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Effects of Climate Change on the Habitat Suitability and Distribution of Endemic Freshwater Fish Species in Semi-Arid Central Anatolian Ecoregion in Türkiye

Mustafa Korkmaz [1,2,*], Fatih Mangıt [3], İlayda Dumlupınar [4], Mehmet Arda Çolak [5], Mustafa Berkay Akpınar [6], Meltem Koru [2], Juan Pablo Pacheco [7,8], Arely Ramírez-García [9], Gültekin Yılmaz [2], Cihelio Alves Amorim [1], İbrahim Kaan Özgencil [1], Deniz İnnal [10], Sedat Vahdet Yerli [3], Korhan Özkan [2,11], Zuhal Akyürek [5,6,11], Meryem Beklioğlu [1,11] and Erik Jeppesen [1,8,11,12,13,14]

1 Department of Biological Sciences, Middle East Technical University, Ankara 06800, Türkiye; alvescihelio@gmail.com (C.A.A.); kaanozgencil@gmail.com (İ.K.Ö.); meryem@metu.edu.tr (M.B.); ej@ecos.au.dk (E.J.)
2 Institute of Marine Sciences, Middle East Technical University, Mersin 33731, Türkiye; korumeltem99@gmail.com (M.K.); tekinims@gmail.com (G.Y.); okorhan@metu.edu.tr (K.Ö.)
3 Department of Biology, Hacettepe University, Ankara 06800, Türkiye; fatih.bio@gmail.com (F.M.); svyerli@gmail.com (S.V.Y.)
4 Graduate School of Science and Engineering, Hacettepe University, Ankara 06800, Türkiye; ilaydadumlupinar96@gmail.com
5 Department of Geodetic and Geographic Information Technologies, Middle East Technical University, Ankara 06800, Türkiye; arda.colak@metu.edu.tr (M.A.Ç.); zakyurek@metu.edu.tr (Z.A.)
6 Department of Civil Engineering, Middle East Technical University, Ankara 06800, Türkiye; berkay.akpinar@metu.edu.tr
7 Centro Universitario de la Regional del Este (CURE), Universidad de la República, Maldonado 11200, Uruguay; jp@ecos.au.dk
8 Department of Ecoscience, Aarhus University, 8000 Aarhus, Denmark
9 Laboratorio de Biología Acuática, Facultad de Biología, Universidad Michoacana de San Nicolás de Hidalgo, Morelia 58000, Mexico; arelyr@umich.mx
10 Department of Biology, Burdur Mehmet Akif Ersoy University, Burdur 15030, Türkiye; innald@gmail.com
11 Centre for Ecosystem Research and Implementation (EKOSAM), Middle East Technical University, Ankara 06800, Türkiye
12 Arctic Research Centre (ARC), Aarhus University, 8000 Aarhus, Denmark
13 Sino-Danish Centre for Education and Research (SDC), Beijing 101408, China
14 Institute for Ecological Research and Pollution Control of Plateau Lakes, School of Ecology and Environmental Sciences, Yunnan University, Kunming 650500, China
* Correspondence: korkmaz.hidro@gmail.com

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Abstract: Climate change is affecting freshwater ecosystems globally, particularly those in semi-arid and arid regions. The Central Anatolian Ecoregion (CAE) in Türkiye has a semi-arid climate and is home to numerous endemic fish species. We used species distribution modelling to elucidate the distribution of sixteen endemic fish species in CAE and predicted their potential distributions for 2041–2060 and 2081–2100 based on the CMIP6 climate model. Half of the species are predicted to experience a significant loss of climatically suitable areas. *Anatolichthys fontinalis*, *Gobio gymnostethus*, *Gobio hettitorum*, and *Pseudophoxinus burduricus* will face a complete loss of suitable areas by 2081–2100 under a high emissions climate scenario, whereas *Cobitis bilseli*, *Egirdira nigra*, *Gobio intermedius*, and *Squalius anatolicus* will experience a significant loss. The other eight species can potentially benefit from climate warming if all other stressors remain equal. Anthropogenic stressors, such as water abstraction for irrigation, pollution, invasive species introductions, and dam construction, are already putting endemic fish populations in CAE under extreme pressure. Climate change is expected to exacerbate these threats. Regular monitoring of freshwater ecosystems and fish fauna in the CAE and protecting the region from key anthropogenic stressors are recommended to successfully conserve these endemic freshwater fishes under climate change.

Keywords: species distribution modelling; habitat quality models; Maxent; endemic freshwater fish

1. Introduction

Freshwater ecosystems are among the most endangered on Earth [1,2]. Despite only making up 2.3% of the Earth's surface, they support high biodiversity, ecosystem functions, and services that underpin human well-being [3–5]. They are undergoing drastic changes globally due, e.g., to changes in land and water use, water abstraction, pollution, and colonisation by invasive species [4]. Climate change further promotes or aggravates these pressures as it increases water extraction, alters hydrological regimes, amplifies the effects of changes in land use, and affects the habitat and dispersion of species [3,6,7]. According to predictions, even slight warming scenarios pose severe threats to global biodiversity, from cellular to population levels [8]. Changing environmental conditions might favour specific species or induce changes in their distribution areas [9,10].

In the context of climate change, species are expected to exhibit one of three responses: They adapt to the altered climate, track favourable habitats, or become extinct [11]. Climate change is likely to have adverse effects on most species, independent of other underlying anthropogenic factors; however, some species may experience benefits when suitable habitat availability increases. Defining the winners and losers of climate change is emerging as a key subject in climate change biodiversity research [12,13]. Once the winners and losers have been identified, it may be possible to develop management plans targeting each species according to its unique response to climate change.

Freshwater fish comprise 40% of all fish species and 25% of all vertebrates on Earth [4,14], and they are among the most diverse taxonomic groups threatened by global changes [6,15,16]. Several studies have revealed that the phenology and distribution of freshwater fish species have already changed due to the climate change [17,18], and drastic declines in population size and their distribution range have occurred in recent decades reflecting an increase in various threats, including habitat loss and degradation, water abstraction, invasive species, overfishing, water pollution, and climate change [7,19,20]. To estimate the consequences of such habitat alterations for fish populations, it is necessary to understand how these threats affect the niche and spatial distribution of the species.

