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RESEARCH ARTICLE

Climatic envelopes of the genus *Lacerta* Linnaeus, 1758 in Türkiye: an application of ecological niche modeling

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Abstract
Six species belonging to the genus *Lacerta* live in Türkiye. In this study, both present and future potential distribution maps were created based on occurrence data and climatic variables for these six species. Two scenarios for future projections (shared socioeconomic pathways, SSPs,: 245 and 585) and two timeframes (2041–2060 and 2081–2100) were used. The present and future potential distributions of these species were compared. As a result, it was predicted that the distribution ranges in the six species will expand in the future, and this expansion has revealed new environments.

Keywords Bioclimate · Climate change · Ecological niche modeling · Reptiles · Wallace

Introduction

Due to the dramatically changing climate, biodiversity on a global scale is under threat (Araújo and Rahbek 2006). Some organisms track shifts in morphology and behavior related to dispersal or migration due to preferred microclimates, and some may physiologically tolerate changing conditions (Sears and Angilletta 2011). In fact, the distribution, behavior, physiology, and phenology of most animal and plant species can shift significantly due to changing climate. Moreover, many species that cannot adapt to these changes may show a tendency for local extinction (Pereira et al. 2010; Vaissi 2022). In the case of cold-blooded living things, especially lizards living in temperate zones like Türkiye, they are considered to be quite vulnerable to climate change (Moreno-Rueda et al. 2012).

Ecological niche modeling (ENM) is a powerful tool to interpret the spatial patterns and shifts in the distribution of organisms in past, present, and future in changing climates (Peterson et al. 2011), and is an empirical and quantitative model of the relationship between species and the environment usually using species occurrence data and the environmental variables considered to affect species distribution (Elith and Franklin 2013). Now, there are many types of ENM software available. For instance, MAXENT (Phillips et al. 2006), the java software based on maximum entropy algorithm, GARP (Stockwell and Peters 1999) that studies with presence-absence data, and GLM (Guisan et al. 2002) that studies with graphical user interface (GUI) software, are some of them. Also, the R language provides most packages: DOMAIN (Carpenter et al. 1993), BIOMOD (Thuiller et al. 2009), and BIOCLIM (Booth et al. 2014) that provide presence-only modelling algorithms and integrate several modelling tools. In addition, random forest (Breiman 2001)

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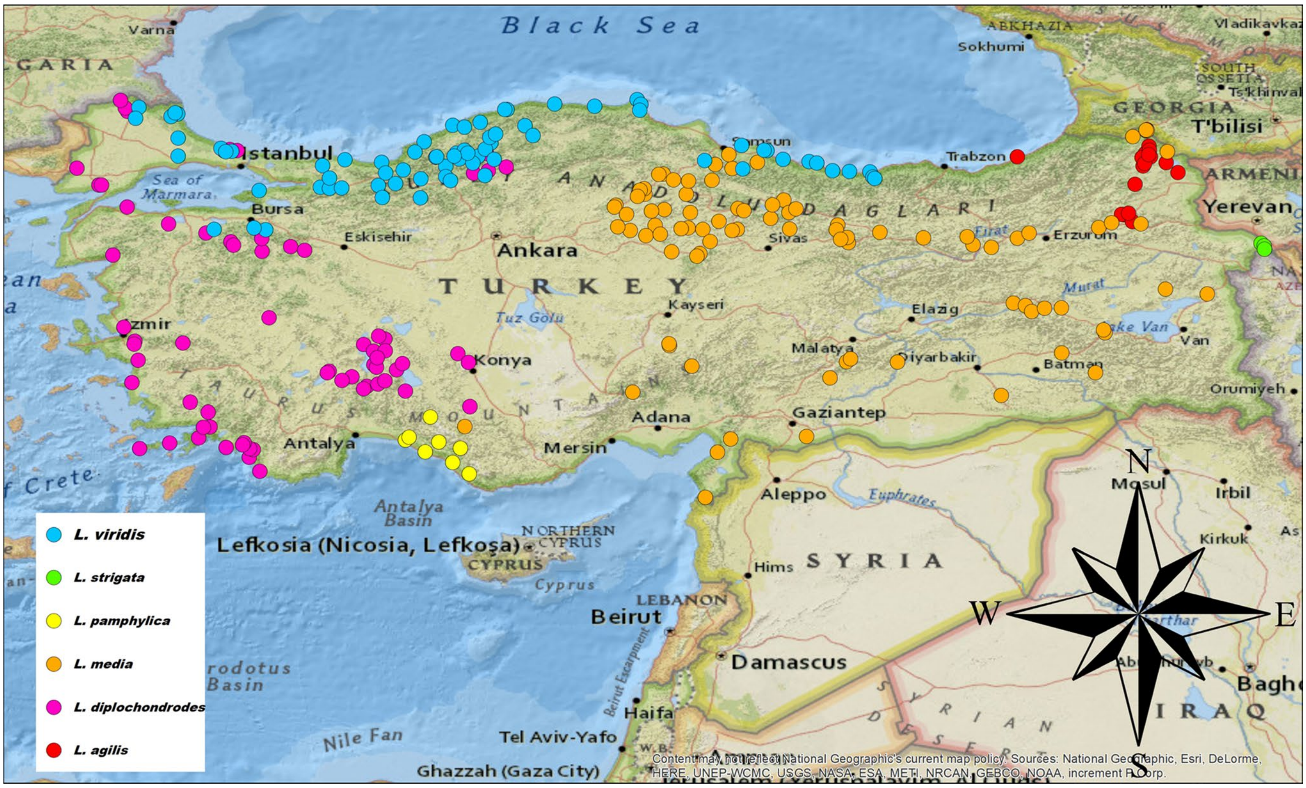

Fig. 1 Distribution patterns and occurrence records of species of the genus *Lacerta* in Türkiye

that provides several ensemble forecasting models is a package within the R software (Sillero et al. 2023). Recently, a modular platform called "Wallace" for ENM applications in ecology and the environmental sciences was developed by Kass et al. (2018). "Wallace," which is flexible, highly interactive, and user-friendly, is an open and modular application with a richly documented graphical user interface with underlying R scripts. "Wallace" provides an integrated ENM from model evaluation to visualization (Kass et al. 2018, 2023). Also, it enables the modeling and simulations using bioclimatic layers to assess the effect of changes in climate on the distribution of species (Kass et al. 2018, 2023).

The genus *Lacerta* linnaeus 1758 a member of the family Lacertidae known as true lacertid lizards, consists of ten species; some of which are endemic (*L. citrovittata* Werner 1938, *L. pamphylica* Schmidtler 1975, and L. schreiberi Bedriaga 1878), and the geographic distribution of the genus *Lacerta* covers widely the Palearctic region, including Europe, Central Asia, and the Middle East (Arnold et al. 2007; Ahmadzadeh et al. 2013; Kornilios et al. 2020). Six species of the genus *Lacerta* live in Türkiye, e.g., *Lacerta agilis* (Linnaeus 1758), *L. viridis* (Laurenti 1768), *L. strigata* (Eichwald 1831), *L. media* (Lantz and Cyren 1920), *L. diplochondrodes* (Wettstein

Table 1 The models calculate the results of Wallace package. FC, feature classes (H, hinge; L, linear; Q, quadratic; P, product); RM, regularization multiplier; delta. AICc and AICc: Akaike information criterion corrected

Species	FC	RM	Auc. train	AICc	Delta AICc
L. agilis	L	1	0.8025	152.227	0
L. diplochondrodes	H	2.5	0.6868	1010.086	0
L. viridis	LQHP	3	0.7923	1033.189	0
L. media	LQHP	2	0.7910	1428.512	0
L. pamphylica	LQH	2.5	0.6769	104.6954	0
L. strigata	LQHP	3.5	0.7284	76.47181	0

