



Current and future potential habitat suitability prediction of an endemic freshwater fish species *Seminemacheilus lendlii* (Hankó, 1925) using Maximum Entropy Modelling (MaxEnt) under climate change scenarios: implications for conservation

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ABSTRACT

Climate change is one of the important phenomena of the century. Species distribution models have become very popular in recent years for conservation planning. When making management and conservation plans for a species, it is essential to know the current and future distributions. Expected temperature and precipitation changes will significantly affect the distribution areas of the species. These changes may result in habitat losses for some species and habitat expansion for others. This study, which current and future distribution area of *Seminemacheilus lendlii*, occurred in a very narrow area in Turkey, which is categorized as 'Vulnerable' by the International Union for Conservation of Nature (IUCN) was explored. Bioclimatic variables (Bio 1-19) were applied to determine the habitat suitability of *S. lendlii* under a current and a future (CCSM4, RCP's 2.6, 4.5, and 8.5 2070) scenario using MaxEnt software. The most influential variables were respectively bio_15, bio_14, bio_8, bio_4, bio_3, and the environmental variable that decreases the gain the most when it is omitted was the precipitation seasonality (Coefficient of Variation) (bio_15). *S. lendlii* is a sensitive species, with a not endurance to environmental stress. As a result of the modeling, it has been observed that there will be a significant decrease in the suitable habitats until 2070.

Keywords: Climate change, *Seminemacheilus lendlii*, Ecological Niche Modeling, Maxent

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Maksimum Entropi Modellemesi (MaxEnt) kullanarak endemik bir tatlı su balık türünün olan *Seminemacheilus lendlii* (Hankó, 1925)'in güncel ve gelecek potansiyel habitat uygunluğunun tahmini: koruma için çıkarımlar

Öz: İklim değişikliği, yüzyılın önemli olaylarından biridir. Son yıllarda tür dağılım modelleri tür koruma planlamaları için popüler hale gelmiştir. Bir tür için yönetim ve koruma planları yaparken, mevcut ve gelecekteki potansiyel dağılım alanlarının bilinmesi esastır. Beklenen sıcaklık ve yağış değişiklikleri, türlerin dağılım alanlarını önemli ölçüde etkileyecektir. Bu değişiklikler, bazı türler için habitat kayıplarına ve bazı türleri için ise habitat genişlemesine neden olabilir. Bu çalışmada Türkiye'de çok dar bir alanda dağılım gösteren ve Uluslararası Doğa Koruma Birliği (IUCN) tarafından koruma statüsü 'Vulnerable' olarak kategorize edilen *Seminemacheilus lendlii*'nin güncel ve gelecekteki potansiyel uygun habitatların araştırılması yapılmıştır. *S. Lendlii*'nin güncel ve gelecekteki uygun habitatlarının belirlenmesi için 19 bioklimatik değişken (Bio 1-19) ve gelecek uygun habitat tahmini için CCSM4'ün üç emisyon senaryosu (RCP 2.6, 4.5 ve 8.5 2070) kullanılmıştır. Türün dağılımında en fazla katkısı sağlayan iklim değişkenleri sırasıyla bio_15, bio_14, bio_8, bio_4, bio_3' tür. Modele kazanımı en fazla etkileyen değişken mevsimsel yağış (Bio 15) olmuştur. *S. lendlii*, çevresel strese dayanıklı olmayan hassas bir türdür. Yapılan modelleme sonucunda 2070 yılına kadar türün uygun habitatlarında önemli bir azalma olacağı görülmüştür.

Anahtar kelimeler: İklim değişikliği, *Seminemacheilus lendlii*, Ekolojik Niş Modellemesi, Maxent

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Introduction

Species distribution models (SDMs) are used in ecology, biogeography, and species conservation (Qin et al. 2017). SDMs are beneficial devices and make an essential contribution in determining the current and future distribution habitats of a species. The usage and frequency have been increasing in recent years.

