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Research Article

Determination of Potential Distribution Areas of *Quercus cerris* (Turkish oak) in Anatolia According to Climate Change Scenarios

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ABSTRACT

The aim of this study is to determine the potential suitable distribution areas for *Quercus cerris* in the future depending on climate change scenarios. For this purpose, current spatial distribution data and 19 bioclimatic variable data downloaded from the WorldClim 2.1 database were used. The bioclimatic variable data consist of the climate data for the 2081-2100 period belonging to the SSP2-4.5 and SSP5-8.5 scenarios of the MIROC6 climate model with resolution of 2.5 arc-minutes. PCA was applied to bioclimatic variable data. MaxEnt 3.4.1 and ArcGIS 10.5 software were used to generate the models. The accuracy of the models was measured as 0.79 accuracy with the AUC test value. The variables that contributed the most to the model were BIO4 (temperature seasonality) with 39.8%, BIO9 (mean temperature of driest quarter) with 26.7%.

According to the results, it is predicted that the spatial distribution of this species unsuitable habitat areas, which is 25.9% today, will increase by 54.1% according to the SSP 245 scenario and by 80.2% according to the SSP 585 scenario. While the suitable habitat areas for *Q. cerris* in Anatolia are 33.2% today, they will change in a decreasing direction in the future by 11.6% according to the SSP 245 scenario and 14.0% according to the SSP 585 scenario. In addition to the direct impact of climate change scenarios on *Q. cerris*, when changes in land use are taken into account, the current distribution areas and suitable distribution areas of the species should be preserved with sustainable development goals.

1. Introduction

Environmental factors have significant effects on the distribution of species. Climate, being a major factor influencing the pattern, structure, and ecology of vegetation, plays a primary role in the spatial distribution of plants. Therefore, changes in plant distribution are expected in response to variations in climate conditions [1, 2].

Since the beginning of the 21st century, climate change has been recognized as one of the greatest threats to global biological diversity [3]. According to the latest report by the IPCC, the Mediterranean region, including the study area, is one of the most affected regions by climate change. Predicting the effects of climate change on species distribution models is one of the most current topics in ecology and biogeography [4]. Species distribution models are essential tools for biogeographical researches. Some of the most widely used species distribution modelling software today include Genetic Algorithm for Rule-set Prediction (GARP) [5], Ecological Niche Factor Analysis (ENFA) [6], Bioclimatic Prediction System (Bioclim) [7], Maximum Entropy (MaxEnt) [8], Flexible Discriminant Analysis (FDA), Generalized Additive Model (GAM), Generalized Boosting Model (GBM), Generalized Linear Model (GLM), Random Forest (RF) [9-10].

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Among software, MaxEnt is one of the most used [11-15]. MaxEnt has significant advantages due to its user-friendly interface and its ability to provide accurate predictions with a small number of species distribution data. MaxEnt predicts species probability distributions based on environmental constraints and identifies potential suitable distribution areas using the current distribution data of species [8].

One of the most pronounced consequences of global warming in the last decade is the increased occurrence of extreme weather events. The increasing climate variability predicts that severe rains, storms, floods, mass movements, severe heatwaves, droughts, and forest fires will be encountered, especially in the Mediterranean region [16-18]. Climate change will affect all biodiversity, including species distributed in Anatolia. Anatolia, habitat approximately 12.000 plant species due to its past exposure to climate change its unique geographical location, is one of the primary locations where these changes occur.

The natural distribution of oak trees has significantly diminished over time [19-21]. *Quercus cerris* is one of the tree species with high economic returns from wood/non-wood products, and it has been one of the most destroyed tree species over time. Although *Q. cerris* can sustain its existence as coppice due to its ability to regenerate, random cuts, inappropriate silvicultural management, fires, overgrazing (especially during rejuvenation), mining activities, and climate change threaten the presence of the species [22]. Rigo et al. (2016), who examined the distribution areas and suitability of *Q. cerris* in Europe, stated that *Q. cerris* is more drought-resistant than other oak species living in the same region [23].

Moricz et al. (2021) examined the sensitivity of *Q. cerris* to drought with rainfall datasets [24]. In their study, Mert et al. (2016) emphasized that *Q. cerris* is highly sensitive to forest fires and that it is necessary to study such species for the continuity of the ecosystem in the Mediterranean region, which is under the threat of climate change [25]. They also conducted a distribution suitability analysis for the Sütçüler basin in Türkiye as a sampling area. Filippo et al. (2010) analysed the response of *Q. cerris* to climate change in Italy [26]. Stafasani and Toramani (2015) conducted dendroclimatological research on *Q. cerris* in Albania, assuming that *Q. cerris* is more sensitive to natural environmental conditions when it grows at different latitudes and ecological conditions [27]. Given the effects of climate change on biodiversity, determining the future status of *Q. cerris* is important. Therefore, the aim of this study is to determine the current and future potential distribution areas/distribution areas of *Q. cerris* in Anatolia.