Species distribution modelling (SDM) combines the principles of ecology, biogeography, and statistical and machine learning techniques to predict the spatial distribution of species based on their environmental preferences. SDM provides insights into species distribution–environment relationships and can be used to estimate the bioclimatic niche of a species by correlating species occurrence or abundance records with climatic data [21,22]. SDM has been widely used in ecology, biogeography, conservation biology, and wildlife management as a tool to predict the potential distributions of a species using projected scenarios based on the likelihood of the existence of a targeted species in response to various environmental factors [22–25]. SDM has also proven to be useful in predicting how species may respond to changes in climate conditions [26]. It represents a practical approach for assessing the vulnerability of a species to climate change and determining its geographical distribution and fundamental niches [27]. Climate projections indicate that (semi) arid regions will be among those most affected by climate change and other anthropogenic impacts that add to habitat alteration. It is, therefore, essential to understand how climate change can affect the distribution of species, particularly those that are more sensitive, such as species endemic to these ecosystems.

There are 25 water basins in Türkiye with more than 420 fish species (including some that still need confirmation) [28,29]. According to the zoogeographical delineation conducted in the Freshwater Ecoregions of the World, Türkiye has 14 freshwater ecoregions [30], among which 3 are specific to Türkiye: the Central Anatolia, Northern Anatolia, and Lake Van ecoregions. Despite the diverse aquatic systems, Anatolia does not have abundant water resources. According to World Resources Institute data, Türkiye is ranked 32 on the water-stress countries list [31]. The Central Anatolia Ecoregion (CAE), which includes the Konya Closed, Burdur, and Akarçay River Basins, is expected to be significantly affected by climate change [32–34]. A significant portion of the CAE can be characterised as having a semi-arid climate [35,36] and a high level of endemism [37]. Geologically, CAE is the remnant of the Central Anatolia Lake System, which showed significant fluctuations through time [38–40] and was inhabited by fishes from central and western Europe, Mesopotamia, and central and western Asia [28,38]. Many endemic fish species in the region are already threatened [32,41,42], and climate change is likely to intensify these threats [43,44]. The current state of the endemic freshwater fish in the region is alarming, with 30 out of the 43 endemic freshwater fish taxa recognised as being threatened [29,32,33].

Here, we elucidate the present habitat suitability and forecast habitat changes for endemic freshwater fish in the Central Anatolia Ecoregion using SDM and various climate change scenarios. We aimed to determine how climate change affects endemic freshwater fish species in the region and to identify winners and losers in the species distribution under climate change scenarios.

2. Materials and Methods

2.1. Study Area

The CAE is a 1000 m high plateau consisting of three major endorheic water basins; Konya Closed, Burdur, and Akarçay Basins, as well as Lake Eğirdir, which is connected to the Antalya Basin and the Mediterranean Sea only historically through karst aquifers [45]. These basin systems have changed considerably in recent years [32,33].

Due to its geological history and geographical structure, Türkiye is known for its high endemism and genetic diversity. The CAE is among the highest contributors to this diversity, with 43 endemic fish species (Table S1 in the Supplementary Materials) [28,29,32,37,41,44]. The region's biodiversity is still incomplete, as new species are regularly being discovered. Many endemic species are distributed in limited areas in central Anatolia's aquatic systems that contain numerous important water bodies and watercourses (Figure 1) but are under serious threats.

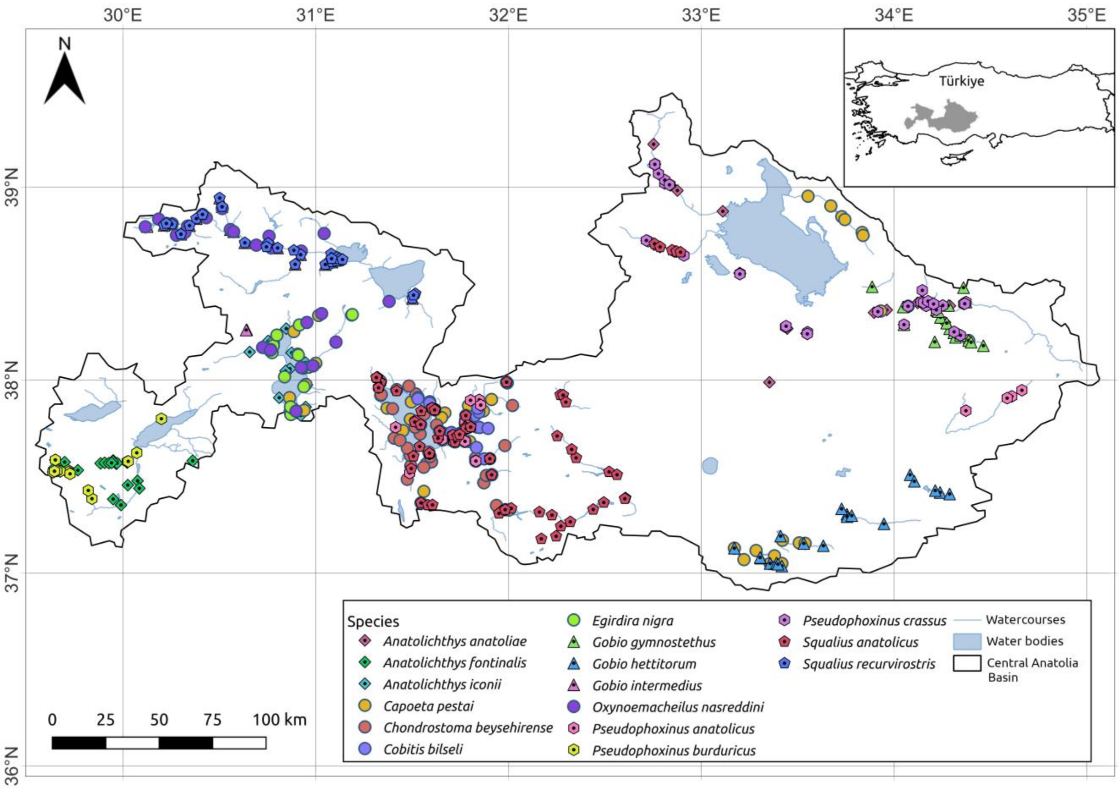


Figure 1. Distribution records of the studied species and their locations in the Central Anatolia Ecoregion in Türkiye.