Biotic, abiotic factors, movement factors, and climate change determine the species' geographical distribution limits (Yousefi et al. 2020). Climate change is responsible for the expansion and contraction of distribution areas of terrestrial and freshwater species (Walls 2009). Anthropogenic effects have an essential role in the distribution of species. Studies have shown that climate changes the phenology and distribution of freshwater species (Yousefi et al. 2020). Species have three responses to climate change; adapting to the new climate, migrating to suitable habitats, or extinction (Olusanya and van Zyll de Jong 2018). Many species are likely to be negatively affected by climate change, but all of them. It is crucial to determine the expansion or contraction of the distribution area of the species as a result of climate change. Once the responses to climate change are determined, it will be possible to make species protection action plans (Kafash et al. 2018).

Geological structure, topography, different features of aquatic ecosystems, and different eco-zones are the main factors affecting the species diversity of Turkey (Çiçek et al. 2018a). The fish species diversity of Anatolia is plentiful, and 47.4% of the fish fauna endemic. However, a significant part of the endemic species is endangered or have population decreasing (18 species 9.3% Critically Endangered (CR) and 38 species 19.6% Endangered (EN), 17 species 8.8% Vulnerable (VU) (Çiçek et al. 2018b).

In Turkey, species distribution model studies have usually been carried out for plants, mammals, and reptilian (Afsar et al. 2016; Tok et al. 2016; Dülgeroğlu and Aksoy 2018; Koç et al. 2018; Gül et al. 2018; Süel et al. 2018; Svenning and Avcı 2018; Rodríguez-Rey et al. 2019) however there are no species distribution modeling studies for freshwater fish. This study will make an essential contribution to filling this gap.

There are six species of the genus *Seminemacheilus* distributing in Turkey. General distribution areas of the genus are the Eastern Mediterranean basin, Sakarya Basin, Göksu river, Konya province, Sultan Marshes (Sungur et al. 2018; Çiçek 2020). *S. lendlii*, distributed the Lakes Akşehir and Eber basins besides from the upper Porsuk stream basin (Çiçek 2020). The IUCN protection

status of the *S. lendlii* is VU (Freyhof 2014). Eber Lake and Akşehir Lake surface volume is gradually decreasing (Şener et al. 2010). Also, Porsuk stream and its tributaries, which are accepted as the type locality of the species (Yoğurtçuoğlu et al. 2020), are under the pressure of agriculture, settlement areas, and increasing industry (Köse et al. 2018). As a result of climate change, a decrease in precipitation, and an increase in temperatures (Öztürk 2002) may cause the loss of the habitats of the species. For this reason, determining the current and future suitable habitats of the species is important for the protection of the species.

The main goal of the study is to determine the current and future potential distribution habitats of *S. lendlii* using SDM.

Materials and Methods

There are many species distribution models (SDM); however, MaxEnt has demonstrated corrected prediction potential in simulations and assessment with presence-only data (Hijmans and Graham 2006; Phillips and Dudik 2008). One of the most broadly used SDMs in the last years is the software Maxent (Kramer-Schadt et al. 2013).

Seminemacheilus genus is represented by six species, *Seminemacheilus ahmeti*, *Seminemacheilus attalicus*, *Seminemacheilus dursunavsari*, *Seminemacheilus ekmekciae*, *Seminemacheilus ispartaensis*, and *Seminemacheilus lendlii* in Turkey (Çiçek et al. 2018b; Sungur et al. 2018; Çiçek 2020; Fricke et al. 2020; Yağurtçuoğlu et al. 2020). The occurrence records of the *S. lendlii* were obtained from the literature (Çiçek 2020; Mangıt et al. 2017; Sungur et al. 2018) and GBIF (Global Biodiversity Information Facility) database (GBIF.org 2020) (Figure 1).

High resolution (30 arc second, ~ 1 km²) climate data were used in the current and future estimation (Table 1) (Hijmans et al. 2005). General Circulation Model (GCM) Representative Climate Community Climate System Model version 4 (CCSM4) is a climate model with ingredient representing the atmosphere, ocean, sea ice, and land surface connected by a flux coupler (Colins et al. 2006; Gent et al. 2011), was used to predict the influence of the future climate on *S. lendlii*. CCSM4 model is an effective climate projection to give notice the impact of future climatic changes on the distribution of animal species (Liang et al. 2018; Mohammedi et al. 2019)

To determine habitat suitability range in the 2070s (2061–2080), RCP2.6 (the optimistic scenario for greenhouse gas emissions), RCP4.5 (the stabilized scenario for greenhouse gas emissions), and RCP8.5 (the pessimistic scenario for greenhouse

gas emissions) were used the version 1.4 (www.worldclim.org) (Hijmans et al. 2005).