<u>*Study Area:*</u>

The Anatolian Peninsula, which is located within the borders of Türkiye, which connects the continents of Asia and Europe, is situated between longitudes 26° and 45° East and latitudes 36° and 42° North. The average elevation of the study area is 1141 meters. The primary geomorphological unit that forms the study area are the Northern Anatolian Mountains, the Central Anatolian Mountains, the Taurus Mountains, and the Southeastern Anatolian Mountains. The Central Anatolia, Southeastern Anatolia, and Western Anatolia Plains cover extensive areas [28, 29]. Although there are various climate types in the study area, the dominant climate type is hot/dry summer and very hot Subtropical Mediterranean climate. [30, 31] (Figure 1).

2. General Methods

Quercus cerris, has two varieties (*Quercus cerris* var. *cerris* and *Quercus cerris* var. *austriaca*). *Q. cerris*, a member of the red oak group, is adaptable to different climate conditions. It can be distributed in areas dominated by the Black Sea climate as well as in regions with a Marmara and Mediterranean climate. It forms pure communities but can also be seen in mixed forests that include different oak species (*Quercus frainetto, Quercus pubescens, Quercus infectoria, Quercus petrea, Quercus libani*), other broad-leaved species (*Fagus, Castanea, Carpinus*), and coniferous trees (*Pinus nigra, Pinus brutia, Pinus pinea*) [32-35]. (Photo 1).

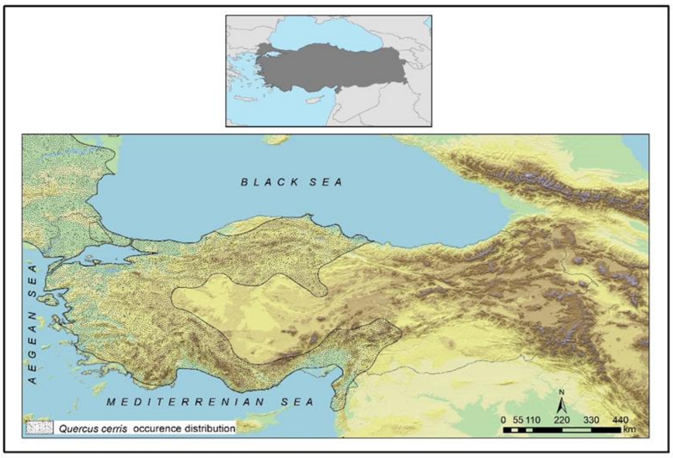

Figure 1. Location map of the study area

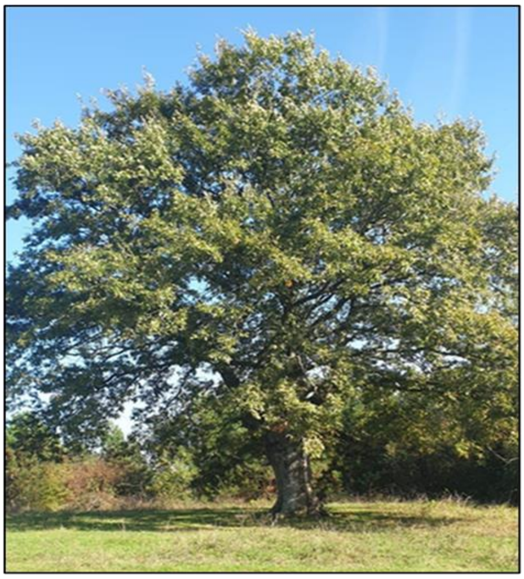

Photo 1. *Q. cerris*, natural distributed in Sakarya

It is a large, fast-growing, deciduous tree naturally found in Europe and Asia. In this region, it is one of the dominant deciduous tree species in mixed forest areas. It has a wide distribution range, stretching from central Europe southward to the Eastern Mediterranean countries. In this region, it forms extensive forests in Italy, the Balkan Peninsula, Türkiye, and Syria. The southern and eastern parts of Anatolia (up to Erzincan), the northern parts of Anatolia (up to Samsun) and the Aegean coast are the distribution areas of two different subspecies of *Q. cerris*. [32-36].