2.2. Fish Presence Data

In this study, we focused on the endemic freshwater fish species in CAE using data from various data sources (Figure 1, Table S1 in the Supplementary Materials), including the Global Biodiversity Information Facility (GBIF) [46], FishBase [47], Eschmeyer's Catalog of Fishes [48], literature [44,49–53], and data from field studies performed between 2012 and 2022 by some of the authors of this article. To reduce the effects of spatial sampling biases [54], the records for each species present were spatially filtered by reducing multiple records within 1 km to a single record with the "spThin" package [55] in R software (version 4.1.3) [56]. In the analysis, we assumed that fish could disperse freely to track suitable climatic conditions. We performed modelling on 16 of these species within CAE, while 15 species were excluded because their distribution extended beyond the CAE. Additionally, another nine species were excluded due to limited distribution data, and a further three species were excluded due to their extremely limited distribution range. Such exclusions were essential for maintaining the accuracy and reliability of our results.

2.3. Hydro-Climate Data

Long-term mean annual temperature and total annual precipitation data for the period 1970–2021 were obtained from the ERA5-Land product. ERA5-Land [57] is a climate reanalysis product generated by ECMWF, and it is the successor of the ERA5 [58] with a long temporal coverage from 1950 to the present (the ERA5-Land data released so far covers the period from 1981 to 2–3 months before the present). ERA5-Land provides hourly data on various atmospheric, land-surface, and sea-state parameters together with estimates of uncertainty with its enhanced 9 km spatial resolution. Surface and subsurface runoff values are used to observe the spatial distribution of runoff within the study area. In the ERA5-Land product, subsurface water fluxes are determined by Darcy's law, and the surface runoff is obtained by the Hortonian runoff formulation [59].

Trend analysis was conducted by using generalized linear models (GLM) [60]. We modelled the temperature and precipitation response variables by defining year as the sole explanatory variable. The models were built by using the glmmTMB function from the "glmmTMB" package [61] in R software (version 4.1.3) [56]. We validated the models by following Zuur and Ienao [62] and checked for the residuals autocorrelation by using autocorrelation and partial autocorrelation plots.

2.4. Environmental Data

The present and future bioclimatic data were obtained from the WorldClim database version 2.1, having a spatial resolution of 30 arc-seconds [63]. For the 2041–2060 and 2081–2100 periods, we used data from the Coupled Model Intercomparison Project Phase 6—CMIP6 [64]. Downscaling and calibration were conducted with the WorldClim database version 2.1 as the baseline climate and based on the Model for Interdisciplinary Research on Climate Version 6 (MIROC6), a global climate model, and two Shared Socio-economic Pathways (SSP2-4.5 and SSP5-8.5) were used. The Shared Socio-economic Pathways (SSP) framework comprises a set of scenarios that outline possible trajectories of future socio-economic development and greenhouse gas emissions. Specifically, SSP2-4.5 envisions a future where greenhouse gas emissions peak around 2040 and subsequently decline. In contrast, SSP5-8.5 projects a future where greenhouse gas emissions continue to increase throughout the century [65]. Nineteen scenopoetic bioclimatic variables [66] were derived from monthly temperature and precipitation values. To ensure that the selected variables were not highly correlated, multicollinearity was assessed using variance inflation factor (VIF) testing, with a threshold of 10 for VIF and 80% for correlation using the "usdm" package (version 1.1-18; [67]) in shinyBIOMOD [68] and the "vifstep" and "vifcor" functions in R software (version 4.1.3) [56].

2.5. Species Distribution Modelling

Maxent v3.4.1 [69] software was used to model the endemic fish species and infer their bioclimatic suitability in the study area in both present and future scenarios. Maxent is a machine learning algorithm that predicts niches by correlating species presence with environmental variables, making it suitable for presence-only data [69]. It iteratively minimises the relative entropy between the probability densities at presence sites and the probability densities of the landscape, and it has been shown to be a useful tool for developing successful distribution models, particularly for small sample sizes [70,71].

The optimal variables and model settings were selected [70,72] in the WALLACE v1.0.6.3 platform [73,74], which is an R-scripted modern workflow. A user-specified study region was created from the presence records to select the background, and 1000 background points were used in the model. Candidate models were tested by combining five combinations of feature classes (linear; linear and quadratic; hinge; linear, quadratic, and hinge; linear, quadratic, hinge, and product) and five values of regularisation multiplier (1 to 5 in increments of 1).

The modelling process involved determining the model settings and developing a final model for each species using the entire dataset, including presence records and 1000 background points, projected onto present and future bioclimatic conditions for the study area. The validation of the models was based on the area under the receiver operating characteristic curve (AUC), which measures the ability of the model to distinguish between presence and absence points. AUC values below 0.5 indicate that the model's performance is not better than random variation [75], while values above 0.7 indicate a good fit, and values above 0.9 indicate an excellent fit.

To identify extrapolation risks in model transfers, multivariate environmental similarity surface (MESS) was used [76,77]. Response curves were used to evaluate the impact of individual variables on model predictions, while a "jackknife" test was used to determine the relative contribution of each variable to the final model. To create maps of habitat suitability, "cloglog" output was used, with values ranging from 0 (low suitability) to 1 (high suitability). Model performance was evaluated using a partial ROC analysis with "ntbox" (NicheToolBox) software [78] (Proportion of omission = 0.05, Percentage of random points = 50, Bootstrap iterations = 1000). Maxent model outputs were converted into binary maps using "SDMtoolbox" software (version 2.5) [79], and calculation of the areas was conducted with the "biomod2" package in R software (version 4.1.3) [56].

