International Journal of Natural and Engineering Sciences
E-ISSN: 2146-0086 14(3): 22-31, 2020
Research Article

ASSESSING IMPACTS OF CLIMATE CHANGE ON DISTRIBUTION RANGE OF *Squalius cephaloides* (Battalgil 1942), ENDEMIC SPECIES IN TURKEY

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(Received 03[th] November 2020; accepted 26[th] November 2020)

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ABSTRACT. Continuing climate change is expected to influence the habitat of existing species and eventually result in changes in species distributions. Although climate patterns are essential to the ability of the species to survive in the region, for several taxa, some environmental conditions, such as land cover, geology, chemical soil properties, and topography, are also important for the availability of sufficient habitat. Also, the influence of air temperature and precipitation on the streamflow patterns and the water temperature is a change for aquatic life. Species distribution models (SDMs) were constituted using MaxEnt (maximum entropy) modelling in the Teşvikiye stream drainage in the northwestern region of Turkey for thick-lipped chub species (*S.cephaloides*), in this research. As a result of the 2100 projections (SSPs, 126, 245, 370, and 585), *S.cephaloides* will lose a significant part of their suitable habitats. Also, *S.cephaloides* showed positive allometric growth (b value 3,03-3,13) in length-weight evaluation.

Keywords: *Climate change, Species distribution modelling, MaxEnt, Freshwater fish conservation, Length-Weight*

INTRODUCTION

The endemic fish fauna is excess due to its geographical location, climate zone, and microclimatic areas in Turkey [1]. However, a significant part of the fish species in the Anatolian plateau's freshwater resources is endangered [2]. Anthropogenic pressures such as habitat loss, pollution, and increased presence of invasive species cause endemic species to decline. Also, climate change is a significant factor influencing freshwater ecosystems since air temperature, and precipitation changes directly affect the water temperature and the flow rate of lotic systems, all of which also control riverine fish's physiological requirements [3, 4, 5]. Species conservation planning for imperiled fish is becoming important due to increasing biotic and abiotic stressors.

The *Squalius* genus has a wide distribution area from Europe to Asia and has a rich species diversity [6]. In our country, 15 endemic species belonging to the *Squalius* genus have been identified [2]. IUCN status of these species is *Squalius adanaensis* [Near Threatened (NT)], *Squalius anatolicus* [Least Concern (LC)], *Squalius aristotelis* [LC], *Squalius cappadocicus* [Critically Endangered (CR)], *Squalius carinus* [Endangered (EN)], *Squalius cephaloides* [Vulnerable (VU)], *Squalius fellowesi* [LC], *Squalius kosswigi* [EN], *Squalius kottelati* [NT], *Squalius pursakensis* [LC], *Squalius recurvirostris* [VU], *Squalius semae* [Not evaluated (NE)], *Squalius seyhanensis* [Data Deficient (DD)], *Squalius turcicus* [LC] [6,7].

S.cephaloides was first described from the Armutlu stream [6]. *S.cephaloides*, known to be distributed in the Armutlu stream and Teşvikiye stream, has wholly disappeared in the Armutlu stream today [6]. The species survives only in a limited area. In this sense, protecting the species is a priority. This study aimed to determine the current and future habitat suitability of *S. cephaloides* by ecological niche modelling.

MATERIALS AND METHODS

Study area and sampling

The occurrence data were obtained from the Teşvikiye stream of field studies (Fig. 1). Different points were selected from the region where the creek flows into the sea to the Great Dipsiz Lake, which forms its source. In the sampling, the method of hunting with electricity and standard nets were used. In the sampling method, a minimum of 200 m^2 area was sampled for 15 minutes. After the captured samples were taken into a water-filled fish tank, their length-weights were measured. The lengths were measured on the measuring board with 0.1 mm precision, standard, fork, and total length. The weights were made with a 0.1g precision scale, and the measured weights were written on the measuring papers.