Current distribution data of the species in Anatolia and its surroundings were obtained from the Global Biodiversity Information Facility (GBIF) [37], and EUFORGEN databases [38], and by scanning the relevant sections of the work titled "Flora of Türkiye and the East Aegean Islands" [33, 34]. While using the distribution data of the selected species from Anatolia and its surroundings (*Q. cerris*: 105 occurrence data), care was taken to ensure that the data had a homogeneous distribution. For this purpose, a spatial filter will be used on species distribution data using the "Spatially Rarefy Occurrence Data" tool in ArcGIS 10.5 SDM Toolbox.

For the development of current and future models for *Q. cerris*, climate data obtained from the WorldClim 2.1 database was used. Climate data for the present time covers the period of 1970-2000, while for future projections, the MIROC6 model and climate projection data for the 2081-2100 period under the SSP2-4.5 and SSP5-8.5 scenarios were used (Fick & Hijmans, 2017; [39, 40]. The climate data used for both current and future scenarios have a resolution of 2.5 arcminutes, approximately 5 km.

The SSP scenarios are consolidated by the IPCC 6th Assessment reports and used as 21st century scenarios. Among these scenarios, SSP1 and SSP5 scenarios foresee significant investments in education and health, rapid economic growth and well-functioning institutions. In terms of where they differ from each other, while there is a transition towards sustainable practices in SSP1, SSP5 assumes that it will be governed by an energy-intensive, fossil fuel-based economy [41].

As in many plants, climate is the most important ecological factor influencing the distribution of Quercus cerris in Anatolia [16, 42-48].

Therefore, other ecological factors were not included in the modelling. In this study, 19 bioclimatic variables were obtained from the WorldClim database. To understand the relationships between the 19 bioclimatic variables and to create a model with good performance, a PCA (Principal Component Analysis) analysis was applied to the bioclimatic variables. Highly correlated data were removed from the model to avoid multicollinearity problems.

For this purpose, Pearson correlation coefficient was calculated to look at the linear relation of bioclimatic variables with each other using PCA analysis. These bioclimatic variables that did not exhibit collinearity with a correlation coefficient less than 0.85 were used in the models. The following bioclimatic variables were used in the modelling: BIO2 (Mean Diurnal Range - Mean of monthly (max temperature - min temperature)), BIO3 (Isothermality), BIO4 (Temperature Seasonality), BIO8 (Mean Temperature of Wettest Quarter), BIO9 (Mean Temperature of Driest Quarter), BIO12 (Annual Precipitation), BIO13 (Precipitation of Wettest Month), BIO14 (Precipitation of Driest Month), BIO15 (Precipitation Seasonality) [14, 45, 46, 47, 48].

To create species distribution models for *Quercus cerris* using the current distribution data and climate data, the MaxEnt (Maximum Entropy) software was employed.

MaxEnt is one of the most widely used and important statistical techniques for species distribution modelling. MaxEnt is effectively used to predict and determine the current geographical areas of the species in question. In addition, future projections based on environmental changes help evaluate the effects of possible changes and niche shifts [49, 50].

During the run of the models, a 15 replicates cross-validation technique was used; where 70% of the species presence data was utilized as training data and 30% as test data, with the iteration fixed at 500 [1, 14, 49]. To evaluate model performance, the AUC (Area Under the Curve) obtained through the ROC (Receiver Operating Characteristic) curve analysis method with accuracy testing was used. The obtained AUC values range from 0.5 to 1. Values between 0.5-0.6 indicate poor performance, 0.6-0.7 weak performance, 0.7-0.8 moderate performance, 0.8-0.9 good performance, and 0.9-1 excellent performance. An AUC value close to 1 indicates that the results are far from random distribution, the correlation between environmental variables and the predicted geographic distribution of species is high, and the model performs accurately [15, 50]. To assess the contribution and importance of each bioclimatic variable used in the model, a Jackknife test (leave-one-out) was applied.

Using the obtained models, distribution suitability classes were determined in ArcGIS 10.5 software. As a result of the classification, values ranging from 0 to 0.2 represent unsuitable distribution, 0.2 to 0.4 represent partially suitable distribution, 0.4 to 0.6 represent suitable distribution, 0.6 to 0.8 represent highly suitable distribution, and 0.8 to 1 represent very highly suitable distribution [15, 51]. Additionally, spatial changes for the future were calculated with respect to current suitable distribution areas using ArcGIS 10.5 software.