3. Results

3.1. Model Performance

We found that the models for all 16 endemic species performed well based on the area under the receiver operating characteristic curve (AUC); all were above 0.85 (Table 1).

3.2. Importance of Climate Variables

The VIF analysis eliminated 13 of the 19 climate variables (Table S2 in the supplementary materials), and the remaining variables used as model input were annual mean temperature (Bio1), isothermality (Bio3), temperature seasonality (Bio4), mean temperature of wettest quarter (Bio8), annual precipitation (Bio12), and precipitation seasonality (Bio15).

Annual precipitation was the most critical influential factor as it determined the distribution of the selected fish species, with 7 of the 16 species exhibiting a solid association with specific annual precipitation. Furthermore, annual mean temperature, temperature seasonality, and precipitation seasonality for the remaining nine species emerged as critical predictors of their distributions with 43 endemic fish species.

3.3. Climatic Scenarios

In the scenario analysis, we found that five species (*Anatolichthys fontinalis*, *Cobitis bilseli*, *Gobio gymnostethus*, *Gobio hettitorum*, and *Pseudophoxinus burduricus*) are likely to experience a reduction in their predicted distribution range in both periods (2041–2060 and

2081–2100) and scenarios (SSP2-4.5 and SSP5-8.5) due to climate change (Figure 2; Table 2). Additionally, according to the predictions, *Egirdira nigra* is expected to undergo a reduction in the 2081–2100 period in both scenarios, and the 2041–2060 period in the SSP5-8.5. *Gobio intermedius* is expected to experience a range reduction in the 2081–2100 period under both scenarios. Furthermore, *Squalius anatolicus* is predicted to undergo a range reduction during the 2081–2100 period, specifically under the SSP5-8.5 scenario (Figure 3). Eight species (*Anatolichthys anatoliae*, *Anatolichthys iconii*, *Chondrostoma beysehirense*, *Capoeta pestai*, *Oxynoemacheilus nasreddini*, *Pseudophoxinus anatolicus*, *Pseudophoxinus crassus*, and *Squalius recurvirostris*; Table 2; Figures S1 and S2 in the Supplementary Materials), however, are predicted to have a potential distribution range increase.

Table 1. Area under the receiver operating characteristic curve (AUC) values for the 16 endemic freshwater fish distribution models.

Species	AUC Values
Anatolichthys anatoliae (Leidenfrost 1912)	0.88
Anatolichthys fontinalis (Akşiray, 1948)	0.98
Anatolichthys iconii (Akşiray, 1948)	0.98
Capoeta pestai (Pietschmann, 1933)	0.85
Chondrostoma beysehirense Bogutskaya, 1997	0.93
Cobitis bilseli Battalgil, 1942	0.96
Egirdira nigra (Kosswig & Geldiay, 1952)	0.97
Gobio gymnostethus Ladiges, 1960	0.97
Gobio hettitorum Ladiges, 1960	0.94
Gobio intermedius Battalgil, 1944	0.96
Oxynoemacheilus nasreddini Yoğurtçuoğlu, Kaya & Freyhof, 2021	0.94
Pseudophoxinus anatolicus (Hankó, 1925)	0.88
Pseudophoxinus burduricus Küçük, Gülle, Güçlü, Çiftçi & Erdoğan, 2013	0.95
Pseudophoxinus crassus (Ladiges, 1960)	0.89
Squalius anatolicus (Bogutskaya, 1997)	0.91
Squalius recurvirostris Özuluğ & Freyhof, 2011	0.97

Table 2. Conservation status [80] of the endemic freshwater fishes of the CAE and changes in their distribution range for various future climate scenarios and periods (grey shaded areas indicate the predicted losses in species distribution range).

Species	Conservation Status *	Range Size Change (%)			
		SSP2-4.5 2041–2060	SSP2-4.5 2081–2100	SSP5-8.5 2041–2060	SSP5-8.5 2081–2100
Anatolichthys anatoliae	NT	214	216	226	239
Anatolichthys fontinalis	NE	−100	−100	−100	−100
Anatolichthys iconii	NE	1386	1521	1468	1172
Capoeta pestai	CR	150	175	162	189
Chondrostoma beysehirense	EN	138	123	107	47
Cobitis bilseli	EN	−21	−48	−47	−100
Egirdira nigra	EN	7.8	−76	−70	−100
Gobio gymnostethus	CR	−100	−100	−100	−100
Gobio hettitorum	CR	−100	−100	−100	−100
Gobio intermedius	EN	6.1	−30	17	−70
Oxynoemacheilus nasreddini	NE	106	91	97	75
Pseudophoxinus anatolicus	EN	155	164	162	172
Pseudophoxinus burduricus	EN	−97	−100	−100	−100
Pseudophoxinus crassus	EN	118	132	130	146
Squalius anatolicus	LC	251	162	177	−26
Squalius recurvirostris	VU	49	22	60	8.5

Note: * CR, critically endangered; EN, endangered; VU, vulnerable; NT, near threatened; LC, least concern; NE, not evaluated based on the IUCN Red List.