Using the Pearson correlation test (ENM Tools, 1.4.4) (Warren et al. 2010), similar variables were removed from the model. In models, $r^2 < 0.90$ threshold value was taken, and variables with a coefficient higher than 0.90 were excluded from the model (Table 2). MaxEnt Modeling was used in the study (MaxEnt version 3.4.1) (Phillips et al. 2017). MaxEnt operated with maximum iterations of 5000, convergence threshold of 0.0001, and six background points. 80% of occurrence records were randomly selected and used for training data, the rest were used test data (20%), and twelve times replicated. To evaluate the performance of the model, the area under the curve (AUC), the receiver operating characteristic (ROC) were used. AUC model

performance is a measure, ranges between 0 and 1, and excellent discrimination demonstrates a value of 1 (Gebrewahid et al. 2020).

We gathered six reliable sites of the current presence of *S. lendlii*, distributed across the Porsuk stream, Eber lake, and Akşehir lake (Figure 1), which corresponded to previously described areas (Çiçek 2020; Freyhof et al. 2011; Mangıt et al. 2017). The complete model was trained with the twelve variables already selected. After working this model with MaxEnt, an adjustment of variables that significantly subscribed to explain the geographic distribution of the species, by % contribution, or permutation significances were chosen for an ultimate predictive model. All environmental and climate layers are prepared in ArcMap 10.8 version (ESRI Inc.; www.esri.com).

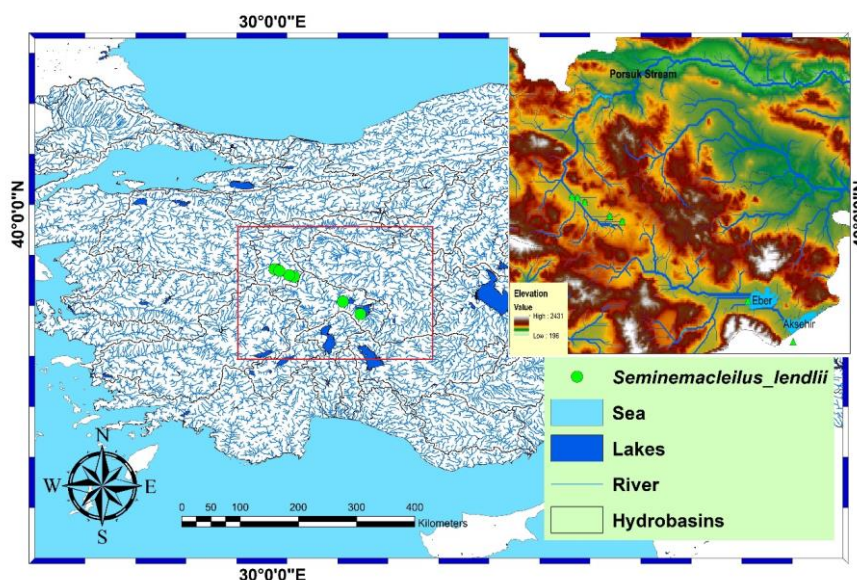


Figure 1. Distribution map with the occurrence localities of the *S. lendlii*

Table 1. Environmental variables used for modeling the potential distribution of *S. lendlii*.

Variable	Description	Source
Bio1	Annual Mean Temperature	http://www.worldclim.org
Bio 2	Mean Diurnal Range (Mean of monthly (max temp/min temp)	http://www.worldclim.org
Bio 3	Isothermality (BIO2/BIO7) * 100)	http://www.worldclim.org
Bio 4	Temperature Seasonality (standard deviation *100)	http://www.worldclim.org
Bio 5	Max Temperature of Warmest Month	http://www.worldclim.org
Bio 6	Min Temperature of Coldest Month	http://www.worldclim.org
Bio 7	Temperature Annual Range (BIO5-BIO6)	http://www.worldclim.org
Bio 8	Mean Temperature of Wettest Quarter	http://www.worldclim.org
Bio 9	Mean Temperature of Driest Quarter	http://www.worldclim.org
Bio 10	Mean Temperature of Warmest Quarter	http://www.worldclim.org
Bio 11	Mean Temperature of Coldest Quarter	http://www.worldclim.org
Bio 12	Annual Precipitation	http://www.worldclim.org
Bio 13	Precipitation of Wettest Month	http://www.worldclim.org
Bio 14	Precipitation of Driest Month	http://www.worldclim.org
Bio 15	Precipitation Seasonality (Coefficient of Variation)	http://www.worldclim.org
Bio 16	Precipitation of Wettest Quarter	http://www.worldclim.org
Bio 17	Precipitation of Driest Quarter	http://www.worldclim.org
Bio 18	Precipitation of Warmest Quarter	http://www.worldclim.org
Bio 19	Precipitation of Coldest Quarter	http://www.worldclim.org