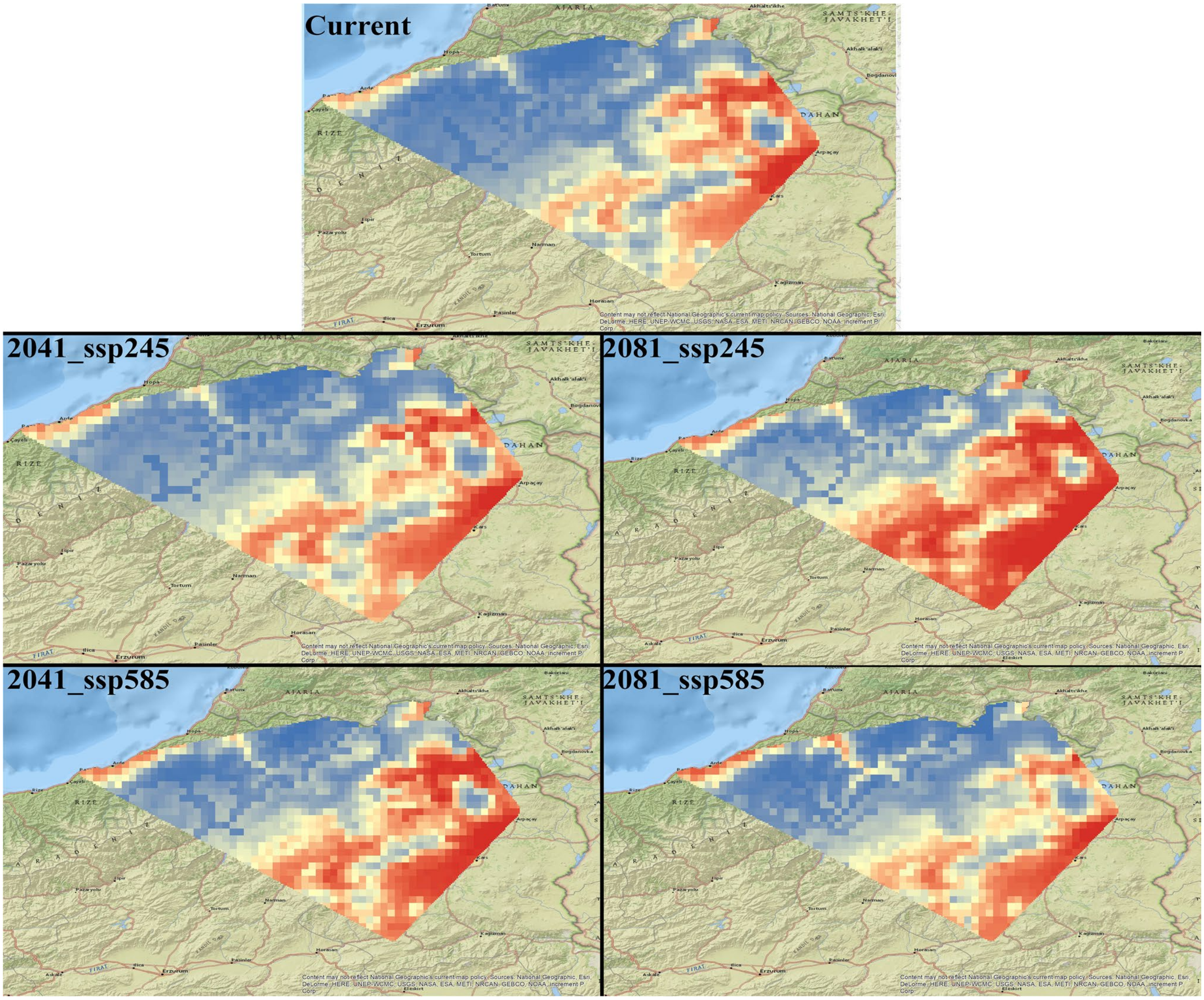

Fig. 2 Potential distribution of *L. agilis* under both current and future climatic scenarios in Türkiye. The warm colors indicate the most suitable areas

1952), and *L. pamphylica* (Schmidtler 1975). The distribution of *L. agilis* reaches Kars, Ardahan, Erzurum, Trabzon, Rize, and Artvin provinces in Türkiye. On the other hand, *L. diplochondrod* is across western, northwestern, and central Anatolia, as well the southeastern coast of Türkiye. In contrast, *L. media* shows its distribution in a major part of central Anatolia, and northeastern, southeastern, and eastern Anatolia. *L. pamphylica* is an Anatolian endemic species that is restricted to the south slope of the Toros Mountains in the Mediterranean region. Although *L. strigata* indicates the limited distribution around the mountain of Ağrı in Iğdır provinces, it is an not endemic species. As for *L. viridis*, its distribution ranges across the Black Sea coast from Giresun province to the Trachea region (Baran et al. 2021). We chose these species because (1) their movements are restricted, (2) some species have large distribution and some have narrow distribution, and (3) they are vulnerable to climate change.

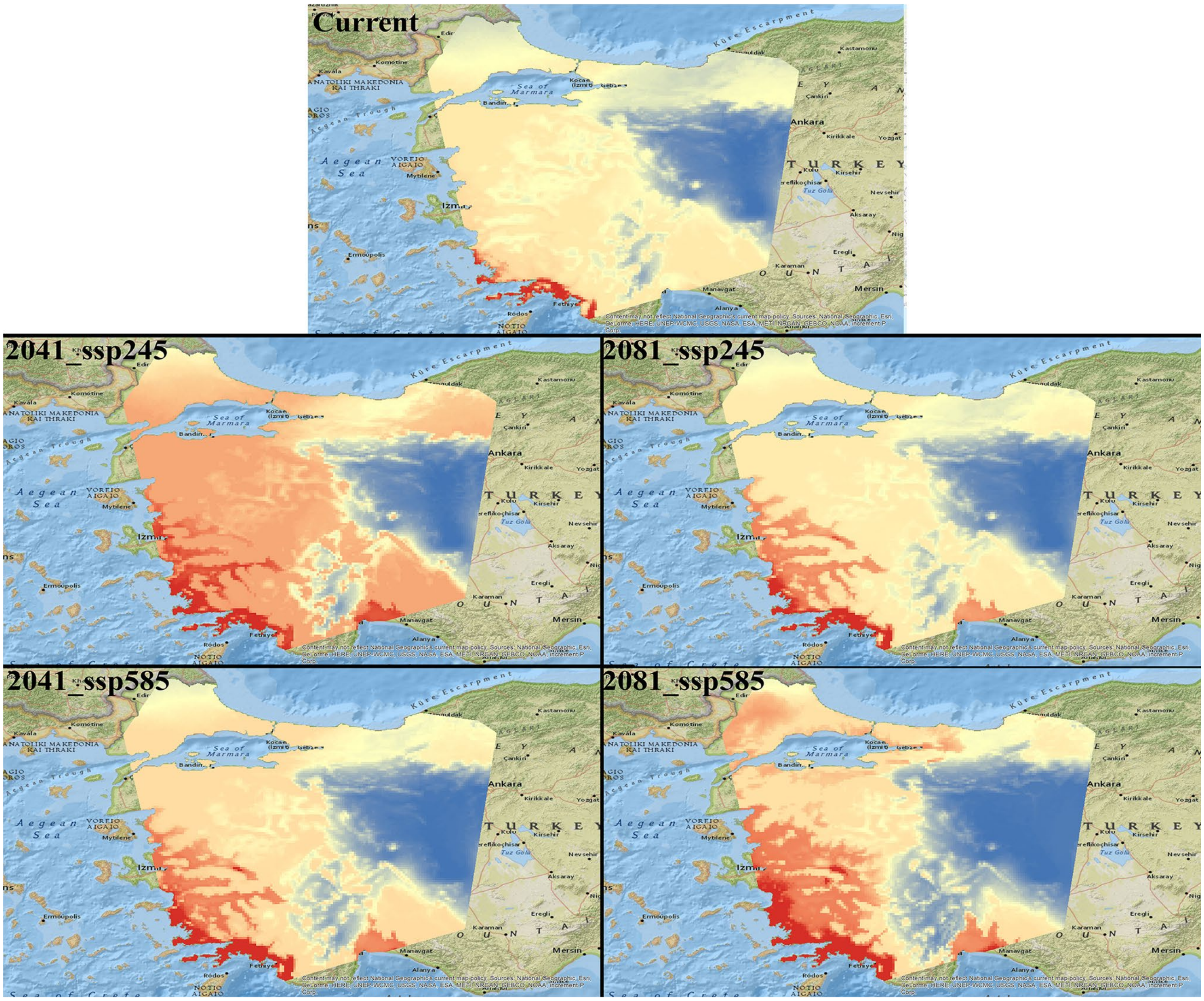

Fig. 3 Potential distribution of *L. diplochondrodes* under both current and future climatic scenarios in Türkiye. The warm colors indicate the most suitable areas

Here, we evaluate the potential effects of changes in climate on species of the genus *Lacerta* in Türkiye using ENM. For this, we project a global climate model and two representative concentration pathways. Thus, for the first time, the potential distribution patterns of species belonging to the genus *Lacerta* across Türkiye due to the changing climate are revealed. It is expected that the results will be used in conservation activities on local scale.