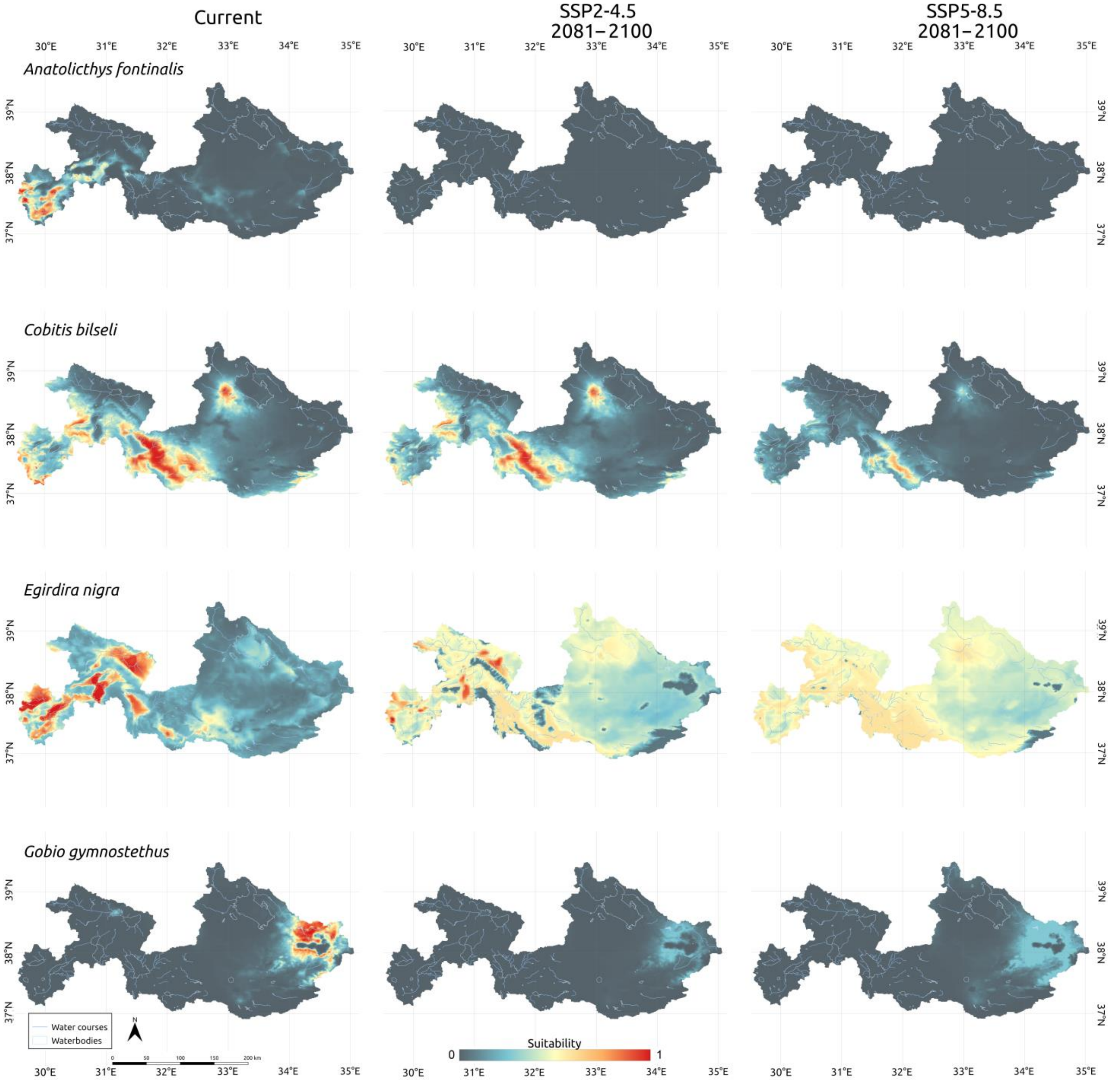


Figure 2. Current and future distribution of *Anatolichthys anatoliae*, *Cobitis bilseli*, *Egirdira nigra*, and *Gobio gymnostethus* in the CAE. Colours show habitat suitability, and the value of suitability increases in red areas.