3. Results and Discussion

The current and future (2100) potential distributions and changes of *Q. cerris* were determined using the MIROC6 climate model and the SSP245 and SSP585 climate scenarios with MaxEnt and ArcGIS 10.5 software.

The models achieved a high level of reliability, with an AUC test value of 0.79 (Figure 2). The percentage contribution of the bioclimatic variables in the models has been included in the model outputs. According to the Jackknife analyses, BIO4 has a contribution of 39.8%, BIO9contributes 26.7%, and BIO14 contributes 15.8% (Table 1, Figure 3). When looking at the percentage contributions of the variables, it can be observed that drought is particularly important for *Q. cerris*. Considering the current distribution areas of the species, the conditions of temperature and precipitation are determinants.

When models produced for *Q. cerris* are examined, it is observed that the potential suitable distribution areas of the species are like the current distribution areas. These areas are outside of eastern and southeastern Anatolia. When looking at the potential suitable distribution areas for the species in the future, under the SSP 245 scenario, it is possible that *Q. cerris* will have suitable distribution areas in the northern regions of Anatolia. According to the SSP 845 scenario, it is predicted that the species will lose most of its suitable habitat areas. It is possible that *Q. cerris*, which has a wide distribution in Anatolia today, will narrow down these areas in the future and find suitable/partially suitable habitat areas in the Black Sea and its surroundings. (Figure 4). Similar results to those obtained in the study were also found by Mert et al. (2016) in the analysis applied with different scenarios in the Sütçüler Basin in the southwest of Anatolia, predicted that the distribution area of the species will narrow in the coming years [23].

When we look at the temporal change in the suitable distribution areas for the species, it is striking that unsuitable distribution areas will increase, and suitable distribution areas will decrease.

While the areal distribution of habitat areas that are not suitable for the growth of *Q. cerris* is 25.9% today, it is predicted that it will increase by 54.1% according to the SSP 245 scenario and 80.2% according to the SSP 585 scenario in the future. While the suitable habitat areas for *Q. cerris* in Anatolia are 33.2% today, they will change in a decreasing direction in the future by 11.6% according to the SSP 245 scenario and 14.0% according to the SSP 585 scenario. The areal change of highly suitable habitat areas for this species will decrease by 8.3% (present), 3.3% (SSP245) and 0.3% (SSP585), respectively, according to climate scenarios. It is predicted that very high suitable habitat areas will almost disappear. (Table 2).

Table 1. Contribution of bioclimatic variables obtained as a result of jacknife analysis (%)

	Bioclimatic variables	**Percent contribution**
Quercus cerris	BIO4 Temperature Seasonality	39.8
	BIO 9 Mean Temperature of Driest Quarter	26.7
	BIO14 Precipitation of Driest Month	15.8

Table 2. Temporal Change Rates of Potential Distribution Areas of *Quercus cerris*

	Present	**SSP 245**	**SSP 585**
Unsuitable distribution area (0–0.2)	25.9	54.1	80.2
Barely suitable distribution area (0.2–0.4)	32.5	31.1	5.5
Suitable distribution area (0.4–0.6)	33.2	11.6	14.0
Highly suitable distribution area (0.6–0.8)	8.3	3.3	0.3
Very highly suitable distribution area (0.8–1.0)	0.1		

