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ORIGINAL ARTICLE

A quantitative method to investigate the shift in response of *Barbus cyri* (De Filippi, 1865) to bioclimatic variables

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Abstract
Barbus cyri is one of the most abundant species in the Urmia Lake basin, being found across the basin. In this study, the impact of bioclimatic variables on future species distribution, as well as a shift in the species' response to several bioclimatic variables under the present and future conditions across various climatic scenarios, was quantified. Fish specimens were caught at various points of the Urmia Lake basin, and their occurrence was recorded. Using the MaxEnt model, the probability of presence for the species under existing conditions and in the future was simulated across the entire basin. Based on raster maps of the probability of species presence for present and future, response curves for both periods were obtained, and the overlapping area between the two curves was calculated over a gradient of bioclimatic variables. This study came out with the fact that the probability of incidence of the species in the future will significantly decline and will be confined to the southern parts of the basin. Moreover, the species will respond differently towards bioclimatic variables than the existing trend. The value of existing response curves and the value in the future has declined when compared along a time dimension, with a positive deviation indicating a larger change in habitat suitability of this species in the future.

Keywords: *Barbus cyri*, Maxent, Climate change, Response curve

INTRODUCTION

Climate change is threatening aquatic organisms, specifically freshwater fish communities (Heino et al. 2009), by modifying their habitats and interfering with their life cycles. Increased water temperature can increase the metabolic rate of fish, which can lead to higher oxygen requirements that will not be satisfied in warmer water, and consequently, stress and lower survival rates (Whitney et al. 2016). In addition, alteration in rainfall patterns leads to more intense flooding and altered flow regimes, affecting the biodiversity of freshwater ecosystems (Aldous et al. 2011).

Degradation of these vital habitats, such as riparian corridors and wetlands, makes the problem more difficult since they provide breeding, feeding, and refuge for fishes. In addition, climate change can initiate invasion by exotic (Rahel & Olden 2008), warmer-loving species that displace native fish and reorganize entire community structures. These threaten the biodiversity of freshwater fish communities, undermining their health and the integrity of freshwater ecosystems.

Barbus cyri is a cyprinid fish of the family Cyprinidae (Jalili et al. 2015; Eagderi et al. 2022). The fish is found predominantly in rivers and lakes and is characterized by the elongated body of the fish, which may be variable in colour and typically silvery or golden in colour with dark stripes or spots on the sides. Being a species of barbel, it possesses sensory organs in the shape of barbels on the top jaw that aid in detecting food on the substrate. It is an important ecological species within the ecosystem, in terms of its contribution to the diversity of freshwater aquatic ecosystems.

Barbus cyri is an omnivorous species whose diet is comprised of algae, detritus, and small invertebrates, thereby being balanced within the aquatic food web. However, as with all freshwater fish, it is also vulnerable to pollution, climate change, and destruction of habitat, which can alter water quantity and quality. Protection of the habitat and species is required to provide a means of perpetuation for freshwater ecosystems in which they occur. Information on the distribution and ecological requirements of *B. cyri* is critical in formulating effective management and conservation strategies, particularly in the framework of existing environmental change.

Presence-only models, such as MaxEnt (Elith et al. 2011), have generally been applied to assess fish species distribution in response to climate change, particularly for freshwater fishes (Tabasinezhad et al. 2024). Occurrence data are used by the models, allowing scientists to model the potential range of fish species based on environmental data, without requiring absence data. By incorporating bioclimatic properties, i.e., temperature alteration and precipitation alteration, along with habitat features, MaxEnt can identify target habitats of fish under current as well as projected future climate conditions. This approach has been pivotal in understanding how altered climatic conditions are able to change the freshwater fish distribution and, hence, enable conservationists and resource managers to forecast potential range shifts, identify key habitats facing threats, and implement strategies to mitigate climate influences on vulnerable fish populations. Presence-only models can also be deployed at a significant benefit, especially when data possess the lowest resolution, i.e., binary as presence-absence.

MaxEnt models have also been employed to effectively determine the future distribution of freshwater fish species in the context of climate change and provide significant information on potential range shifts and habitat suitability under environmental change (Comte et al. 2021). However, these models have not been utilized to estimate how and to what extent freshwater fish responses can change with respect to specific bioclimatic variables. There is no defined quantitative framework currently in place to study systematically the intensity of such responses to all of the bioclimatic factors, namely temperature, precipitation, and habitat modification.