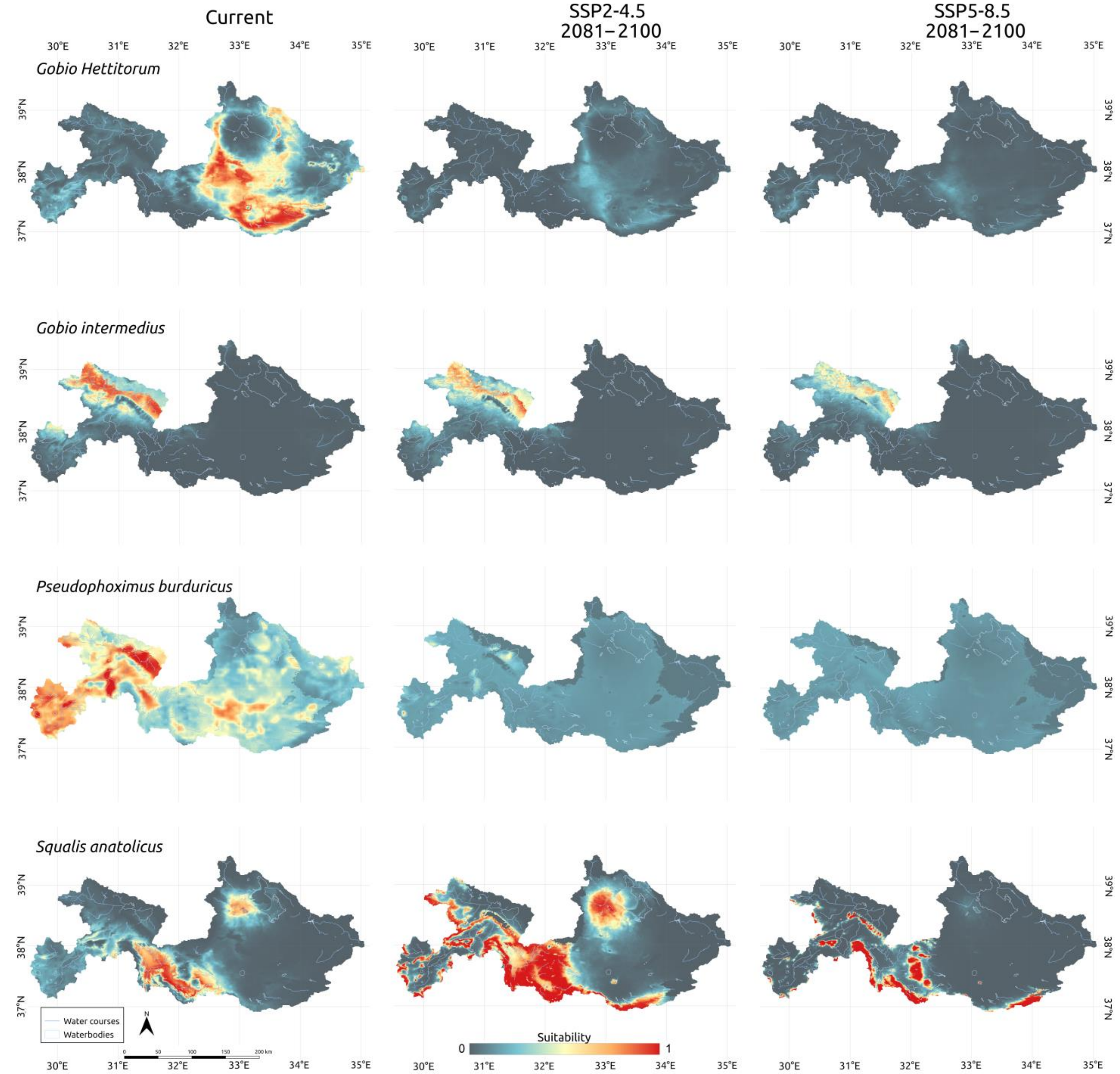


Figure 3. Current and future distribution of *Gobio hettitorum*, *Gobio intermedius*, *Pseudophoxinus burduricus*, and *Squalius anatolicus* in the CAE. Colours show habitat suitability, and the value of suitability increases in red areas.

3.4. Hydro-Climate Trends

The model we built for the trend in mean annual temperature yielded an effect size estimate of 0.056 (gamma GLM with log link, standard error = 0.001), and the one we built for the trend in total annual precipitation yielded an effect size estimate of −0.032 (gamma GLM with log link, standard error = 0.018).

During the 52-year study period (1970–2021), the increasing trend in mean annual temperature indicated by ERA5-Land was 0.041 °C/year, and the annual total precipitation decreased by 50 mm, from 465 mm to 416 mm (Figure 4). According to the ERA5-Land reanalysis dataset, total annual runoff in the study area showed a significant decreasing trend ($p < 0.05$) for May in all of the study areas and for August in the major part of the study area (Figure 5).

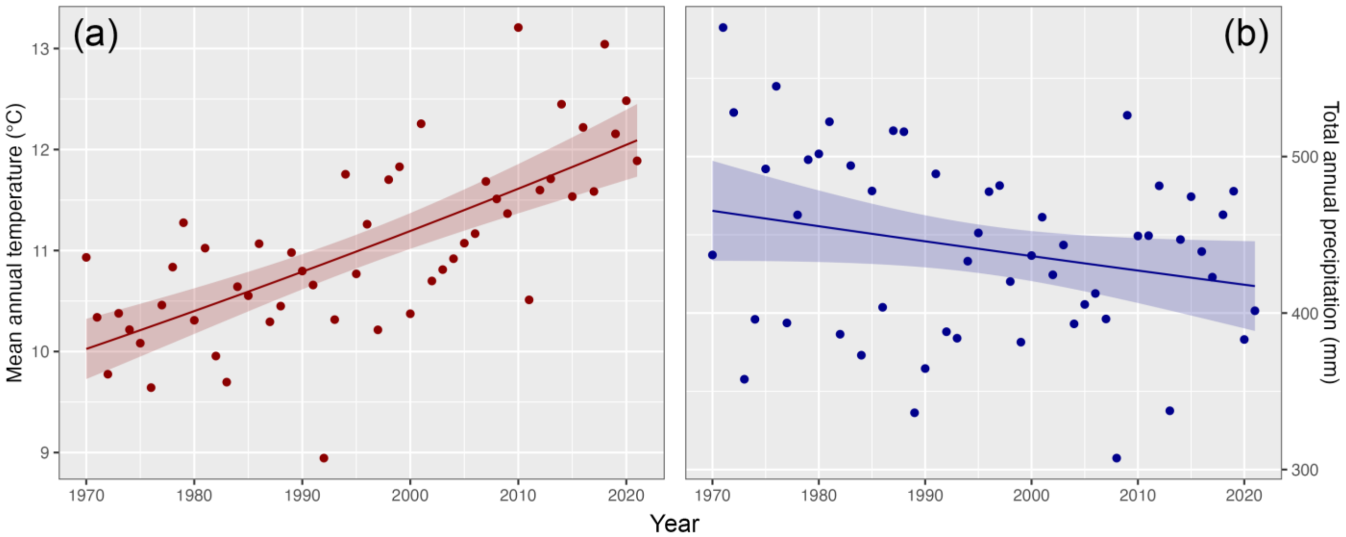
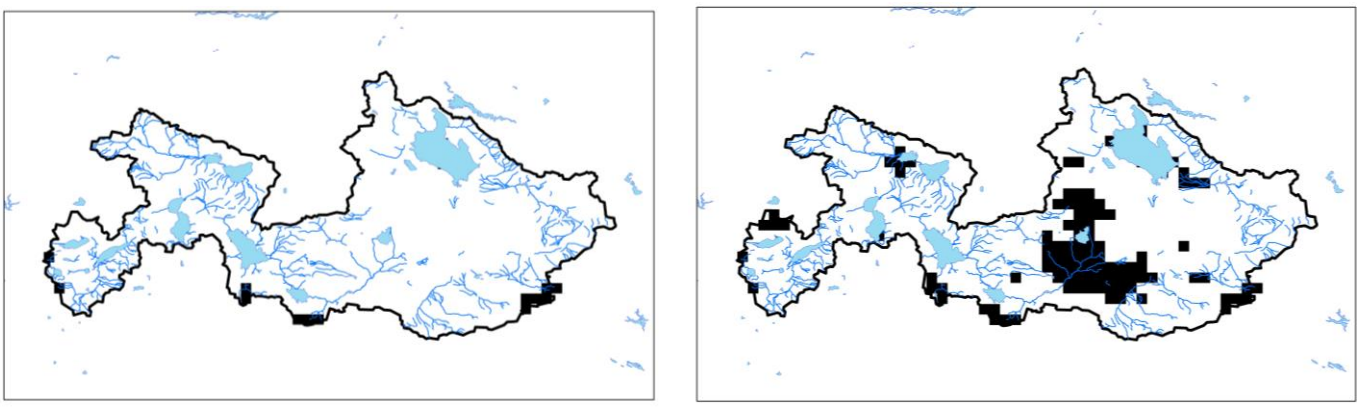


Figure 4. Changes in mean annual temperature (**a**) and annual total precipitation (**b**) for the period 1970–2021. Points: data points; solid lines: predicted values (from the generalized linear models—see Section 2.3); ribbons: 95% confidence intervals of the predicted values (from the generalized linear models).