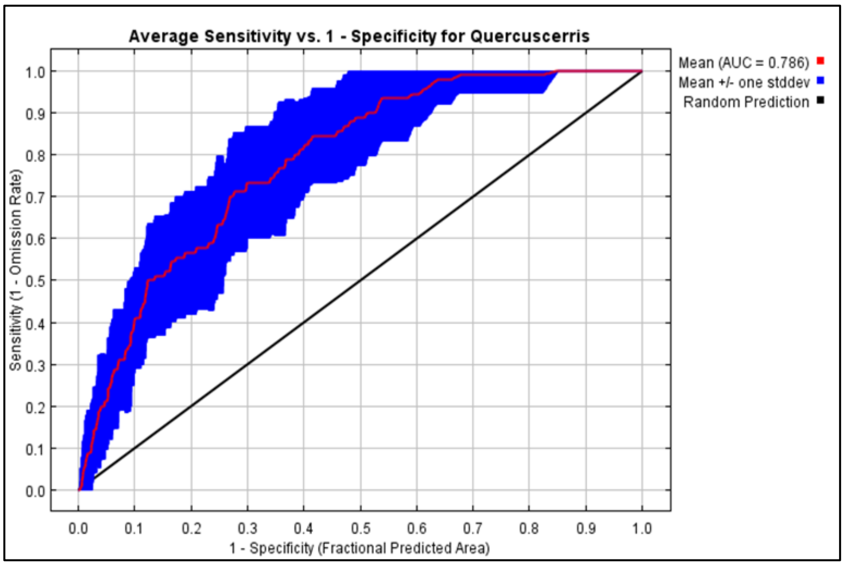

Figure 2. ROC curve and AUC values for MaxEnt model

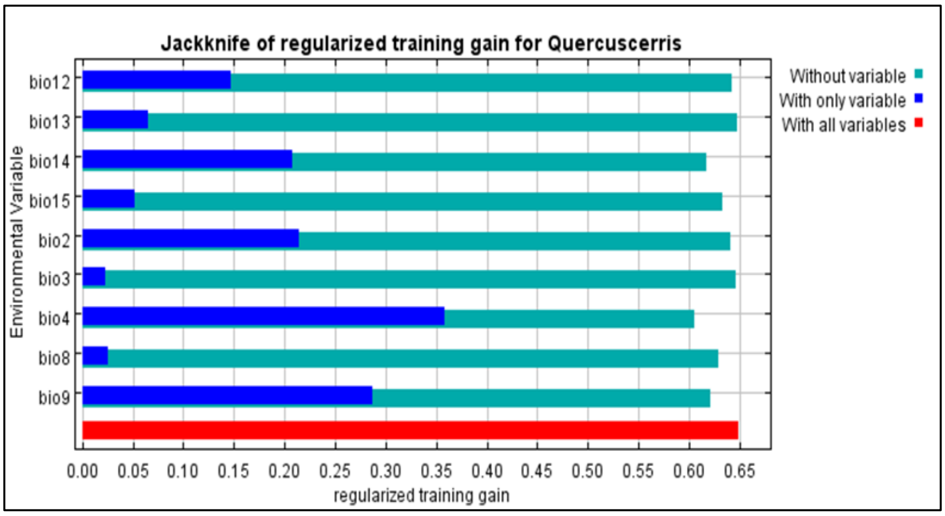

Figure 3. Jackknife test of variable importance of *Quercus cerris*

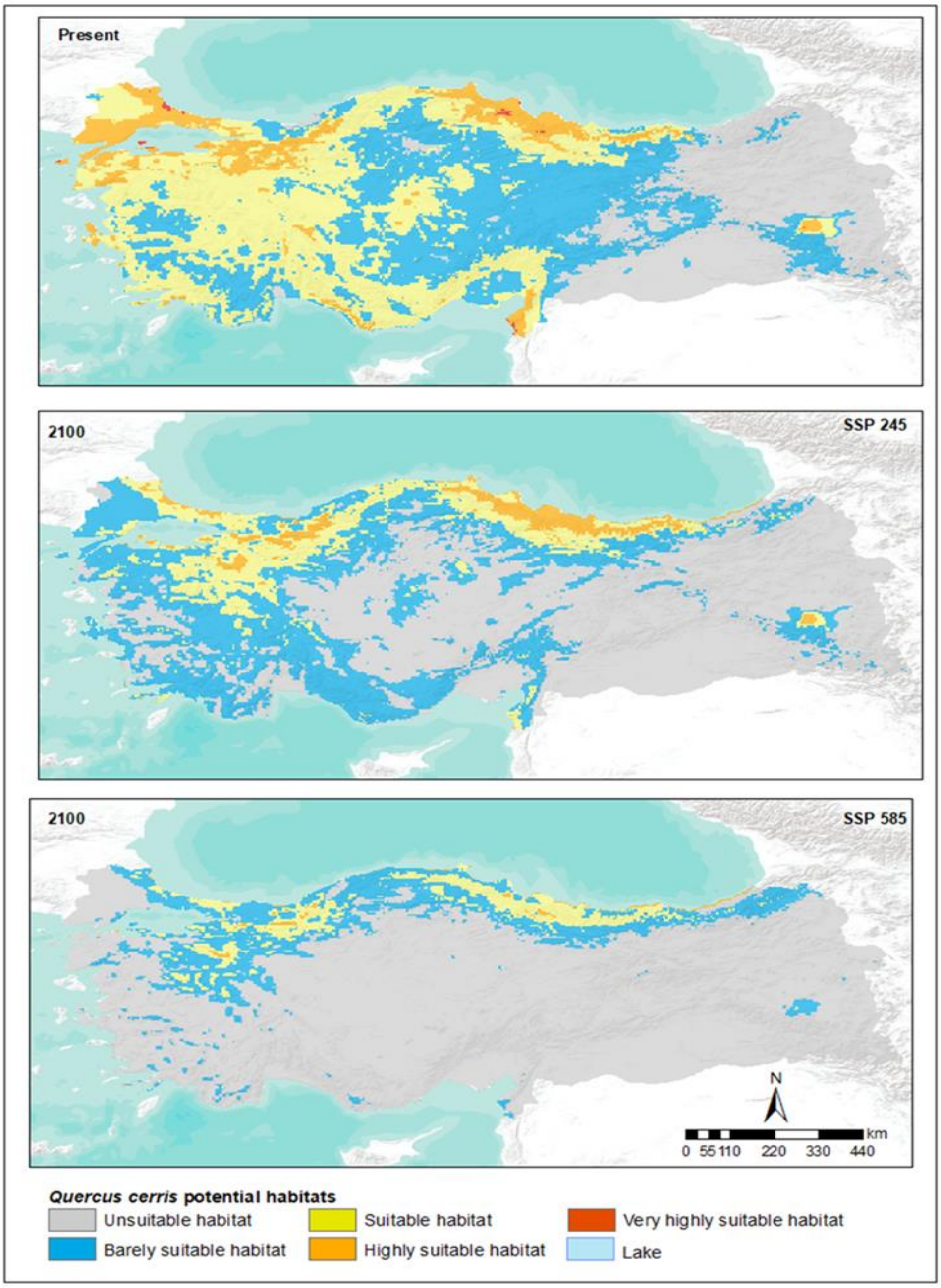

Figure 4. Current and future potential distribution areas of *Quercus cerris* in Anatolia

4. Conclusion

In this research, the current and future potential distribution areas of *Q. cerris* in Anatolia have been determined. The results obtained are model-based and contain predictions, therefore, the results are not definitive. Statistical methods have been used to ensure the validity of the models, and according to the results obtained, the model outcomes are accurate and usable. Although different ecological factors have an impact on the distribution of plants, when viewed on a broad scale, temperature and precipitation are the factors that affect species distribution. Theoretically, all ecological processes are required for detailed study in ecological niche modeling, but potential niches and potential distributions can only be predicted based on climatic variables [52-54].

As in many similar studies, the factors to be considered in species distribution modeling are bioclimatic variables [46-55-57]. The study was examined from a geographical perspective and "climatic conditions", one of the physical geography elements, were considered as independent variables. In this context, bioclimatic variables will be discussed primarily in the study since variable climatic conditions have the most impact on vegetation distribution. In addition, although present-day numerical data can be provided, future data (ecological, edaphic and topographic) limit the study because they cannot be modeled, especially since they are not in digital format and on a large scale, and therefore they were not used. Therefore, it was aimed to determine the possible effects of climate change on the distribution of *Q. cerris*.