Results

The calibration of the model for *S. lendlii* was excellent (AUC_{mean}=0.957 and standard deviation 0.079, Figure 2). The results indicated that *S. lendlii*'s current distribution, characterized by the selected variables, is excellent. Maxent models with adequate predictive power were applied to present and future climate data to assess the potential distribution of *S. lendlii* in these periods. The test of the jackknife analysis indicates the distribution of *S. lendlii* was mainly influenced by the mean temperature of the wettest quarter (Bio 8), temperature seasonality (standard deviation *100) (Bio 4), and isothermality (BIO2/BIO7) * 100 (Bio 3) (Figure 3). The average temperatures of the rainiest season (1980-2010) natural distribution areas of the species are between 0.7-15.3 °C, and the annual average temperatures are in the range of 0 - 22.5 °C (MGM 2020). The region where *S. lendlii* is distributed in the Porsuk River (Eymir), water temperature 4.80, 19.7 °C, pH 7.31-

8.02, Dissolved Oxygen 7.74-12.13 mg / L, Salinity (0.27-0.33) and EC (326-1767 µs/cm) (Köse et al. 2016).

The AUC values and standard deviations were 0.957 and 0.079 respectively, indicating that the expected findings were correct. The species habitat model was by twelve environmental variables (Figure 3 and Table 3). In this study, five climatic parameters (Bio_8, Bio_15, Bio_14, Bio_3, Bio_4) for contributed more than 10% (Table 3). Predictions of the relative contributions of bioclimatic variables to the target species are indicated in Table 3. Mean Temperature of Wettest Quarter (Bio_8) was the climatic variable with the highest percentage contribution for *S. lendlii*.

According to the result of future modeling, the distribution range of the species will dramatically change in 2070, suggesting that *S. lendlii* would lose a significant part of its suitable habitats (Figure 4).