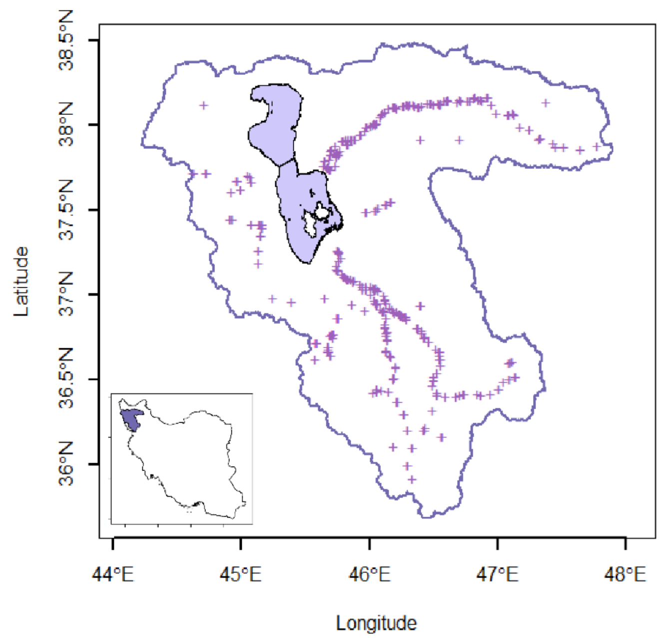

Fig.1. The sampling points are in the Urmia Lake basin in northwestern Iran. The inset indicates the basin's location on the Iran map.

Such a lack of research limits our knowledge of the complex effects of climate change on freshwater fish so that effective targeted conservation strategies are not possible. Treatment of the said issue is crucial for more effectively managing and preserving freshwater fish species during the overcoming of the hindrances posed by increasing climate change. For this reason, the present study was compelled to frame a quantitative method to find out to what degree the response of a freshwater fish, i.e., *B. cyri*, could be changed in bioclimatic variables in the catchment area of Urmia Lake with various climatic projections.

MATERIALS AND METHODS

Fish presence data: Electric fishing was done using a portable electronic device (Samus 750) in the Urmia Lake basin rivers (Fig. 1). Sampling was performed downstream to avoid fish dispersal to the upstream side. Species were noted and coordinates recorded at the sampling points. Caught fish were released into a container along the river and subsequently released after recovery. Fish occurrence data by gender, species, latitude, and longitude were imported into

Table 1. Bioclimatic variables that were examined for colinearity and the remaining ones being used for modelling are denoted by an asterisk.

Bioclimatic variables	Acronym	Used in the model
BIO1= Annual Mean Temperature	AMT	*
BIO2= Mean Diurnal Range (Mean of monthly (max temp - min temp))	MDR	
BIO3= Isothermality (BIO2/BIO7) (×100)	Iso	*
BIO4= Temperature Seasonality (standard deviation ×100)	TS	*
BIO5= Max Temperature of Warmest Month	MTWM	
BIO6= Min Temperature of Coldest Month	MTCM	
BIO7= Temperature Annual Range (BIO5-BIO6)	TAR	*
BIO8= Mean Temperature of Wettest Quarter	MTWeQ	*
BIO9= Mean Temperature of Driest Quarter	MTDQ	
BIO10= Mean Temperature of Warmest Quarter	MTWaQ	
BIO11= Mean Temperature of Coldest Quarter	MTCQ	
BIO12= Annual Precipitation	AP	
BIO13= Precipitation of Wettest Month	PWM	
BIO14= Precipitation of Driest Month	PDM	*
BIO15= Precipitation Seasonality (Coefficient of Variation)	PS	*
BIO16= Precipitation of Wettest Quarter	PWeQ	
BIO17= Precipitation of Driest Quarter	PDQ	
BIO18= Precipitation of Warmest Quarter	PWaQ	*
BIO19= Precipitation of Coldest Quarter	PCQ	*

MySQL (version 8.0.31), and redundant entry based on all the aforementioned factors combined was deleted. Sample point coordinates were recorded utilizing a portable GPS device (Garmin eTrex 30X, Taiwan).