(**a**) (**b**)

Figure 5. Runoff trend in the Central Anatolia Ecoregion. Black: no trend, white: decreasing trend. (**a**) Runoff trend in May; (**b**) Runoff trend in August.

4. Discussion

We predicted the impact of climate change on the distribution of 16 out of 43 endemic fish species in the CAE that were suitable for modelling using SDM. We found that these species exhibited distinct responses to climate change, with eight species predicted to lose their climatically suitable habitats and four being at risk of complete extinction, while eight may potentially expand their climatically suitable habitats. Our findings of loss of climatically suitable habitats align with prior studies assessing the potential effects of climate change on freshwater fish fauna using SDM. For instance, Stewart et al. [81] projected that, by 2080, 9 of the 13 native fish taxa in southwestern Australia would lose their suitable habitat. Similarly, Yousefi et al. [12] predicted that 15 endemic freshwater fish species in Iran would experience range reductions, with 5 endemic species facing significant losses. Frederico et al. [82] suggested that the Amazon basin may lose 2% of its freshwater fish fauna due to unsuitable climatic conditions, with a further 34% expected to be adversely affected. Our finding is consistent with a study by Yılmaz et al. [32], revealing that, of the 38 fish species occurring in the Konya Closed Basin (one of the basins in CAE), 61% are threatened and highly vulnerable to the effects of climate change and water use, including a decline in water level.

Specifically, the models predict that *A. fontinalis*, *G. gymnostethus*, *G. hettitorum*, and *P. burduricus* will experience a complete loss of climatically suitable area by 2081–2100 under a high emissions scenario (SSP5-8.5). This potential loss highlights the extreme consequences of climate change in semi-arid regions, considering that the current conservation status for these species are NE, CR, CR, and EN, respectively [80]. Additionally, *C. bilseli*, *E. nigra*, *G. intermedius*, and *S. anatolicus* are predicted to have a significant loss of climatically suitable areas.

Of the 22 *Squalius* species in Türkiye, 4 are distributed in CAE. Members of this genus prefer pelagic areas and can be found in streams and lakes. They are considered tolerant to environmental alterations [80]. The model predicts that *S. anatolicus* may potentially expand its distribution by 2041–2060 but lose climatically suitable habitat by 2081–2100, and *S. cappadocicus*, a critically endangered species according to IUCN [80], is expected to lose its climatically suitable areas by 2081–2100 under the high emissions scenario (SSP5-8.5). The *Gobio* genus consists of benthic and rheophilic species. They generally prefer streams, but some species can also be found in lakes. *G. gymnostethus* and *G. hettitorum* are predicted to lose their suitable habitats completely by the end of this century. However, climatically suitable areas for *G. intermedius* showed a slight increase by 2041–2060 in both scenarios (SSP2-4.5 and SSP5-8.5), followed by a significant decrease by 2081–2100 in both scenarios.

Anatolia is a vital diversification centre for the genus *Pseudophoxinus* [83], and 24 species appear in Anatolia, accounting for nearly 90% (except 3 species) of the known species, and *P. burduricus* is endemic to the Burdur Basin. Even though the current distribution model defines Beyşehir and Akarçay basins as climatically suitable areas, it is not possible for this species to naturally disperse to these basins. Therefore, even a predicted increase in suitable habitats can only be functional if human management intervention, such as assisted migrations, is anticipated [84]. Based on the SDM results for *C. bilseli*, the species will experience a reduction in its climatically suitable habitats in both scenarios and periods. *C. bilseli* primarily inhabits small rivers and streams in Beyşehir lake tributaries. Despite its limited distribution, the species faces multiple threats, such as widespread pollution, excessive water abstraction, and the introduction of non-native fish species [44,85]. The distribution areas of *E. nigra* are predicted to decrease in both scenarios by 2081–2100, while an increase in climatically suitable habitats is projected by 2081–2100 under the SSP2-4.5 scenario. *E. nigra* is facing threats from water abstraction, pollution, and the introduction of non-native fish species, and *E. nigra* was previously distributed throughout the Lake Eğirdir Basin, including the lake; however, the introduction of the predatory non-native pikeperch *Sander lucioperca* (Linnaeus 1758) caused a significant decline in population size as well as significant range reduction [44].

The SDM identified potentially climatically suitable distribution areas for four endangered (EN) species of the eight that are predicted to experience an expansion in climatically suitable habitats: *Capoeta pestai*, *Chondrostoma beysehirense*, *Pseudophoxinus anatolicus*, and *Pseudophoxinus crassus*. These are the predicted winners of climate change, and the combined impact of climate change and other stressors may have unforeseen consequences due to the model uncertainty and other limitations. However, multiple other stressors threaten these species, including invasive species, water abstraction, drought, pollution, and dam construction [41,44,80,86–88]. For *C. pestai*, introduction of the non-native predatory pikeperch is one of the primary concerns [89]. *C. beysehirense*, which is found in the Beyşehir basin, is also mainly threatened by the introduction of the non-native predatory pikeperch [90]. *P. anatolicus* is under threat from water abstraction for irrigation, pollution, overfishing, restricted water levels, and non-native pikeperch introduction [91], and two of the three drainage basins where it occurred were already drained for agriculture [44]. Finally, *P. crassus* is limited to Central Anatolia, specifically İnsuyu Creek and Lake Gökgöl, located west of the Lake Tuz basin, and it is threatened by excessive water abstraction and the construction of dams and weirs [80].