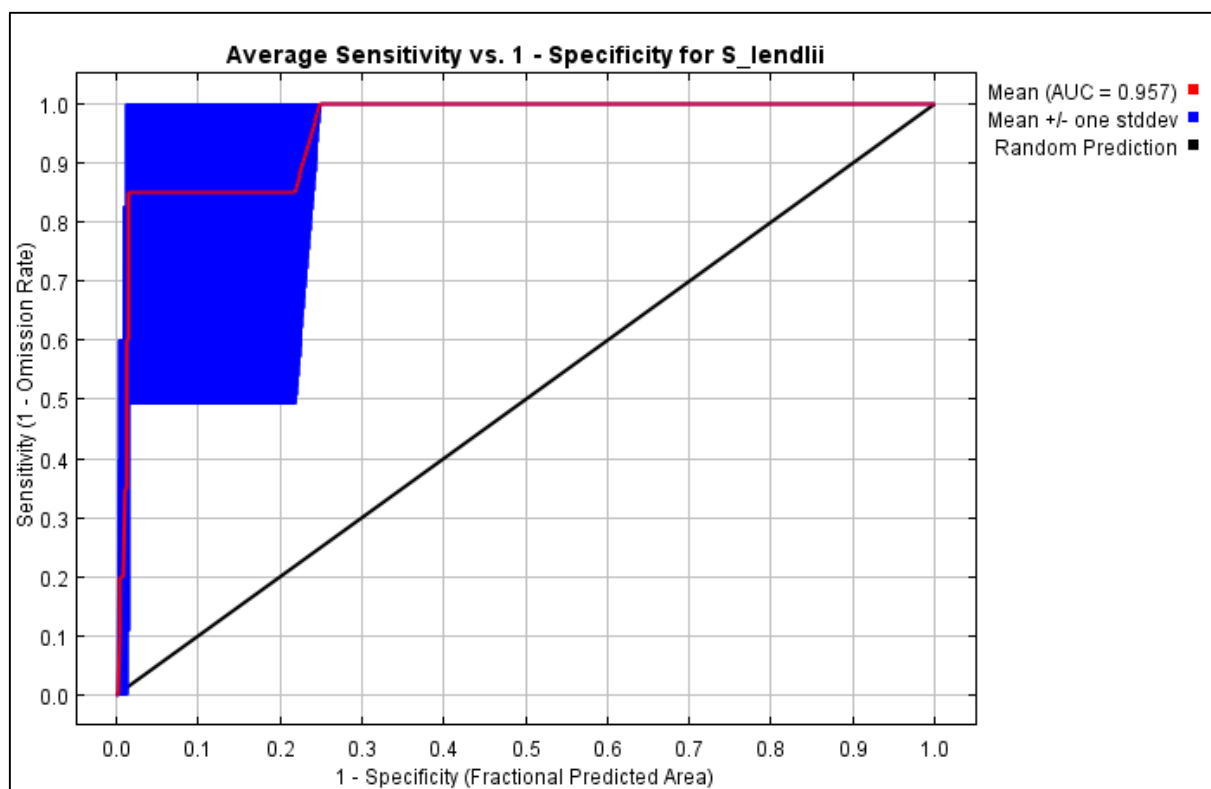


Figure 2. ROC curve and AUC values for Maxent model

Table 3. Prediction of relative contributions and permutation significance of the predictor environmental variables to the MaxEnt model.

Variable	Bio 8	Bio 15	Bio 14	Bio 3	Bio 4	Bio 6	Bio 1	Bio 2	Bio 9	Bio 5	Bio 13	Bio 12
Percent contribution	25.6	25	22.6	12	9.5	3.8	0.9	0.3	0.1	0.1	0	0
Permutation importance	12.2	20.6	36.9	1.2	10.3	6.9	8.8	2.2	0	0.9	0	0