Selection of the global climate model (GCM): Over 35 Global Climate Models (GCMs) are employed to estimate climatic parameters for the next decades. The output data from these models varies, and these variations contribute to establishing the final prediction outcomes. For this, efforts have been made to identify the most appropriate GCM model (Fajardo et al. 2020). Through this study, GCMeval software was used to identify the best GCM model that is supportive of Iran's geographical characteristics (Parding et al. 2020). From this comparison, the most appropriate model was CMIP6. HadGEM3 was recognized as the proper source of future climatic data for Iran using the WorldClim database.

Making bioclimatic variables: The climatic information applied in this research was accessed through the WorldClim website between 2000 and 2021. Precipitation, minimum temperature, and maximum temperature were among the data provided, which were translated into bioclimatic variables using the biovar function of R (Hijmans et al. 2020) (Table 1). Collinearity was tested using Pearson correlation, while the removal of variables with high correlation was applied. Specifically, for the pairs of variables with a Pearson correlation of 0.9 or greater, the variable with the higher overall correlation with other variables was excluded (Zuur et al. 2007). The findCorrelation function in the `caret` package (Kuhn 2021) in R was utilized in this analysis. All the bioclimatic variables were developed at 0.008 degrees by 0.008 degrees resolution, and the nine resulting variables were organized into a raster stack and clipped to the Caspian Sea basin. Lastly, upon examination for collinearity, nine variables were selected for the study (Table 1).

Modeling the presence of the species: The occurrence points of the species were entered into R, and the raster layer values of the raster stack of the bioclimatic variables were retrieved for the points by utilizing the extract function of the raster package. The Maximum Entropy model was applied to predict the presence of fish both currently and in the future (Elith et al. 2011). 70% of the presence data was employed for training