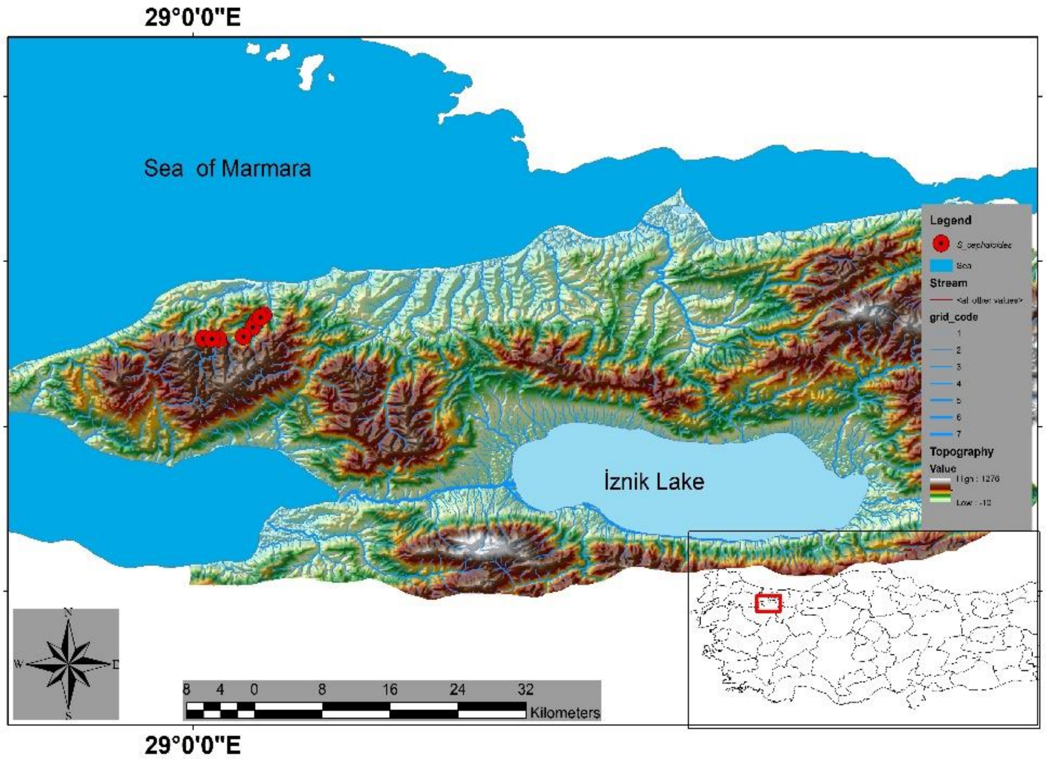

Fig. 1. *Geographical distribution of S. cephaloides in the study area*

Environment layer

Bioclimatic variables (bio 1-bio19) (Table 1) obtained from WorldClim (worldclim.org), which have been commonly used to predict species distribution, may represent precipitation, temperature, and seasonal variation characteristics [8, 9]. Environmental variable were obtained from land cover (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018) [10], elevation (worldclim.org), and chemical soil (ph-soil-water) properties (soilgrids.org) [11]. We used average GCMs (BCC-CSM2-MR) of four emission scenarios in the most recent IPCC version 6 (CMIP 6) for future climate projections [12, 13]. These emission scenarios or SSPs (Shared Socioeconomic Pathways), including SSPs 126, 245, 370, and 585, were used to examine variations around these climate scenarios for the year 2100 [14]. BCC-CSM1 and MPI-ESM-MR (RCP4.5, RCP8.5) have similar temperature projections for Turkey [15]. For this reason, the BCC-CSM2-MR was used in the CMIP6 future projection. The hydrological analysis was performed using the digital elevation model (dem) layer. The river layer (stream feature) was obtained as a result of the analysis. Zonal statistics were performed on the obtained river layer with Arcmap spatial analysis tools [16]. The mean value of all climate layers was added to the river layer at the same scale. All layers in ArcGIS version 10.8 [16] were clipped to the stream basin size and converted from raster to ASCII file format to be integrated into MaxEnt version 3.4.4 [17]. Maxent modeling was performed with the new environmental layers obtained.