Material and methods

Species occurrence data

The species studied have different conservation status, and according to the Red List (IUCN 2023), many of these species are least concern category (*L. agilis*, *L. viridis*, *L. media*, and *L. pamphylica*), but *L. diplochondrodes* species does not have conservation status

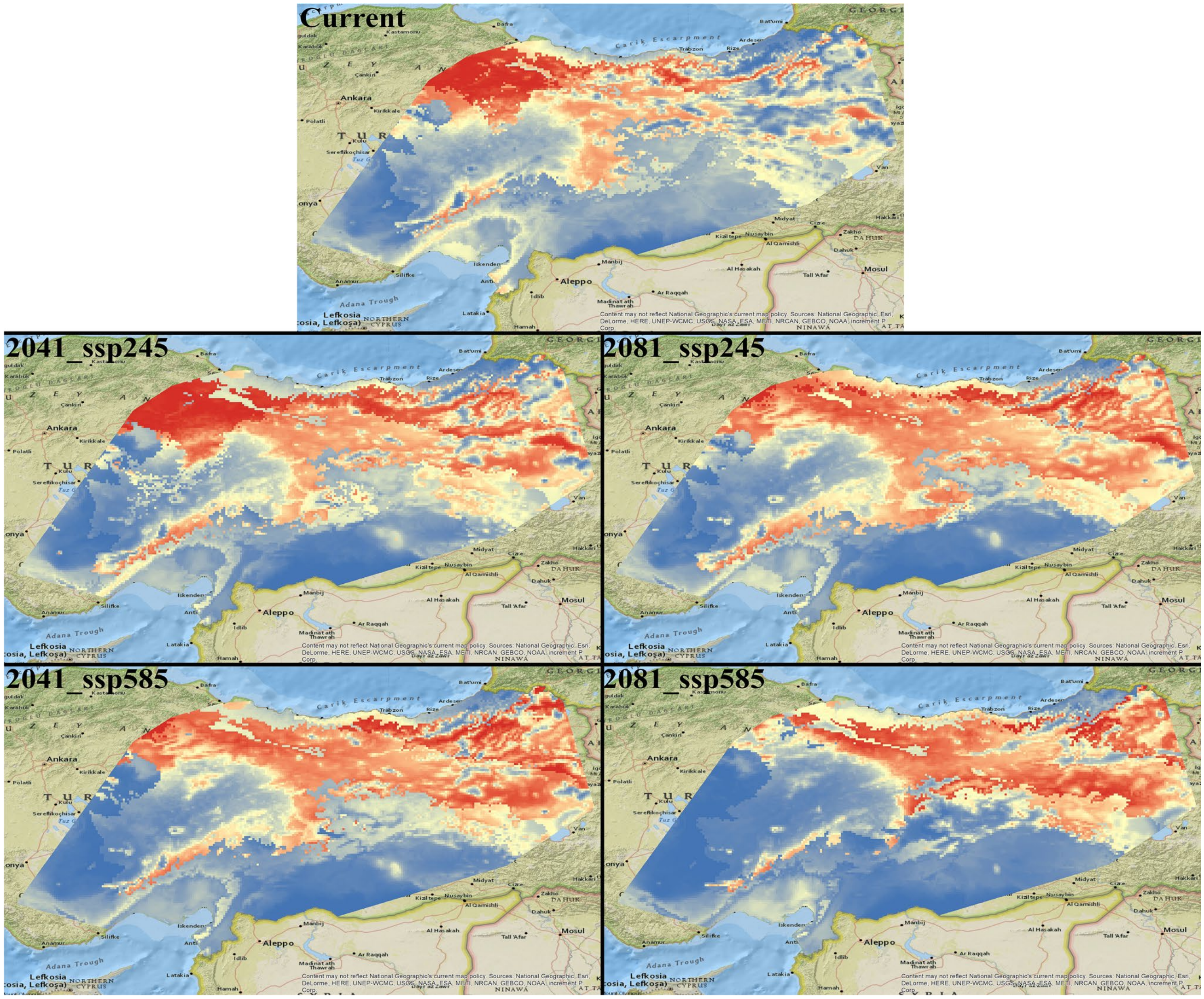

Fig. 4 Potential distribution of *L. media* under both current and future climatic scenarios in Türkiye. The warm colors indicate the most suitable areas

yet. Occurrence data were collected from the fieldwork between years 2005 and 2015 (Fig. 1, Supplementary materials Table S1). To reduce the effects of biased sampling, 1 km was used as thinning distance. Total sampling records were used: 18, 65, 74, and 87 for *L. agilis*, *L. diplochondrodes*, *L. viridis*, and *L. media*, respectively. However, the thinning was not done for small sampling records, and 8 and 3 records were used for *L. pamphylica* and *L. strigata*, respectively (Hernandez et al. 2006).

Climatic variables

Bioclimatic variables were downloaded from WorldClimv2.1 (Fick and Hijmans 2017) at a spatial resolution of 2.5 min. These nineteen variables cover the average for the years 1970–2000. First, these nineteen variables were masked for Türkiye using the “spatial analyst” feature in ArcGIS v10.4.1; then, the variables with a correlation of higher than 0.75 (Vaissi 2021a,b) were removed using SDM toolbox v2.5 (Brown et al. 2017)

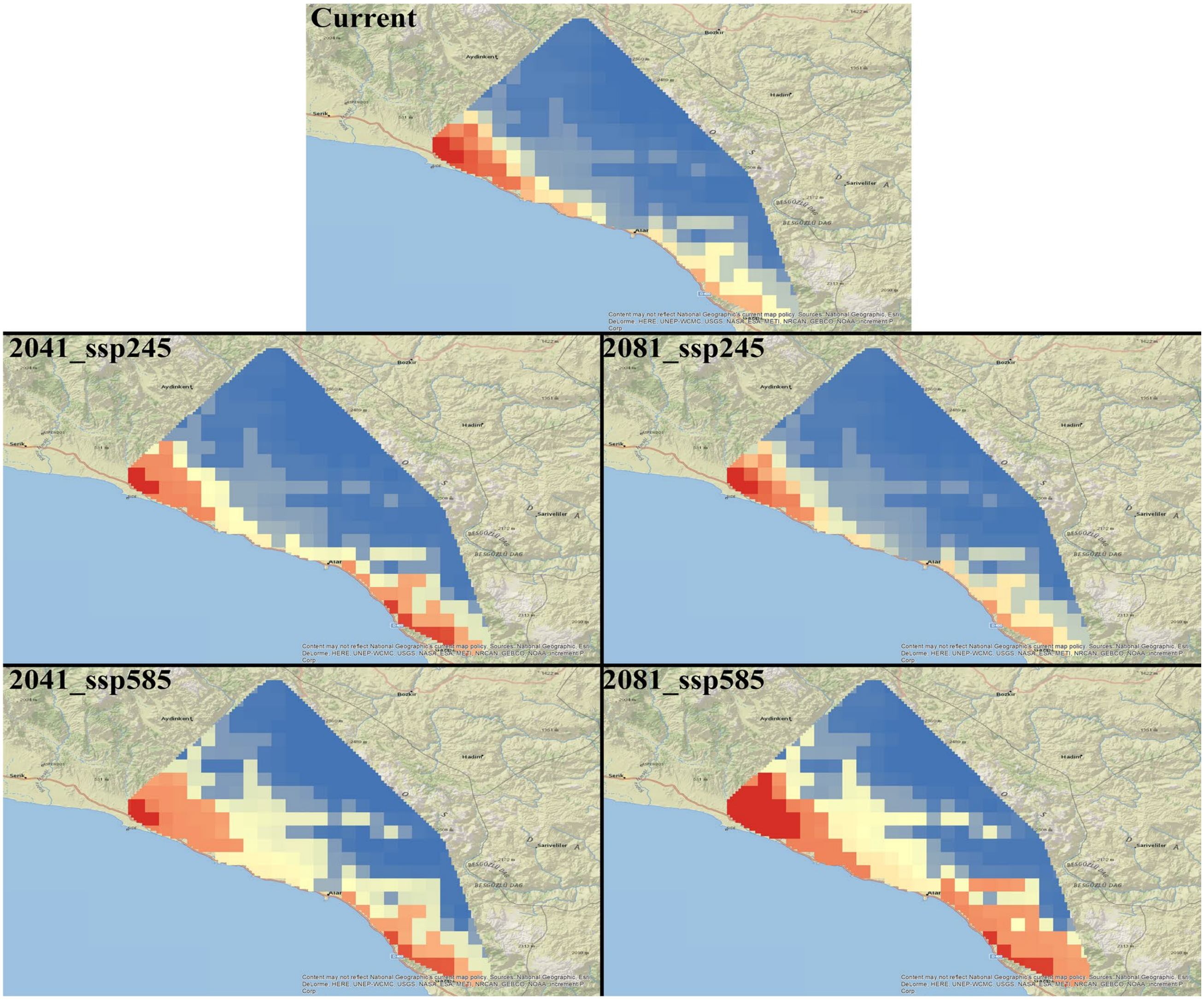

Fig. 5 Potential distribution of *L. pamphylica* under both current and future climatic scenarios in Türkiye. The warm colors indicate the most suitable areas