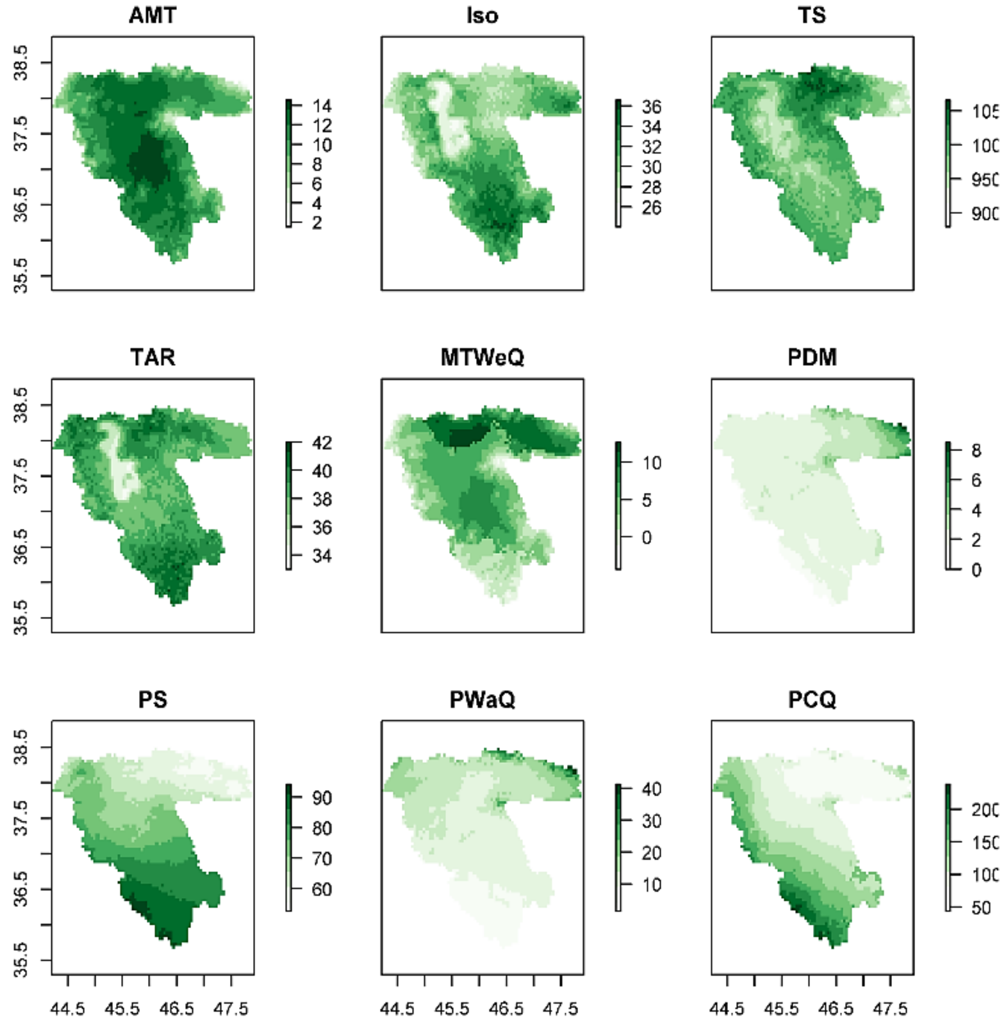

Fig.2. Variation of the bioclimatic variables across the Urmia Lake basin was used in the model after removing the highly correlated variables.

the model, and 30% was reserved for model testing. Model performance was validated using the AUC measure. The jackknife test was utilized to test for the significance of each bioclimatic variable. Prior to the construction of the model, bioclimatic variables highly correlated with other variables (over 90%) were excluded.

Preparing the response curves: The calibrated model was employed in predicting the current probability of fish occurrence in the Urmia Lake basin, enabling the creation of response curves for each bioclimatic variable. The response curves show how the probability of species presence varies along a gradient of one of the bioclimatic variables while keeping the other bioclimatic variables constant at their mean values. These curves effectively show the marginal effects of one bioclimatic variable. The same was done for future decades. To generate the response curve of every bioclimatic variable in the present time, the pixel values of the raster files of all the bioclimatic variables, except the one for which the response curve was being drawn, were substituted with the mean value of their respective bioclimatic variable. After removing highly correlated variables, 13 bioclimatic variables remained in the study, and the process was repeated 13 times to produce 13 response curves for the current time. Raster files for future projections were provided for three scenarios—ssp126, ssp245, and ssp585—covering 2021 to 2040, 2041 to 2060, and 2061 to 2080, respectively. Therefore, response curves were plotted nine times for the various combinations of scenarios and years for the 13

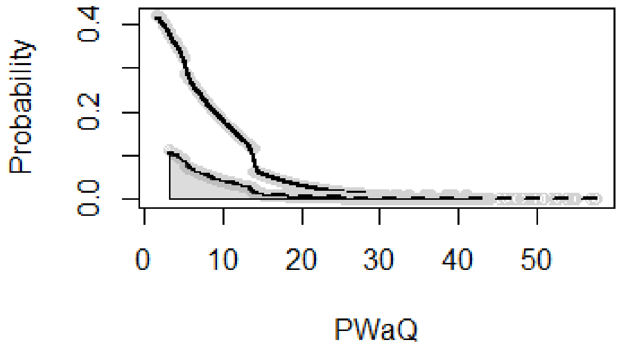

Fig.3. Predicted values by the MaxEnt model with current (●) and future (○) data. The independent variable in this graph is PWAQ. The solid black line, which is positioned higher, represents the predicted data for the present time, while the dashed black line (--), positioned lower, represents the predicted data for the future. The gray shaded area indicates the shared area between these two curves, as shown as, $A \cap B$ in equation 1.

bioclimatic variables, resulting in a total of 117 curves. Since the resolution of the future raster files differed from the resolution of the current raster files, the future bioclimatic files were reprojected to the resolution of the current bioclimatic variable raster files using the projectRaster function to facilitate computation of overlap between the current and the future curves.

Calculating the overlap of the present and future response curves: For each bioclimatic variable, there were two curves (for a combination of scenario and year). One curve represented the calculated probability values of species presence, reflecting the species' response to that bioclimatic variable for the present, and the method of its calculation was described earlier. The other curve represented the species' response to the same bioclimatic variable in a specific scenario and year. For each curve, kernel smoothing was performed to create a smooth function that would be used for subsequent overlap calculations. Since the obtained smooth functions were non-parametric, a polynomial of degree 25 was fitted to them to enable the prediction of species probability. The optimal bandwidth was also determined. Details of this method can be found in Ahmadzadeh et al. (2019). A similar application of this method was conducted for the overlap of freshwater fish niches (Mouludi-Saleh et al. 2024a, b). For each bioclimatic variable, the degree of overlap between the two curves, the shared area under the two curves, was calculated using equation 1. In this equation, $A \cap B$ is the areas under the two curves are A and B. The shared area between the two curves is illustrated as a gray-shaded area in Figure 3.