Table 1. *Bioclimatic variables* [17]

BIO1 = Annual Mean Temperature
BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3 = Isothermality (BIO2/BIO7) (×100)
BIO4 = Temperature Seasonality (standard deviation ×100)
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range (BIO5-BIO6)
BIO8 = Mean Temperature of Wettest Quarter
BIO9 = Mean Temperature of Driest Quarter
BIO10 = Mean Temperature of Warmest Quarter
BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality (Coefficient of Variation)
BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter

MaxEnt Modeling

Diverse species distribution models (SDMs) such as CLIMEX, GARP, and Maximum Entropy (Maxent) are used to determine ecological requirements, ecological responses, and distribution areas [18, 19, 20]. Among these modelling approaches, Maxent is widely used because it performs better than other modelling methods [21, 22, 23, 24].

Four environmental (land cover, elevation, stream order, chemical soil properties) and 19 bioclimatic layers (bio1–bio19) were used as predictors of the current habitat suitability of *S.cephaloides*. Following the first model's development for all twenty-three variables, a subsequent model was established for species, which included only the environmental variables that contributed to the first model. After the first model with all variables was created, a future model was performed that only incorporated the environmental variables with permutation importance in the initial model. There were ten replicates, and a random test percentage was defined for each replication.

MaxEnt modelling procedure was implemented with the auto functions. Percent contribution and permutation significance of environmental variables were calculated, and jackknife procedures were implemented in MaxEnt. MaxEnt was used in the following functions: convergence threshold (0.00001), the maximum number of iterations (5000), 25% of the existing data were separated as test data, regularization multiplier (1), replicates (10), the maximum number of context points (10000). We also used the threshold rule, maximum training sensitivity plus specificity, because it provides better results for conservative study [25]. In the Maxent output, the area under curve (AUC) value is determined from the Receiver Operating Character (ROC) plot.

Length-weight relationship

Determination of the length-weight relationship of the *S. cephaloides* population; Length-weight data were obtained from sampling in years 2018 and 2019. Length-weight data of 103 individuals were used. Length-weight relationships were determined using the formula $W= a \times TL^b$, where W is the total weight (grams), L is the TL (centimeters), and a and b are the parameters of the formula [26, 27].

RESULTS AND DISCUSSION

One final, basin-specific model was developed for the target species, which included only the environmental variables contributing to the permutation value. The AUC value can be viewed as a sole test statistic that measures the model's output with a scale of 0 to 1, implying the capacity of the model to identify the training data used correctly [28, 29]. The AUC values 0.5 to 0.7 indicate a fair model, the values 0.7 to 0.9 indicate a good model, and the values >0.9 display excellent model efficiency [28, 29]. The model was considered to be excellent and descriptive. Both models had a train AUC score of 0.990 and an AUC test score.0.989 (Fig. 2).

Bio_7, bio_16, ph-soil-water and stream order made the most contributions to the current distribution (Table 2). Of the 23 environmental variables incorporated, only eight variables were included in future models, and of the eight variables, six variables were considered meaningful for the target species. Temperature Annual Range (BIO7) and Precipitation of Wettest Quarter (BIO16) were the most informative variable for *S.cephaloides*. In this study, elevation does not affect the habitat suitability of *S.cephaloides*. The future-projected MaxEnt simulations indicate that according to four climate change projections (SSPs 126, 245, 370, and 585), significantly decreases the suitable habitat area of *S.cephaloides* in Teşvikiye stream (Fig. 3).

Table 2. *Relative contributions of the environmental variables to the Maxent model*

Variable	Percent contribution	Permutation importance
bio_7	34.3	47.4
bio_16	30.4	1.9
ph_soil_water	21.7	44
stream_order	6.4	3.1
bio_14	2.9	2.7
bio_4	2	0
bio_19	1	0.4
bio_15	0.8	0
bio_3	0.4	0
bio_12	0.1	0.5

