013), the morphometric and meristic study by Vatandoust et al. (2014), levels of 36 elements in liver and muscle tissue and the relationship with growth indices was investigated by Sattari et al. (2020), and the growth parameters and population traits by Karimi et al. (2021). These studies demonstrate that Caspian vimba is a valuable fish and should be protected.

Hejazi et al. (2023) investigated the impact of climate change on the distribution of *Capoeta damascina* under different climate scenarios by the MaxEnt model in Central Zagros, Iran. The results of this study showed that the accuracy of the implemented model (AUC= 0.906) was excellent. 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). Moreover, modeling the effects of climate change on the distribution of brown trout (*Salmo trutta*) in the Urmia Lake basin's rivers was evaluated by Hajizadeh Lilabadi et al. (2023). The results showed that brown trout populations will decline sharply in the optimistic scenario in 2050. Whilst, in a similar scenario, populations of this species will disappear in 2080. In addition, the populations of this fish would become extinct in the pessimistic scenario, including two time scales in 2050 and 2080. These outcomes seriously warn that conservation and management plans are required to protect valuable fishes in the future. Recently, a study aimed at predicting the future distribution of *Esox lucius* as an important edible species in the southern Caspian Sea basin in Iran was conducted by Tabasinezhad et al. (2023). The results indicate that the distribution range of northern pike is likely to be reduced by 2050 and 2080 under both optimistic and pessimistic climate change scenarios.

Many researchers suggested that it is essential to have an extensive plan for protecting rivers with the popular corporations in a responsible fishery management system (Mostafavi et al., 2022; Mousavi-Sabet et al., 2023; Abbasi et al., 2023; Makki et al., 2023b). Currently, the first step to prevent the destruction of rivers and fishes, loss of biodiversity, and environmental disasters on the Earth is to take action to mitigate climate change on a global scale (Scherer et al., 2023; Mostafavi and Kambouzia, 2019). As a solution, taking action at the regional and global levels can help reduce the effects of climate change on ecosystems and biodiversity and also increase the resilience of aquatic life against upcoming threats (Pimm et al., 2014). At the local level, governments can focus on creating protected areas, preventing the destruction of habitats that are susceptible to species migration, removing barriers, creating migration corridors, and restoring lost habitats where vulnerable wildlife can take shelter (Pimm et al., 2014; Schmutz et al., 2018; WWF, 2020). Globally, governments should focus on reducing greenhouse gas emissions through measures such as investing in renewable energy sources and implementing carbon pricing schemes. These measures will help reduce the amount of greenhouse gas emissions in the atmosphere and thus slow global warming over time (IPCC, 2022; Pletterbauer et al., 2018).

Conclusion

According to the results of the current study, the range of distribution of Caspian vimba is expected to decrease in the future. However, this species is an important species that provides nutrition for local communities, and anglers catch this species in rivers. In conclusion, a decrease in the distribution of this species is a threat to food security livelihoods. As climate change will increasingly put pressure on food production and access, especially in vulnerable regions, undermining food security and nutrition, it is necessary to seriously start basic measures to control and reduce the effects of climate change as soon as possible.

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