According to the model results, the species currently has distribution in the regions around the Black Sea, Marmara, Aegean, and Mediterranean. However, in the future, suitable distribution areas in regions characterized by a Mediterranean climate, particularly around the Mediterranean and Aegean regions, are expected to decrease.

Recent studies focusing on the Mediterranean Basin indicate that species sharing distribution areas with *Q. cerris* in Anatolia or similar regions may likely reduce their ranges, experience shifts in distribution areas, or even face extinction due to climate change [25]. This is especially relevant for dominant species in northern Anatolia, such as *Carpinus betulus*, *Tilia tomentosa*, *Tilia cordata*, *Tilia platyphyllos,* and *Fagus orientalis*, where it is probable that their distribution areas in the north will narrow, resulting in the loss of refuge areas [15, 58-60]. In addition, according to modeling studies carried out for some species such as *Laurus nobilis, Juniperus drupacea, Abies ciliccia*, *Cedrus libani*, *Quercus coccifera*, which are distributed in areas where *Q. cerris* is distributed and where characterized by a Mediterranean climate, it is predicted that the mentioned species will narrow their distribution areas and loss completely from some areas [15, 58-64].

Climate change has both direct and indirect effects on biodiversity. Changes in land use characteristics due to climate change are crucial factors that can significantly impact biodiversity. Shifts in areas such as settlements and agricultural fields can lead to the contraction of plant distribution areas. Therefore, for a sustainable ecosystem, it is imperative to preserve the current distribution areas and suitable distribution areas of *Q. cerris.*

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The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial

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