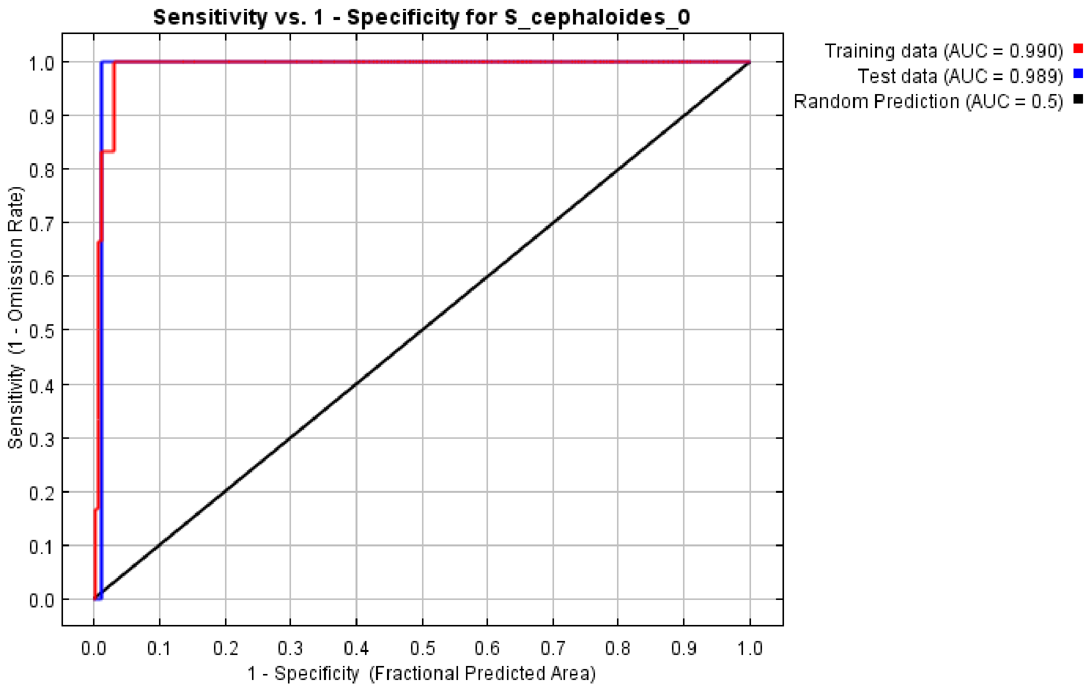

Fig. 2. *ROC curve and AUC value for the present time (10 runs). The current period is from 1970 to 2000*