(Supplementary materials Fig. S1). Finally, eight variables remained and were used to run all analyses: annual mean temperature (bio1), mean diurnal range (mean of monthly max temp-min temp) (bio2), isothermality (bio2/bio7) (× 100) (bio3), temperature seasonality (standard deviation × 100) (bio4), mean temperature of wettest quarter (bio8), annual precipitation (bio12), precipitation of driest month (bio14), and precipitation seasonality (coefficient of variation) (bio15). For future projections, the CMIP6 climate projections from one global climate model (GCMs) (BCC-CSM2-MR), which is a strong predictor of both temperature and precipitation variables in Asia for two shared socioeconomic pathways (SSPs), were downloaded in the GeoTIFF format. SSP245 pathway is a projection to rise by 2°C in 2041–206 and 2.7 C in 2081–2100. On the contrary, SSP585 is a projection that predicts to rise between 2.4 and 4.4°C (IPCC 2021). These pathways were used for all future analyses.

Model calibration

A study region for each species has been delimited in the extent buffered by 0.01° using a minimum convex polygon. Thus, environmental data were masked within

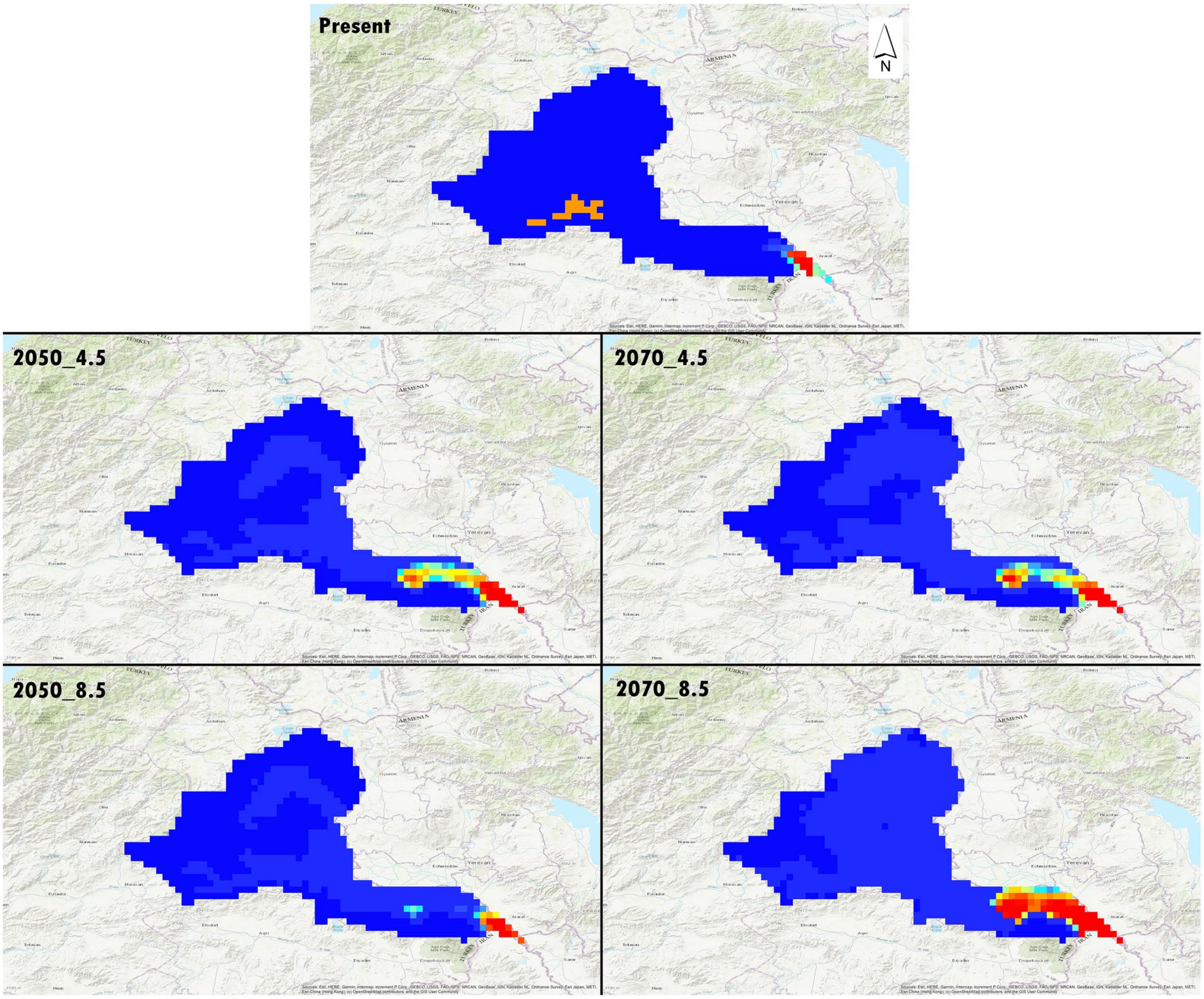

Fig. 6 Potential distribution of *L. strigata* under both current and future climatic scenarios in Türkiye. The warm colors indicate the most suitable areas

the region, and random background points were sampled ($n = 10{,}000$). As small data sets from < 25, we chose the $n - 1$ jackknife method of k-*fold* cross-validation that each of n occurrence localities is used for testing once, whereas all others are used for training in that iteration (Pearson et al. 2007; Shcheglovitova and Anderson 2013; Muscarella et al. 2014). As for 25 > , the checkerboard 2 method with aggregation factor 4 was used (Muscarella et al. 2014).To build and evaluate the niche model, the algorithms were selected to conduct using modeled response flexibility (L, LQ, H, LQH, and LQHP) and penalty against complexity (0.5254.5) by 0.5-multiplier step value. Thus, Maxent based on the presence-background algorithm was successfully run and created evaluation results for 45 clamped models of each species. The best model between these models was selected based on the lowest AICc and delta AICc value (Table 1). Later, according to these models, Maxent v.3.4.4 (Phillips et al. 2017) as 30 replicates was run separately for every species. The analysis also identified the bioclimatic variables that best contribute to the future distribution of each species (Supplementary materials Fig. S2–7).