Equation 1 $$overlap = \frac{A \cap B}{A \cup B - (A \cap B)}$$

An example of the area under the two curves for the PWaQ variable is shown in the figure below. Due to the fact that 81 graphs similar to this one could be plotted in this study, it was not feasible to include all of them in this article, and only this graph was presented to clarify the methodology.

RESULTS

The model had a good quality as the AUC of the model was 0.862 (Fig. 4). The jackknife test indicated that AMT was the most important bioclimatic variable in the model and the presence probability of *B. cyri* in the Urmia Lake basin (Fig. 5).

Prediction of the presence of *B. cyri* across the Urmia Lake basin through the data of the present time. The map indicated that at the present time, the internal part of the basin, from north to south, is the best habitat for this species. Notably, the areas close to the border of the basin have the least suitability for *B. cyri* (Fig. 6).

As the prediction maps indicated (6), the distribution of *B. cyri* will be limited to the southern parts of the Urmia Lake basin. In the climatic scenario ssp126, the presence probability of the species will decline over time, and also in the scenario ssp585. However, in ssp245, though like other scenarios, the presence probability of *B. cyri* will be limited to the southern part of the basin, the area covered by the species will increase from the years 2021-2040 to 2041-2060 but will remain stable for the next years, i.e., 2061-2080.

The overlap of the response curves for different scenarios and years are presented in Table 2. In all scenarios, the overlap of response curves decreased over time. However, there was some fluctuations for some bioclimatic variables, especially in ssp126,

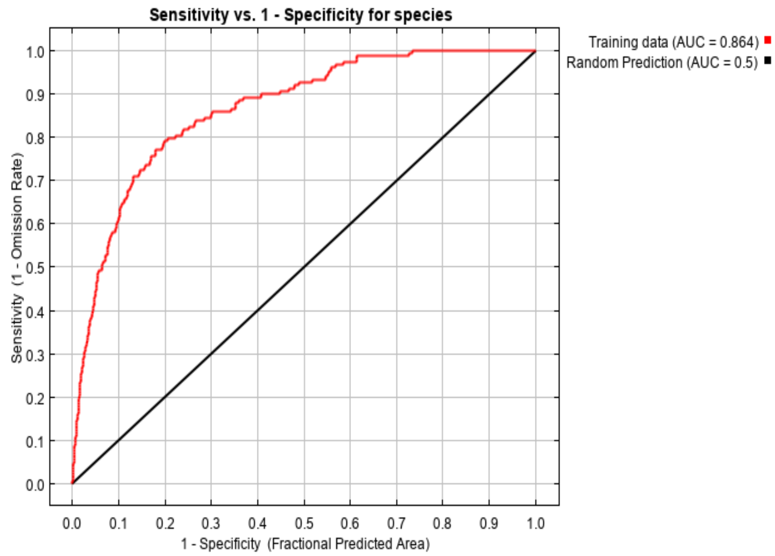

Fig.4. The AUC of the model was 0.982.

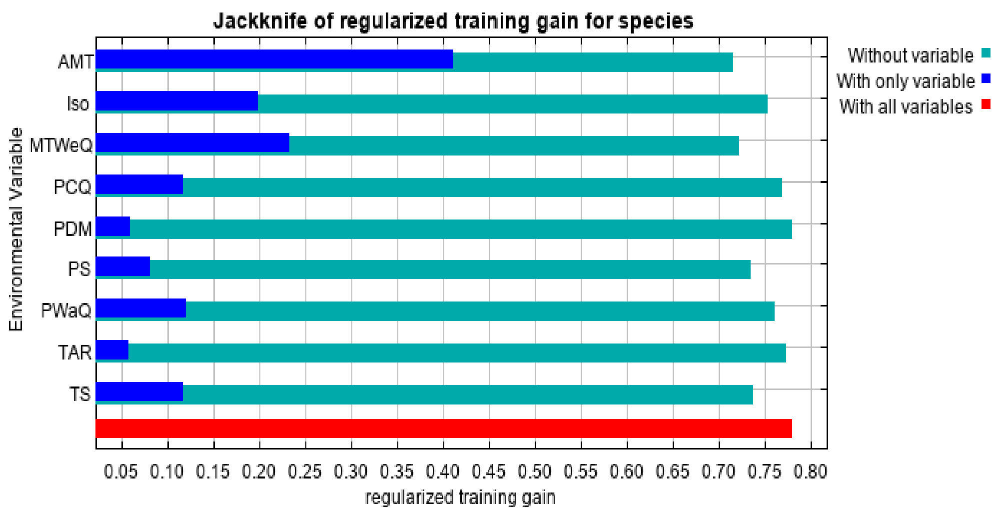

Fig.5. The jackknife test indicated that AMT was the most important factor in the model.

where there was an increase in overlap from the years 2021-2040 to 2041-2060 and a decrease afterwards.