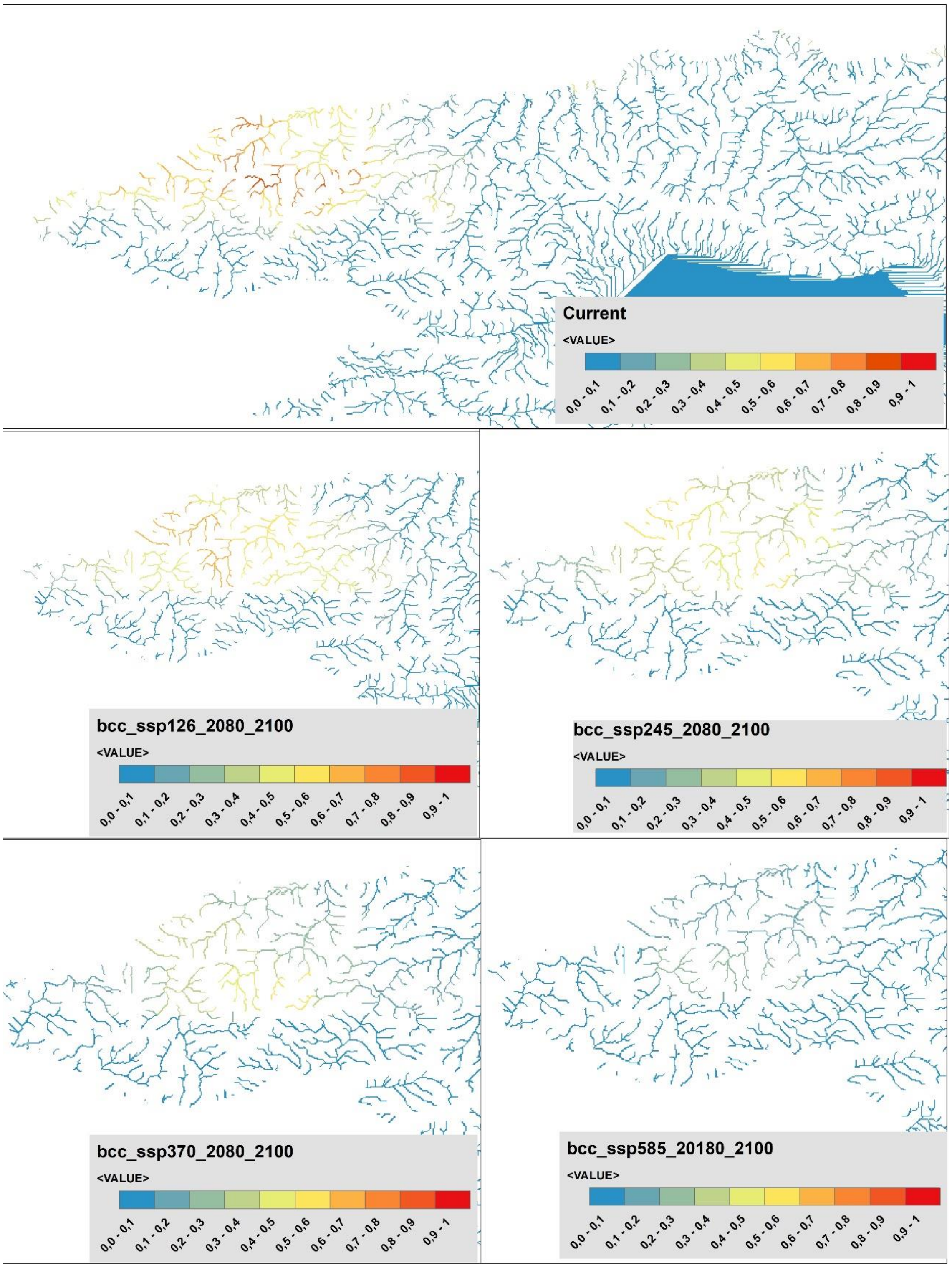

Fig. 3. *Distribution of suitable future areas of S.cephaloides under different climate change scenarios in Turkey*

As a result of the regression analysis performed in determining the length-weight relationship, the confident intervals (r^2 0,99) b value changes between 3.03-3.13. As a result of the length-weight evaluation, it was observed that the Teşvikiye stream population of *S. cephaloides* showed positive allometric growth. (Fig. 4, Fig. 5).