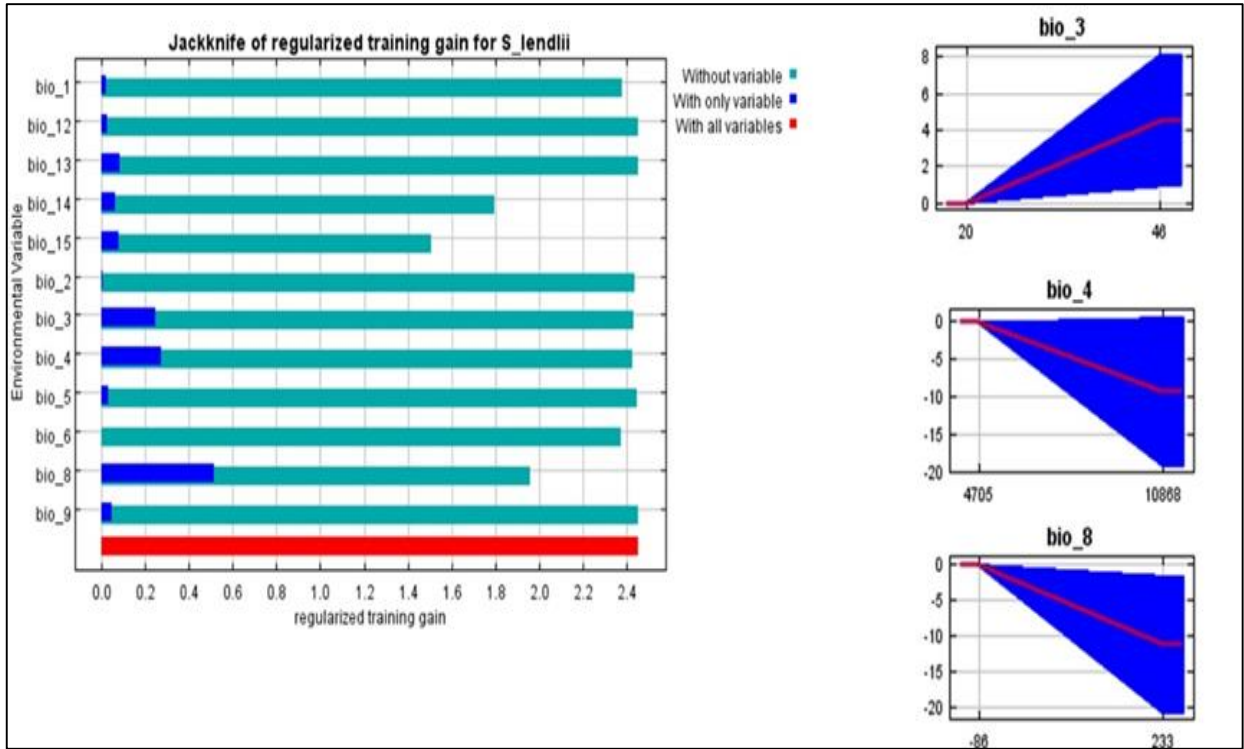


Figure 3. Jackknife test of variable importance of *S. lendlii*.