DISCUSSION

In this study, we analyzed the effect of climate change on the distribution of *B. cyri*, an aquatic fish species that is the most abundant one across the Urmia Lake basin. While the Maxent model has been widely used to predict the distribution of species in the context of climate change, the response of species to bioclimatic variables has not been quantitatively investigated. So, the present study addressed this gap.

Our findings indicate that there has been a future change in the distribution of *B. cyri* and that in the future the species will be confined to the south of the Urmia Lake basin, instead of its present wide distribution across the whole basin. Such an alteration in the distribution of freshwater fishes has been reported for various species (Kim et al. 2020; Sadi 2021). This range contraction is alarming and indicates climate change's threat to freshwater diversity. According to the prediction, the southern region of the basin would be more suitable for *B. cyri* as climatic conditions vary with the incidence of temperature, rainfall, and availability of habitats. However, such localized distribution can put the species at greater risk since it will be subjected to greater resource competition, predation pressure, and

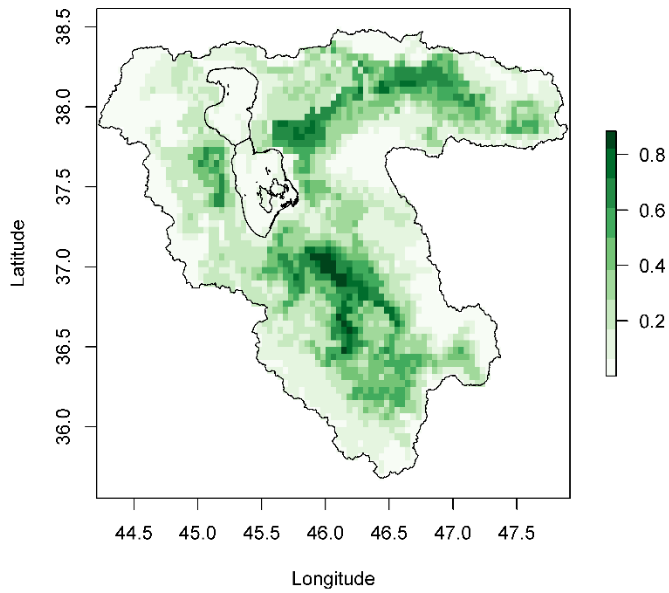

Fig.6. The probability of the presence of *Barbus cyri* across the Urmia Lake basin as predicted by the model.