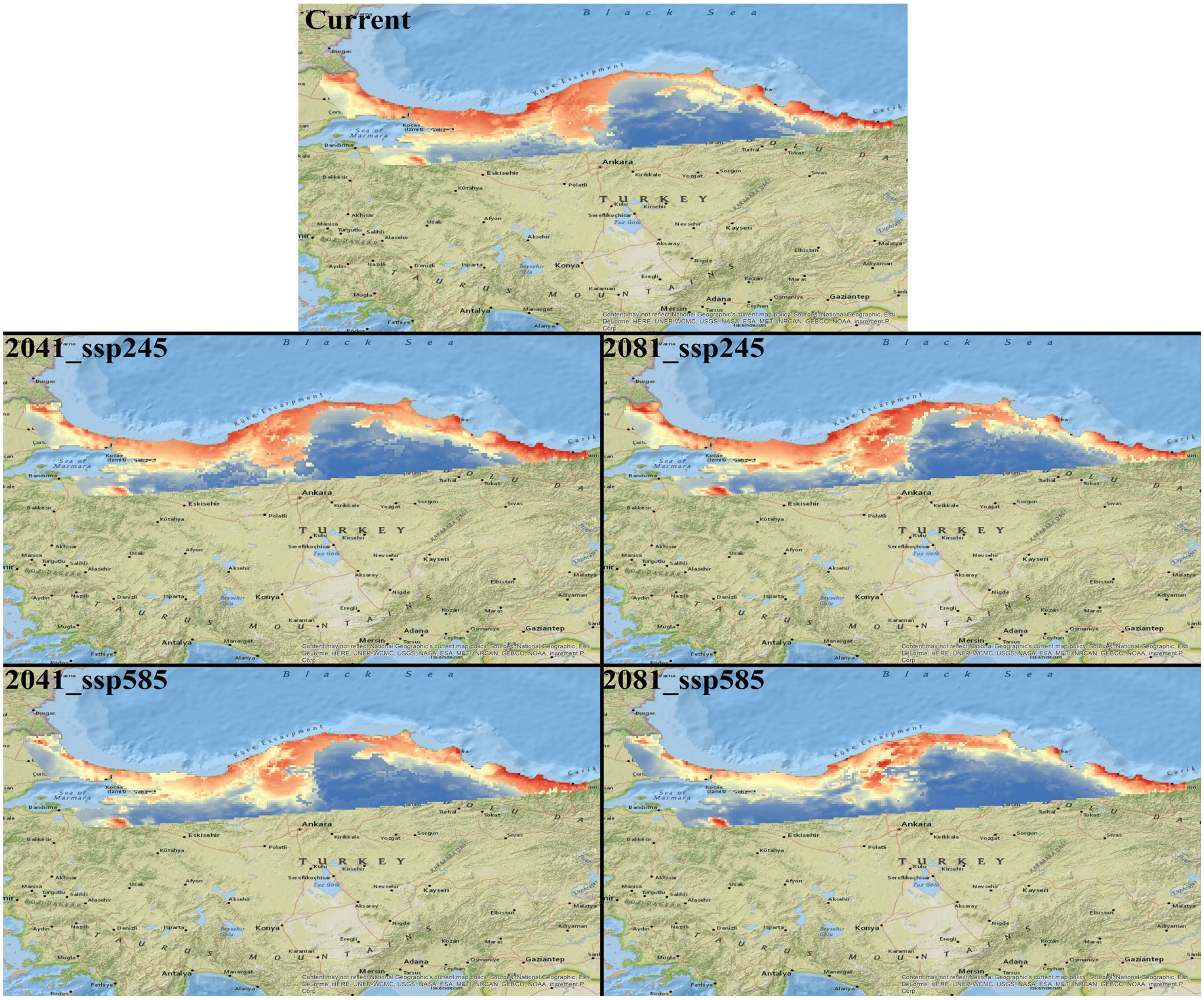

Fig. 7 Potential distribution of *L. viridis* under both current and future climatic scenarios in Türkiye. The warm colors indicate the most suitable areas

We also performed the multivariate environmental similarity surface (MESS) analysis. This analysis calculates the similarity using training data and future climatic layers and thus shows the degree of environmental change. When MESS has a smaller and positive value, it indicates the importance of climatic difference, but when MESS has a negative value, it points out that at least one variable has a value that is outside the range and this is a novel environment (Elith et al. 2010). In other words, positive values of MESS suggest analog (similar) climatic conditions whereas negative values of MESS suggest non-analogue (dissimilar) climatic conditions (Montagnani et al. 2022).

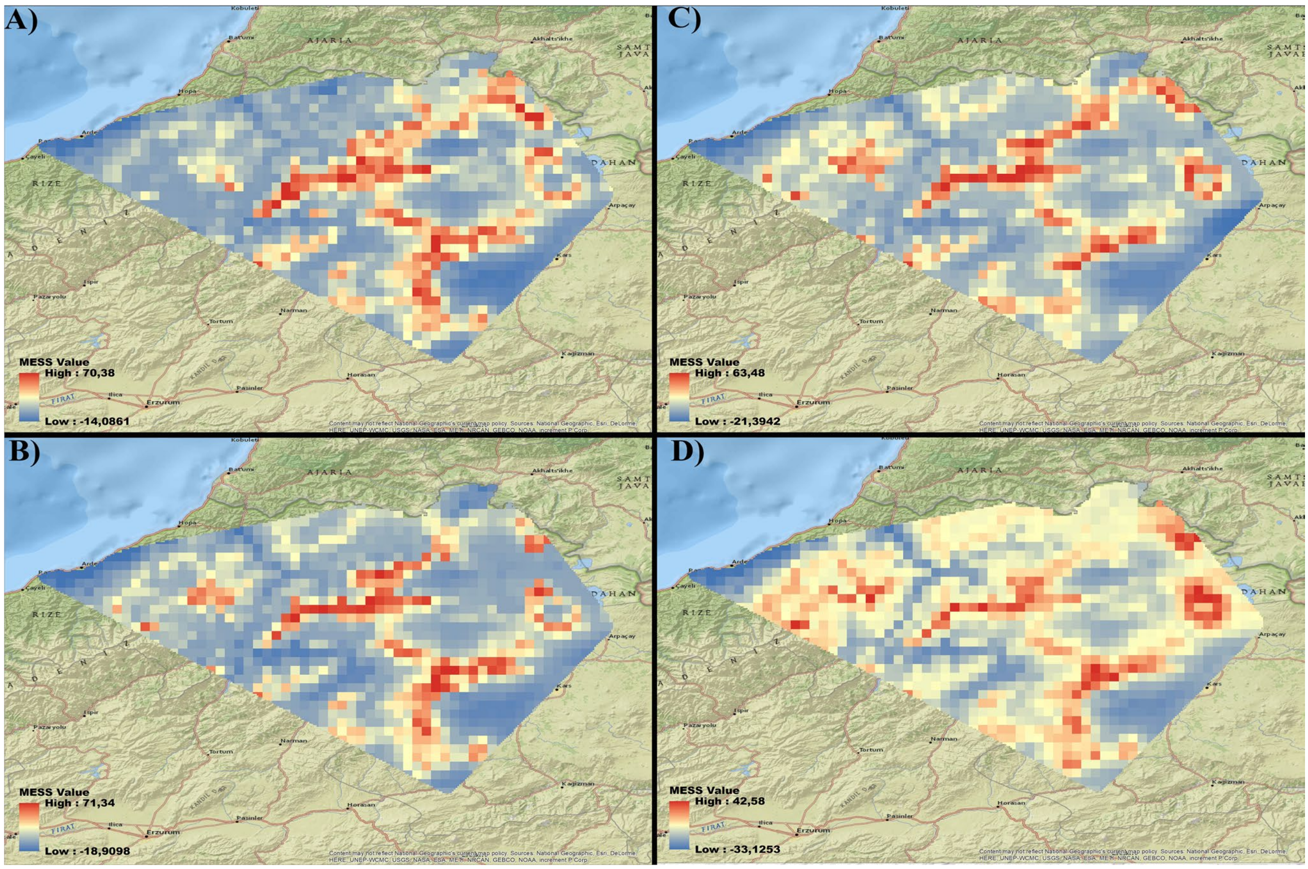

Fig. 8 The multivariate environmental similarity surface (MESS) of the potential area for *L. agilis* under the future projection scenarios. Warm colors show novel environment areas. **A** SSP245 in 2041, **B** SSP585 in 2041, **C** SSP245 in 2081, and **D** SSP585 in 2081

Results

Evaluation and selection of the best model for ecological niche modeling

For each *Lacerta* species, 45 models that have different regularization multiplier and feature class were generated. For *L. agilis*, from these models, it was the best model that uses "L" feature class along with a regularization multiplier of 1 (rm.1_fc.L), and with the lowest delta.AICc. The average test AUC for the replicate runs was 0.734 for *L. agilis*. The model for *L. diplochondrodes* was the one that uses "H" feature class along with a regularization multiplier of 2.5 (rm.2.5_fc.H). Train_AUC was 0.62 for this species. For *L. media*, train_AUC was 0.761 and had "L, Q, H, and P" feature classes with a regularization multiplier of 2 (rm.2_fc.LQHP). In *L. pamphylica*, train.AUC that has "L, Q, and H" feature classes with a regularization multiplier of 2.5 was 0.625 (rm.2.5_fc.LQH). Train_AUC and regularization multiplier of *L. strigata* were 0.73 and 3.5, and it had "L, Q, H, and P" feature classes (rm.3.5_fc.LQHP). For *L. viridis*, train_AUC based on "L, Q, H and P" feature classes with a regularization multiplier