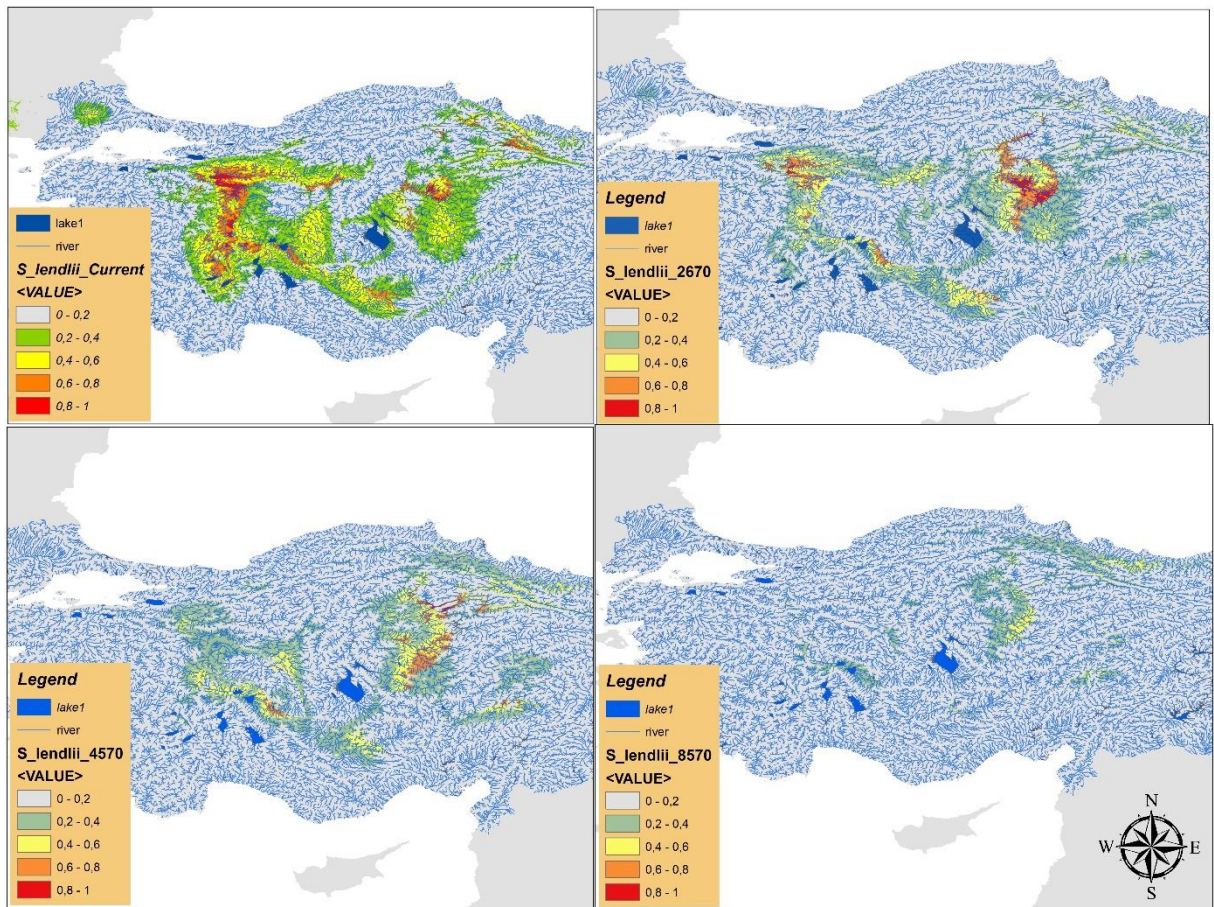


Figure 4. Habitat suitability maps of *S.lendlii* under current conditions and future CCSM4 emission scenario for the year 2070.

Discussion

This study provided important data on the future projection of *S. lendlii*. According to the most pessimistic climate scenario of the species, it has been observed that it is likely to lose a significant part of its suitable habitats.

It is predicted that climate change would affect the distribution of species. Some species expand their distribution areas as a result of climate change, while others may decrease (Yousefi et al. 2020). Aquatic organisms are likely to be directly affected by climate change. Especially the settlement of invasive species, anthropogenic pressures, and changes in water structures will create significant changes in freshwater fish habitats, which collectively might impact native and endemic fish species, in particular, with restricted distribution range and low abundance populations.

Global climate change causes significant changes in temperature and precipitation patterns. Expected changes are predicted that the temperature will increase by 4.5 degrees, and the precipitation will decrease according to the pessimistic scenarios (RCP8.5) (Demircan et al. 2014). This may result in some water sources drying out. This negative change in water systems may result in the extinction of species that are distributed in limited areas.

The IUCN protection status of the *S. lendlii* species is vulnerable. Its population exists in limited areas (Freyhof 2014). Although the existence of the species is known in the Sakarya Basin, the records about it are recent. It was recorded from only one point of Sakarya basin (Çiçek 2020), Lake Eber (Mangıt et al. 2017), and Akşehir lake (Freyhof et al. 2011). Eber and Akşehir lakes have reached the point of losing a significant part of their water (Sener et al. 2010) and Sakarya basin is under pollution pressure (Köse et al. 2018). Further, increasing industrial and agricultural pollution will significantly affect fish habitats. These adverse conditions would end up with the loss of valuable habitat areas of the species.

In the areas where *S. lendlii* species are currently distributed, there is a decrease in water resources in summer. There are intense irrigation activities in the current habitat regions of the species. The Porsuk stream sampling localities have water almost to dry up due to irrigation in summer, and there is only water in rainy seasons. Dissolved oxygen levels can decrease as much as (1.96-7.74 mg/l) due to pollution pressure in the Eber lake basin where the species is distributed (Köse et al. 2016). Eber Lake and Akşehir Lake lose a significant part of the water body in the summer months due to the unconscious use of water and the decrease in precipitation. As a result of climate change (RCP 8.5, 2070-2100), an approximate temperature increase of 4-6 °C and a

decrease in precipitation are expected in Sakarya and Akarçay basins (Akçakaya et al. 2015). This may result in the reduction of spring waters and loss of suitable habitats.

The variables that most affect the current and future distribution of the species are Mean Temperature of Wettest Quarter (bio_8), Temperature Seasonality (standard deviation × 100) (bio_4), Bio 3 Isothermality (BIO2/BIO7) * 100), Precipitation of Driest Month (Bio-14), and Precipitation Seasonality (Coefficient of Variation) (Bio_15). It was seen that the decrease in precipitation and the increase in temperature would change the future habitats of *S. lendlii* (Figure 4). Population decline over the past ten years for *S. lendlii* is inferred to be at least 30% (Freyhof 2014). These losses will increase rapidly with the effect of climate change.

SDM is a reliable tool to determine the future distribution of invasive and native fish species. It is essential to determine the distribution range for the protection and implementing proper conservation of endemic species distributed in a limited area. Fishes can be used as indicators of organism at individual, population, environmental, and community levels (Yousefi et al. 2020); therefore, fish can be continuously monitored to determine how freshwater ecosystems respond to climate change. This study recommends that all freshwater ecosystems in Turkey have to be monitored regularly for the successful conservation of freshwater fishes under climate change.

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