Estimating the potential climatic distribution area of freshwater fish is not as straightforward as for terrestrial elements such as birds, reptiles, and mammals, and there is an ongoing debate about using climatic variables as surrogates for instream conditions [92]. For example, air temperature and precipitation do not directly reflect water temperature and hydrology. Still, some studies have shown that the inclusion of instream parameters (unavailable in our case) does not necessarily improve model accuracy [22]. Representativeness of climatic variables is one thing, but the capacity to settle in a suitable area is quite another. The dispersal of freshwater fish almost entirely depends on suitable freshwater conditions and connectivity. In addition to temperature, environmental factors such as flow (dams, seasonality), habitat, and pollution (physicochemical properties) are important [72] as they may prevent species from reaching new areas [76,93,94]. Biotic interactions (local fauna, predation, population/colonisation density) also affect dispersal capacity [95].

SDM use bioclimatic variables and presence/absence data to predict species distribution. However, correlations between variables do not always imply causality, and the model accuracy has limitations, as it is not accounting for other influential factors such as species adaptations, habitat fragmentation, biotic interactions, and anthropogenic stressors. In addition, estimating species distribution with large-scale predictors, as in this study (climate data), is known to pose a risk of overestimating distributions [96,97]. However, due to the complexity of the distribution process, the requirement for detailed data [92] and the significance of climate for species distributions [98], SDM frequently builds on climate variables alone [99,100]. Furthermore, the large individual grid cells of all climate data sets might not be the best indicators of the occurrence of patches with small-scale (micro) climate conditions that are favourable for a species [101,102]. Notwithstanding the possible drawbacks and limitations, SDM has emerged as a crucial instrument in conservation management for forecasting the dispersion patterns of species. To enable a comparison of how variations in a crucial class of variables might affect model performance, we concentrated on climate predictors.

The ERA5-Land reanalysis datasets revealed a highly significant increasing trend for temperature and a decreasing trend for precipitation for the period 1970–2021. Thus, surface and subsurface runoff values estimated by ERA5-Land have a decreasing trend within the CAE in most of the months. The decreasing trend is significant in May and August around the locations of the studied species. According to trend analysis, an increase in evaporation and transpiration has resulted in water loss in the CAE basin after 2000, indicating a water deficit [32]. The primary driver of water loss in lakes, however, is unsustainable water use for agriculture in the Konya and Burdur Basins, which are the main basins of CAE. Changes in land use and irrigation have detrimental effects on semi-arid and arid regions worldwide, including the Konya Closed and Burdur Basins [32,33]. The uncontrolled use of water for irrigation in the basins, leading to water abstractions, poses one of the primary threats to endemic fish species, irrespective of the impact of climate change. Water abstraction effects directly impact the winners and losers identified in this study. Therefore, species identified as losers may actually lose their predicted climatically suitable distribution areas more rapidly than predicted by the SDM. Furthermore, the species identified as winners may not attain the predicted gains and may potentially become losers if the water management strategy is not changed in the direction of a more sustainable use of water. Thus, our predictions based on the SDM may only be used to provide a conservative prediction of the future for these endemic freshwater fish species.

5. Conclusions

The Central Anatolian Ecoregion (CAE) is expected to experience increased temperature and decreased precipitation due to climate change, which is similar to other arid and semi-arid regions globally [103]. These changes and extensive land and water use in the region are likely to profoundly impact the flow regimes of freshwater systems, making the freshwater fauna highly vulnerable [18]. Our analyses identified 8 out of 16 analysed species in the CAE that will experience a loss of suitable habitats under climate change, making them highly vulnerable. By the end of this century, four of these species are projected to lose their climatically suitable habitats entirely. Moreover, human activities, including but not limited to the destruction of habitats, availability of surface water, and an increase in water usage, are expected to exacerbate the adverse effects of climate change in the upcoming decades. It is plausible that the unconsidered variables in our study could potentially influence the outcomes of this study. Consequently, our findings may underestimate the negative impacts of climate change.

The CAE endemic freshwater fish fauna is currently facing a high level of threat, with 65% of endemic species considered threatened or nearly threatened by the IUCN Red List, and two species are already extinct. Climate change is expected to exacerbate the effects of other anthropogenic stressors, such as water abstraction, irrigation, pollution, the introduction of invasive species, and dam construction, particularly in semi-arid and arid areas and, more specifically, in the CAE, where fish communities are already under extreme pressure. The results of this study indicate that protection of the CAE water resources is essential for preserving the endemic freshwater fish fauna in Türkiye.

In order to preserve freshwater fish populations, appropriate conservation measures need to be implemented. A policy framework is urgently needed to restrict the exploitation of water resources to sustainable limits while simultaneously promoting conservation efforts to reverse ecosystem degradation or maintain current conditions. In this context, a better understanding of the response of endemic fish species to the combined effect of changes in climate and other stressors is needed. Regular monitoring of all freshwater ecosystems in the CAE is recommended, as well as protection of the region from other anthropogenic stressors to effectively conserve freshwater fishes under climate change. Regular monitoring programs can detect the presence of new species or the absence of previously recorded species, track changes in species distribution, richness, and composition, and support conservation planning for freshwater fishes in the face of climate change.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w15081619/s1, Figure S1: Current and future distribution of *Anatolichthys anatoliae*, *Anatolichthys iconii*, *Chondrostoma beysehirense*, and *Capoeta pestai* in the CAE. Colours show habitat suitability, and the value of suitability increases in red areas; Figure S2: Current and future distribution of *Oxynoemacheilus nasreddini*, *Pseudophoxinus anatolicus*, *Pseudophoxinus crassus*, and *Squalius recurvirostris* in the CAE. Colours show habitat suitability, and the value of suitability increases in red areas; Table S1: Endemic fish fauna of the Central Anatolian Ecoregion and their IUCN conservation status; Table S2: The environmental predictors used in the SDM with their variance inflation factors (VIF) after the exclusion of collinear variables. References [104–111] are cited in the supplementary materials.

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