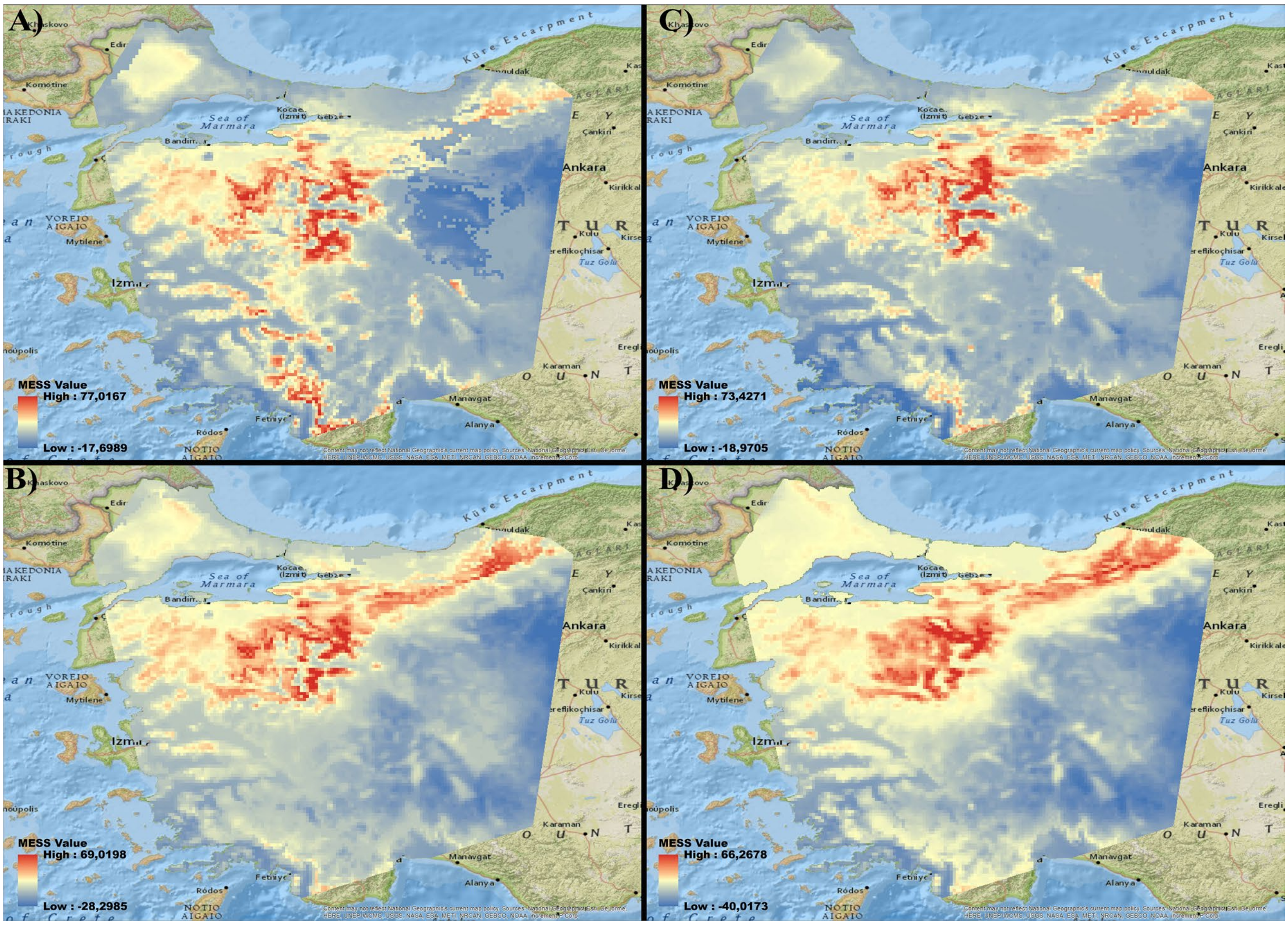

Fig. 9 The multivariate environmental similarity surface (MESS) of the potential area for *L. diplochondrodes* under the future projection scenarios. Warm colors show novel environment areas. **A** SSP245 in 2041, **B** SSP585 in 2041, **C** SSP245 in 2081, and **D** SSP585 in 2081

of 3 was 0.748 (Table 1). The most important variables were precipitation seasonality (bio15) for *L. agilis*, annual precipitation (bio12) and precipitation seasonality (bio15) for *L. diplochondrodes*, annual mean temperature (bio1), mean temperature of the wettest quarter (bio8), annual precipitation (bio12), and precipitation of driest month (bio14) for *L. media*, precipitation of driest month (bio14), annual precipitation (bio12), and annual mean temperature (bio1) for *L. pamphylica*, mean temperature of the wettest quarter (bio8) and annual precipitation (bio12) for *L. strigata*, and annual precipitation (bio12) for *L. viridis* (Figs. S2–7).

Present and future distribution patterns of genus *Lacerta*

Within minimum convex polygon, the present ecological niche model emphasized areas of high suitability in the east region for *L. agilis*. Although there are similar patterns in the future distributions, the highest relevance will be seen in the ssp245 scenario in 2081, while the lowest relevance is projected to occur in the ssp585 scenario in 2081 (Fig. 2). In *L. diplochondrodes*, Central Anatolian regions were unsuitable, while the southern coastal areas were the most suitable. This remained the

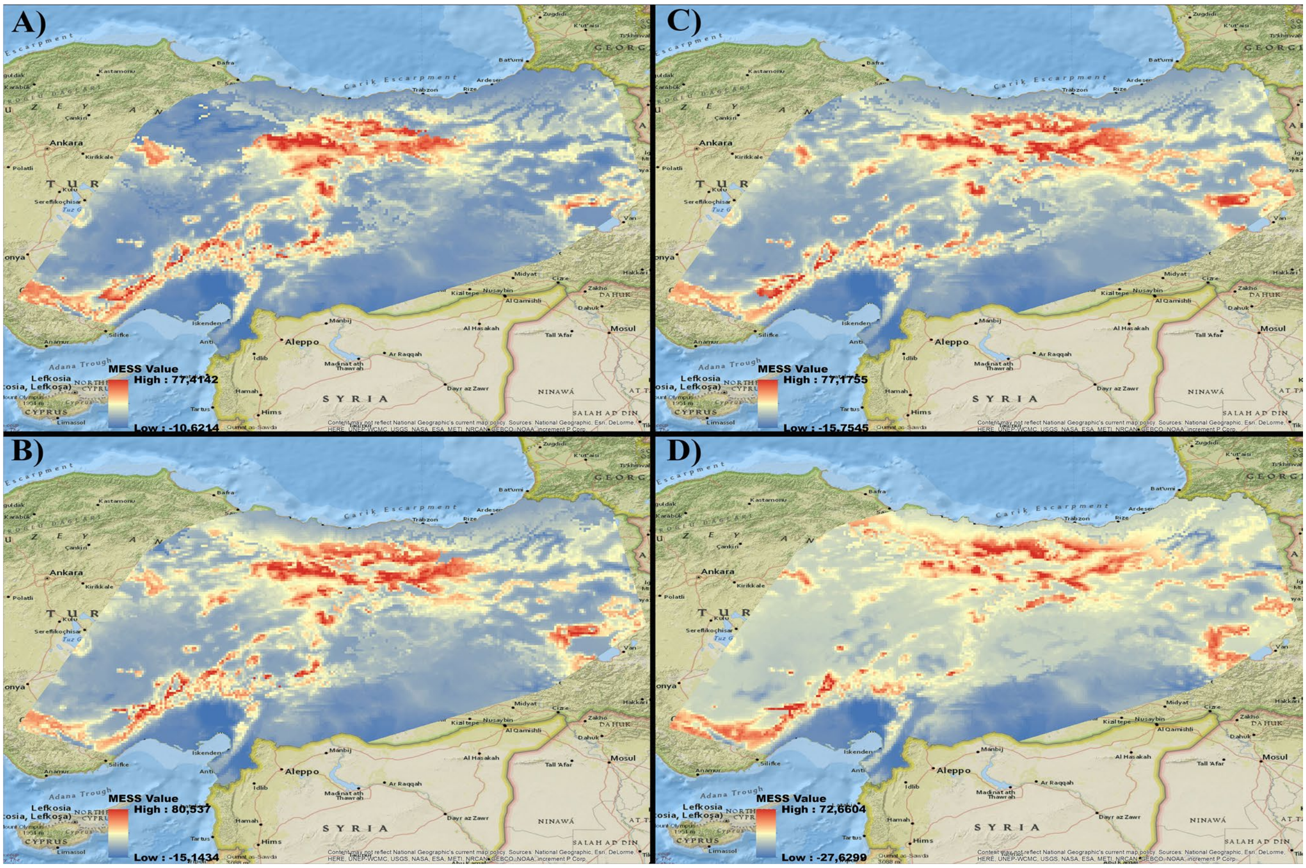

Fig. 10 The multivariate environmental similarity surface (MESS) of the potential area for *L. media* under the future projection scenarios. Warm colors show novel environment areas. **A** SSP245 in 2041, **B** SSP585 in 2041, **C** SSP245 in 2081, and **D** SSP585 in 2081