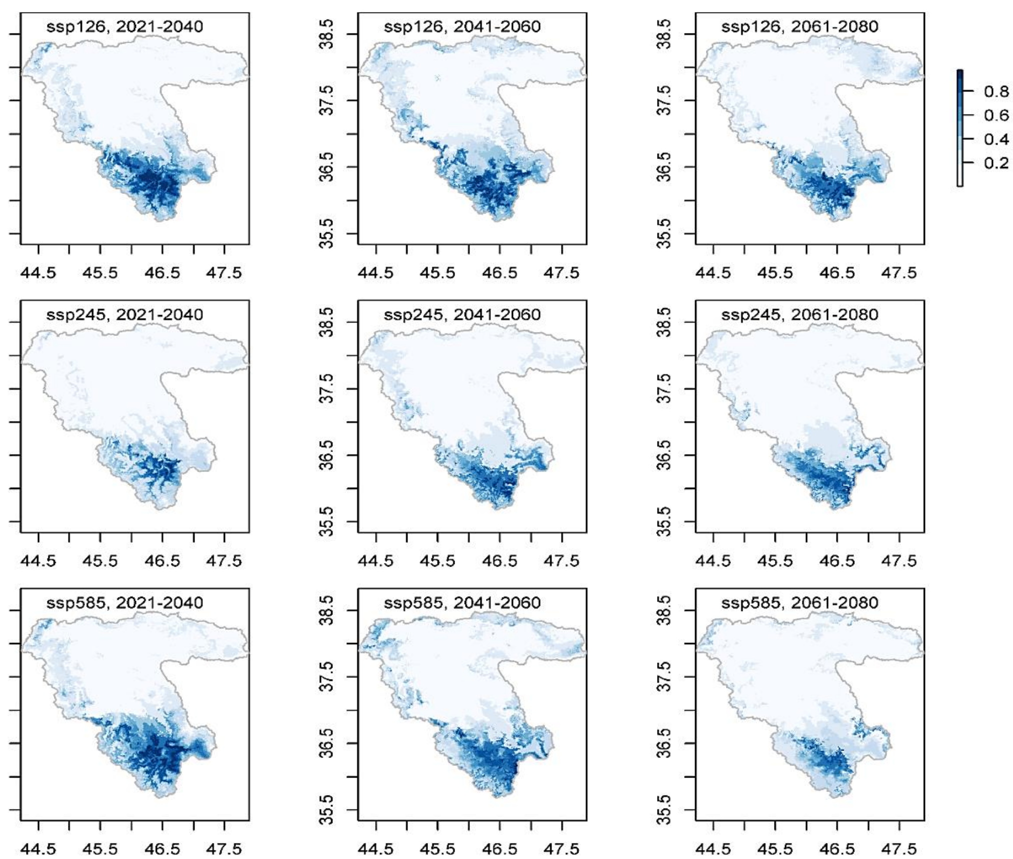

Fig.7. The predicted presence probability of *Barbus cyri* in the Urmia Lake basin.

exposure to environmental stress. Furthermore, the estimated loss of range may have cascading impacts on ecosystem processes in the Urmia Lake basin, as noted in previous studies on climate change (Rodrigues et al. 2024). As *B. cyri* is a key part of the aquatic food web, its decline may disrupt predator-prey relationships and influence other species that rely on it as food.

These observations highlight the need for forward-looking conservation efforts to minimize the impacts

Table 2. The overlap of the present and future response curve to bioclimatic variables over the years.

	Scenarios								
	ssp126			ssp245			ssp585		
	2021-204	2041-2060	2061-2080	2021-204	2041-2060	2061-2080	2021-204	2041-2060	2061-2080
AMT	0.2010	0.1912	0.1240	0.1366	0.1280	0.0925	0.1653	0.1519	0.0951
Iso	0.2977	0.3038	0.1915	0.1587	0.1516	0.0810	0.2491	0.1674	0.1095
TS	0.2100	0.1478	0.0969	0.1474	0.0759	0.0455	0.1331	0.0995	0.0812
TAR	0.2386	0.2081	0.1278	0.1634	0.1190	0.0971	0.1736	0.1235	0.1112
MTWeQ	0.2814	0.2899	0.1946	0.1897	0.1736	0.1263	0.2369	0.2145	0.1602
PDM	0.2434	0.2391	0.1562	0.1575	0.1410	0.0949	0.2083	0.1526	0.1201
PS	0.2437	0.2603	0.1735	0.1724	0.1400	0.0798	0.2150	0.1504	0.1147
PWaQ	0.8744	0.9178	0.7454	0.7717	0.6249	0.4420	0.9467	0.5748	0.4169
PCQ	0.2417	0.2137	0.1513	0.1541	0.1373	0.0896	0.1935	0.1407	0.1092
Mean	0.3147	0.3080	0.2179	0.2279	0.1879	0.1276	0.2802	0.1973	0.1465

of climate change on *B. cyri* and other water organisms. These interventions need to be directed toward the protection, restoration, and establishment of ecological corridors to facilitate potential range shifts. Furthermore, additional work should be conducted to detail the mechanisms behind such patterns of distribution and to develop adaptive management tools that will ensure the resilience of *B. cyri* and the aquatic environment as a whole within the context of ongoing climatic change.