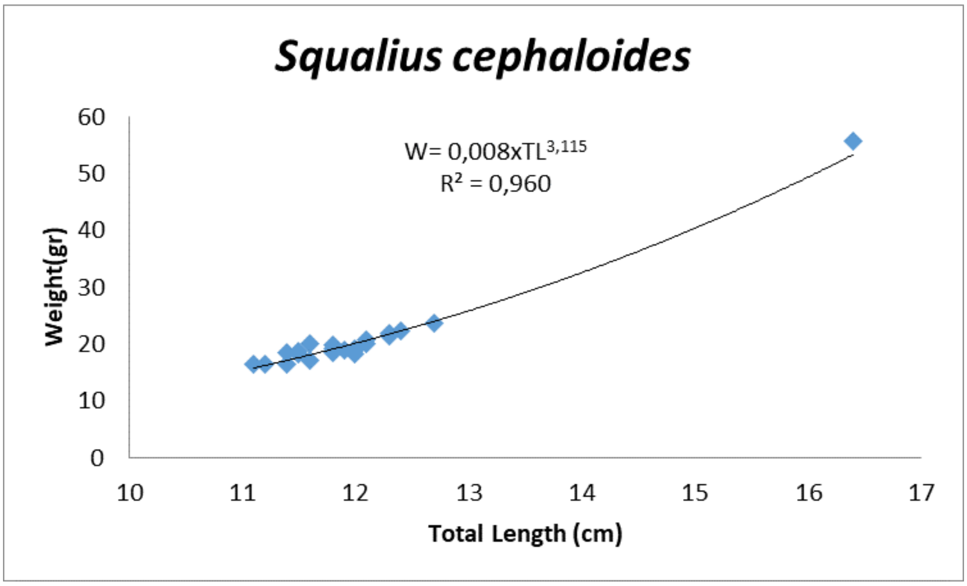

***Fig. 4.** Length-weight relationship S.cephaloides (2018)*

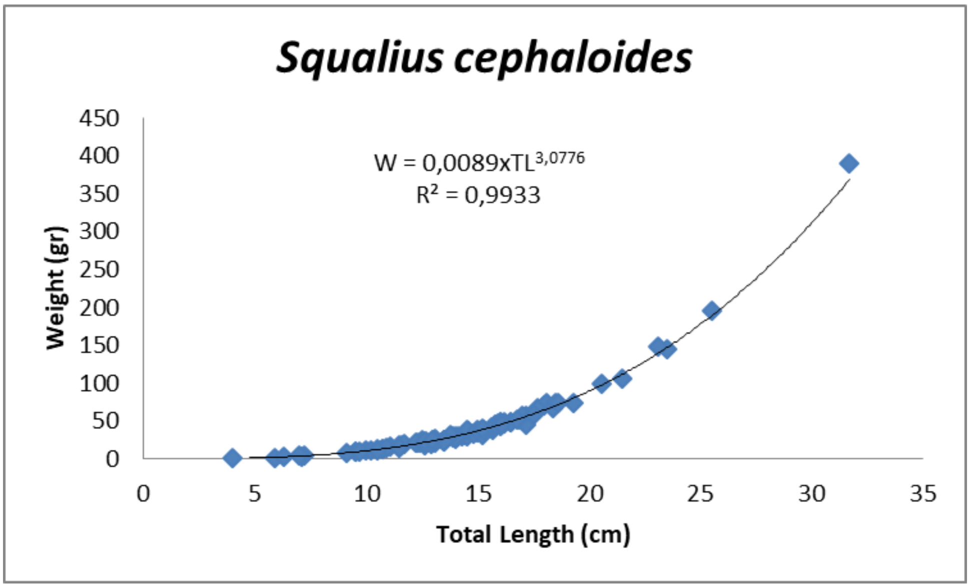

***Fig. 5.** Length-weight relationship S.cephaloides (2019)*

Information about constantly changing water and terrestrial environments can prove invaluable with modern distribution knowledge for freshwater fish, particularly in places with high endemic fish rates like Turkey. The incorporation of information-based environmental variables into the model building process is one of the key factors influencing the consistency and predictability of ENMs, as such variables are used in combination with event records to create suitable habitat for the organism [30, 31, 32, 33]. The lack of large or regional aquatic data layers is a highly significant issue in aquatic organisms. The lack of aquatic variables in the study area, such as water temperature and streamflow, could limit niche models' quality since these are some of the most significant aquatic variables without a doubt. Maxent is an appropriate instrument to explore new populations of species native, rare habitat specialists, which can be extended to other endemic, rare species [26].

CONCLUSION

It is essential to know the species' current and potential habitats while planning species conservation [5]. *Squalius* genus is represented by 22 types of Turkey [2]. Fifteen of these species are known to be endemic [7]. The IUCN protection status of *S. cephaloides* is vulnerable (VU). It is known that the species is currently distributed in an area of 10 km in the Teşvikiye stream [6, 34]. It is stated that in case of any climatic change (drought) of *S.cephaloides* species, the species will be taken to the Critical Endangered level [34]. Our study revealed that the precipitation of Wettest Quarter and Temperature Annual Range was the most influencing climate variable for the species' future habitats. *S.cephaloides* cmip6 SSPs 126,245,370 and 585 lose a significant part of their suitable habitats according to the year 2100 scenarios. In our current study, it was observed that the species lost its habitats in lower parts of the stream. The species, which is distributed in a limited area, share the same habitat with *Cyprinus carpio* in the Great Dipsiz Lake and with the alien species *Oncorhynchus mykiss* in the lower basins. Such anthropogenic pressures and drought endanger the existence of the species. The results of our study support the IUCN assessment [34]. In this sense, it may be more appropriate that the species conservation status is Critical Endangered.

Acknowledgement. We would like to thank to Republic of Turkey Ministry of Agriculture and Forestry General Directorate of Nature Conservation and National Parks Yalova and Bursa Directorates for supporting this study.

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