same in all future distributions and only unsuitable areas increased in Central Anatolia. In addition, favorable climatic environments are projected to increase in all future scenarios (Fig. 3). For *L. media*, the middle Black Sea regions were most favorable and the other parts showed partial eligibility. However, in all future scenarios, this favorable environment will probably appear in both the middle Black Sea and eastern areas of the polygon (Fig. 4). *L. pamphylica* has a narrow distribution; the west and southeast parts of the coastal areas were the best suitable. This status remained the same in all future dispersal, but the scenario in the ssp585 scenario in 2081 showed the most suitable areas across all coastal parts (Fig. 5). Likewise, the southeastern region was the most favorable for *L. strigata*. This was the case in all areas of future distribution patterns (Fig. 6). For *L. viridis*, the Black Sea coastal parts indicated the best suitable areas and this remained the same in all future scenarios. However, these suitable areas is projected to reduce in both 2041 and 2081 of the ssp585 scenario (Fig. 7).

Multivariate environmental similarity surface analysis

Under the future projection scenarios, dissimilar climatic conditions in all distribution areas of species are available in general (Figs. 8, 9, 10, 11, 12, and 13). When they are compared with the future distribution area under the

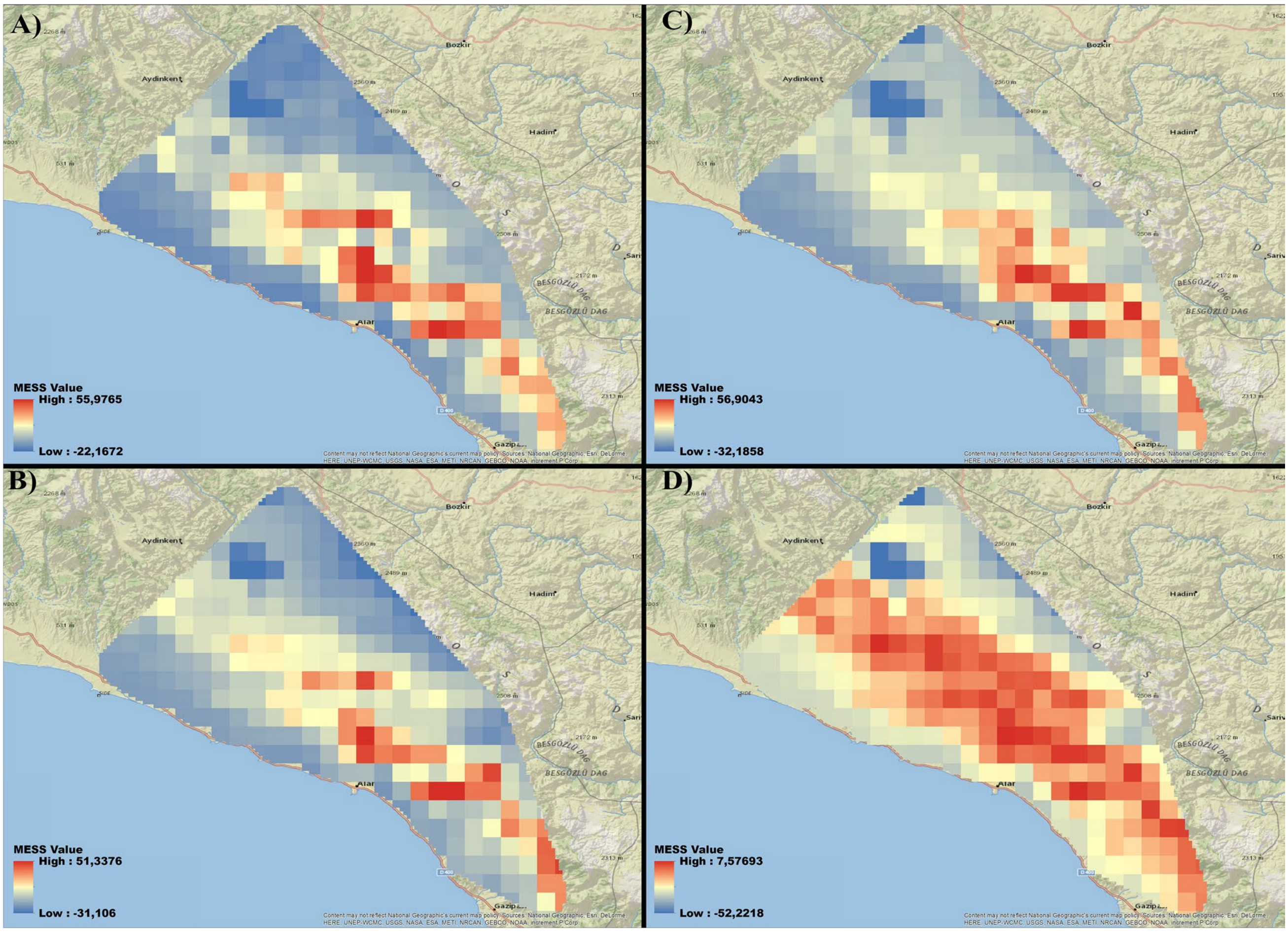

Fig. 11 The multivariate environmental similarity surface (MESS) of the potential area for *L. pamphylica* under the future projection scenarios. Warm colors show novel environment areas. **A** SSP245 in 2041, **B** SSP585 in 2041, **C** SSP245 in 2081, and **D** SSP585 in 2081

same future projection scenarios and time periods, the suitable potential areas of *Lacerta* species are predicted in dissimilar climatic conditions.

Discussion

Climate change affects all components of biodiversity from organism to biome and is an important threat to biodiversity (Bellard et al. 2012). Therefore, adaptation to climate change in the near future will require vertebrates to change their climatic niche at an unprecedented rate (Quintero and Wiens 2013). In this context, we investigate how six lacertid species respond to the expected climate change using ecological niche modeling. Overall, our results predict an increase in suitable habitats for these six species under future climatic conditions. However, while this may seem positive for these species, it may also be negative because reptiles that have an intermediate ability to move are influenced by the change in climate (Bozkurt 2022). Therefore, in the future, species' range can shift, but this movement might be very slow (Vaissi 2022) such that from 1940 to 2005, Spanish reptiles had been able to move 32.5 km (Moreno-Rueda et al. 2012). It is a known fact that if warming trends continue because of climate change, then the species in the lowland habitats will be forced to migrate to higher elevations to find the most optimal