MaxEnt model determined that the annual mean temperature (AMT) was the most significant bioclimatic parameter in controlling *B. cyri* distribution. Such findings support the pivotal role of temperature in characterizing the quality of fish habitat. AMT is one of the most significant parameters of the general thermal regime where aquatic animals live and influences many physiological processes such as growth, reproduction, and metabolism (Whitney et al. 2016). There is a preferred temperature that has a critical role in the case of *B. cyri* for the sake of maintaining a healthy population, and departure from it can result in stress, reduced reproductive success, and increased mortality. This further implies that with climatic change on the increase and temperature rise, habitats for *B. cyri* will be more and more restricted. Besides, our findings alert to the presence of invasive tropical species that may find opportunities to expand their home range (Sauz-Sánchez et al. 2021) and hence further limit *B. cyri* to a confined area. Since 11 exotic fish species (37.93% of its total ichthyofauna) have been reported in this basin (Ghasemi et al. 2015), their negative impact will increase due to climate change in the future.

The observed reduction in the area under the response curve of *B. cyri* for all the bioclimatic factors for all the climatic conditions over the years is an alarm signal of the declining habitat suitability of the species in relation to climate change. The trend projects that under changing climatic conditions, the climatic factors suitable for *B. cyri* are being converted to unsuitable factors, reducing the likely range of suitable habitats. Response curve covered area reduction demonstrates quantitatively the shrinkage of the ecological niche of *B. cyri* and proves that the species will not easily be able to exist in the future climate. Further, the consistency of the decline across all the climatic scenarios suggests that the issues for *B. cyri* are not specific to particular future conditions but instead a more general result of the overall effect of climate change. The shared area underneath the present and future response curves indicated the extent of differences in habitat suitability of *B. cyri* in various climate scenarios over time.

In conclusion, the present study emphasizes the significant influence of climate change on *B. cyri* distribution in the Urmia Lake basin, depicting an alarming pattern of habitat decline and range reduction. Our findings highlight the crucial significance of the annual mean temperature as a vital bioclimatic factor controlling the species distribution, necessitating urgent conservation. The expected change toward more limited distribution risks B. cyri's survival and that of the overall aquatic community, with implications for disruption in predator-prey dynamics and dependency of other associated species. Since climate change still disrupts habitats, it becomes vital to center efforts on habitat protection and rehabilitation, and the construction of ecological corridors for projected shifts in ranges. In addition, further research would be required to completely understand the processes causing such changes and formulate adaptive management alternatives that will render *B. cyri* and the aquatic environment more resilient. Preempting such challenges, we can attempt biodiversity conservation in the Urmia Lake basin amid the present climatic changes.

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مقاله کامل

یک روش کمی برای بررسی تغییر در پاسخ سس‌ماهی کورا (*Barbus cyri* (De Filippi, 1865، به متغیرهای زیست اقلیمی

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چکیده: گونه سس‌ماهی کورا *Barbus cyri* یکی از فراوان‌ترین گونه‌های حوضه دریاچه ارومیه است که در سراسر حوضه یافت می‌شود. در این مطالعه، تأثیر متغیرهای زیست‌اقلیمی بر توزیع آینده گونه، و همچنین تغییر در واکنش گونه‌ها به چندین متغیر زیست‌اقلیمی تحت شرایط حال و آینده در سناریوهای مختلف اقلیمی، کمی‌سازی شد. نمونه‌های در نقاط مختلف حوضه دریاچه ارومیه صید و وقوع و حضور آن‌ها ثبت شد. با استفاده از مدل MaxEnt، احتمال حضور گونه در شرایط موجود و در آینده در کل حوضه شبیه‌سازی شد. براساس نقشه‌های رستری احتمال حضور گونه‌ها برای حال و آینده، منحنی‌های پاسخ برای هر دو دوره به‌دست آمد و سطح همپوشانی بین دو منحنی بر روی یک گرادیان متغیرهای زیست‌اقلیمی محاسبه شد. این مطالعه با این واقعیت انجام شد که احتمال بروز گونه در آینده به طور قابل توجهی کاهش می یابد و محدود به بخش‌های جنوبی حوضه خواهد بود. علاوه بر این، گونه به متغیرهای زیست‌اقلیم متفاوت از روند موجود پاسخ می‌دهد. ارزش منحنی‌های پاسخ موجود و ارزش در آینده در مقایسه با بعد زمانی کاهش یافته است، با یک انحراف مثبت که نشان‌دهنده تغییر بزرگ‌تر در مناسب بودن زیستگاه این گونه در آینده است.

کلمات‌کلیدی: *Barbus cyri*، مکسنت، تغییرات اقلیمی، منحنی پاسخ.