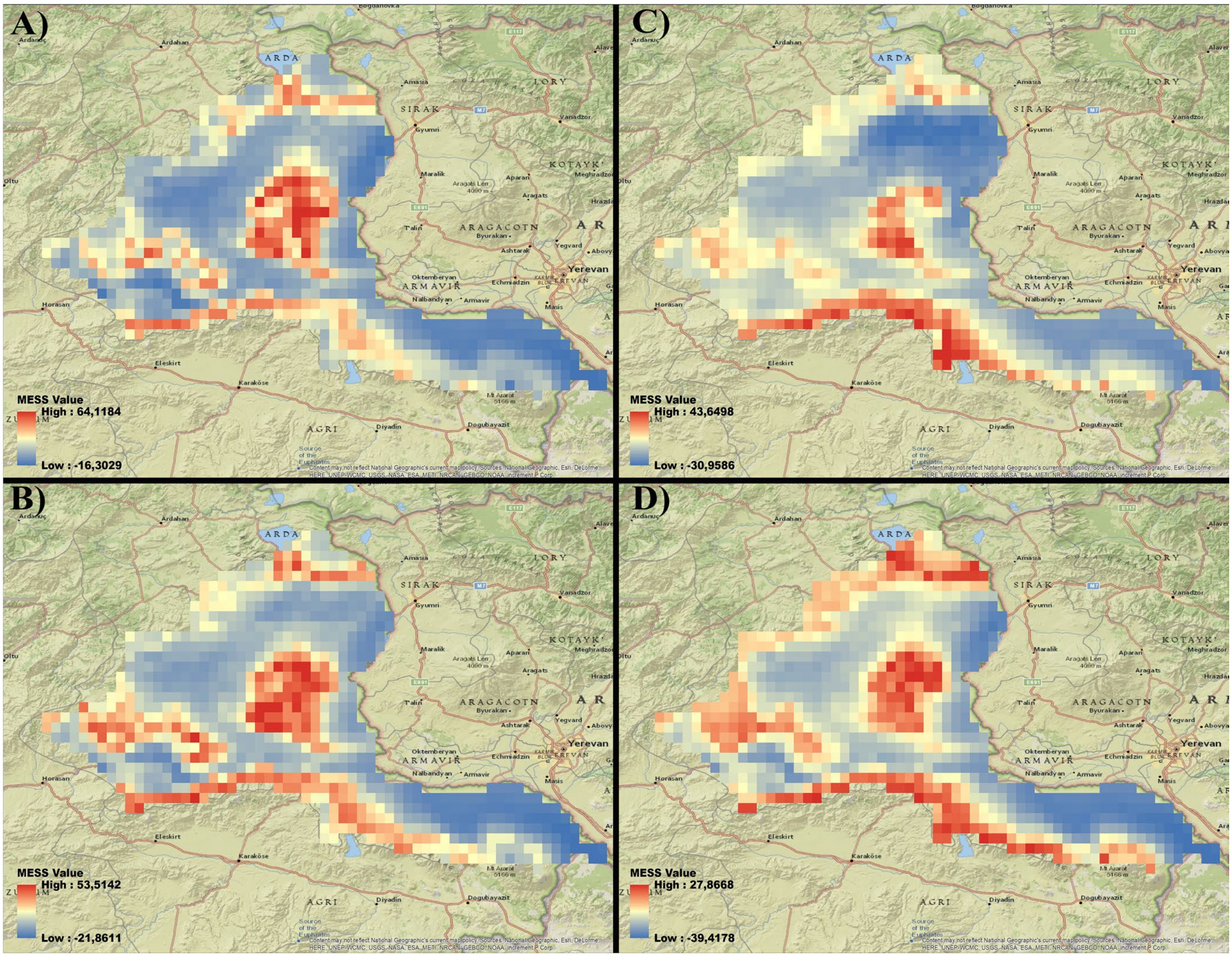

Fig. 12 The multivariate environmental similarity surface (MESS) of the potential area for *L. strigata* under the future projection scenarios. Warm colors show novel environment areas. **A** SSP245 in 2041, **B** SSP585 in 2041, **C** SSP245 in 2081, and **D** SSP585 in 2081

conditions; however, the species that do not achieve this might meet the risks of extinction (Dayananda et al. 2021).That is why the rapid decline and local extirpations of many lizards populations as a consequence of change in climate might happen (Laspiur et al. 2021).

Generally, species close to each other can give similar responses to environmental conditions (Vaissi 2022). Although five of the studied species are widely distributed, *L. pamphylica*, an endemic species, has a narrow distribution. This species occupies a small area in the southwestern Taurus between 0 and 1078 m altitude (Bülbül et al. 2022), but its future range has higher probability of persistence than the current. For a lizard species that exists in a limited area of 2 square kilometers, suitable habitats were similarly found to exist in future climatic conditions (Laspiur et al. 2021). It is seen that there will be expansions in the suitable habitats of almost all of the species we have studied here. Vaissi (2022) reported a similar pattern in *Phrynocephalus maculates* Anderson 1872 and *P. persicus* De Filippi 1863 that will have the potential to expand their distribution range as a result of climate change in future years. Additionally, Gómez-Cruz et al. (2021) showed

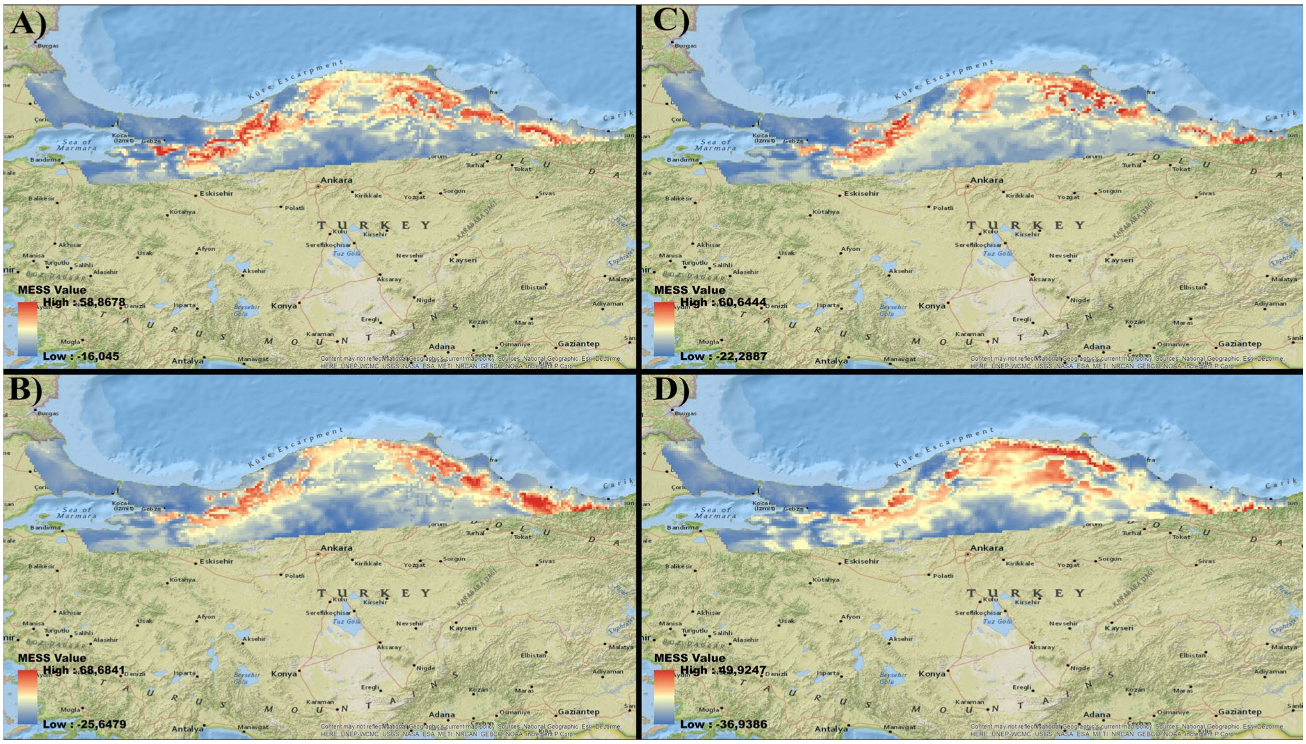

Fig. 13 The multivariate environmental similarity surface (MESS) of the potential area for *L. viridis* under the future projection scenarios. Warm colors show novel environment areas. **A** SSP245 in 2041, **B** SSP585 in 2041, **C** SSP245 in 2081, and **D** SSP585 in 2081

that there was a substantial increase in the distribution range of *Heloderma alvarezi* Bogert and Martin Del Campo 1956 in 2070 according to future projections. In fact, climatic conditions affect the behavior of living things and their habitat selection. This can be positive or negative. Our study shows that the distribution range of the species will expand in future projections. Also, it is predicted that novel environments will be formed for the species belonging to the genus *Lacerta* in future climate scenarios. However, the process of moving and adapting to new environments for these species cannot be predicted because the adaptation process to changes in climate is substantially slow and the ability to resist these changes is restricted (Foden et al. 2007).

Consequently, it is predicted that there is a general expansion in the suitable habitats of species belonging to the genus *Lacerta* due to climate change. However, if the ability of species to move and reach these areas with suitable habitat is limited, it is obvious that this situation will be negative, especially for species with narrow distribution areas. Our study also serves as a recommendation for the assessment of the current status on the IUCN red list. This is particularly important for the identification of protected areas in terms of suitable habitats for the narrowly distributed *L. pamphylica* species. In addition, the conservation status of *L. diplochondrodes*, which is not yet included in any category in the IUCN red list in terms of climatic characteristics, is expected to provide an idea for the evaluation of suitable habitats.

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Author contribution SG, YK, ÇI, and KC conceived and designed research. SG analyzed data and wrote the manuscript. All authors read and approved the manuscript.

Data availability All data generated or analyzed during this study are included in this published article.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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