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Original Article

Climate Change Effect on Potential Distribution of Anatolian Chestnut (*Castanea sativa* Mill.) in the Upcoming Century in Türkiye

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ABSTRACT

Climate change, which is effective on a global scale, affects almost all living creatures and ecosystems directly or indirectly. Forests are at the top of the ecosystems that are predicted to be affected more by climate. This study intended to determine how the growth regions of the Anatolian chestnut in Türkiye belong to one of the utmost vital forest tree species, which will be affected by climate change. Within the study scope, suitable areas for the growth of the species in 2040, 2060, 2080, and 2100 were determined under different scenario models [intermediate (shared socio-economic pathways 245) and most extreme (shared socio-economic pathway 585)] and compared with the natural distribution areas of today (the year of 2020). As a result of the study, it is predicted that the suitable distribution areas for Anatolian chestnut cultivation will decrease significantly, especially after 2060–2080, and even disappear entirely by 2080, according to the extreme scenarios. Even with the best scenario (shared socio-economic pathway 245), it is projected that the suitable growth regions for Anatolian chestnuts will decrease to one-fifth of today's levels in 2100. It may be recommended to create mixed forests with better-adapted chestnut varieties or origins for future conditions due to being more resilient to various environmental stress factors. In addition, considering the future projections, new chestnut plantations should be established in suitable areas for chestnut production.

Keywords: *Castanea sativa* Mill., climate change, habitat distribution, modeling

Introduction

Anatolian chestnut (*Castanea sativa*) naturally occurs in Türkiye from the Bulgarian border along the North Anatolian to the Caucasus, around the Western Anatolia and Marmara region. It is also locally distributed in the Mediterranean region, such as Alanya, Manavgat, and Isparta province (OGM, 2013). Anatolian chestnut, such as other chestnut species, is an important forest tree species with economic importance with its fruit and wood production. It grows very fast, makes a smooth and plump trunk, and has precious wood. Its wood is beneficial in terms of durability and decorative features. Also, it is essential for the building and furniture industry. It can easily penetrate polish and paint and bounds well with nails or glue. In addition to water vehicles such as furniture, boats, yachts, and ships, it is primarily preferred in pier construction (Conedera et al., 2004; Kakavas et al., 2018; Mirela, 2020).

Chestnuts contain 5–6% tannins in their shells. This feature is utilized by using it in making wood for wine barrels and adding wood pieces directly into the wine. It is also used in the paint industry to obtain brown color due to its tannin content. Edible fruits contain 5% protein, 5% fat, 40–50% carbohydrate, 40–50% moisture, and 1.5–2% clay. It contains more than 80% fatty acid types. Some of these fatty acids are oleic, linoleic, and palmitic. It contains vitamins A, B1, B2, B3, B6, and E, as well as Ca, Mg, K, Mn, P, Na, and Zn minerals, along with high amounts of vitamin C in its fruit. Its fruits are transformed into approximately 150 different products, such as chestnut sugar, chocolate-covered chestnut, chestnut cream, and mash (Barreira et al., 2020; De Vasconcelos et al., 2010; Dinis et al., 2012; Serdar et al., 2018).

Anatolian chestnut tree fruit production in Türkiye is supplied mainly from natural forests. However, it is thought that natural forests will be significantly affected by global climate change in the near future. Under climate change, extreme temperature fluctuations may cause cold and chilling stress (Yildiz et al., 2014) or drought stress on living things in some regions worldwide (Koç, 2022a). Considering today's climate conditions, the main

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adverse effect of climate change in Türkiye is the drought problem, which is thought to intensify and increase in the future (Koç, 2022a). Drought is one of the most vital global and regional environmental problems that threaten humanity's future when considering its consequences (Koç & Nzokou, 2022; Koç et al., 2022; Turan, 2018; Yigit et al., 2016). Besides this, forest fires (Talu et al., 2011), air and soil pollution (Cobanoglu et al., 2022; Isinkaralar et al., 2022a), and heavy metal contamination (Isinkaralar et al., 2022b; Key et al., 2022) are other problems that are mostly created by human beings in Turkey and worldwide. These problems adversely affect plant species distribution in their natural growing areas and plantation sites. The situation in arid and semi-arid areas and marginal lands are even worse (Shults et al., 2020).

Türkiye is highly vulnerable to climate change and is among "countries at risk" (United Nations Development Programme [UNDP], 2019). Global climate change will show itself in the Mediterranean Basin with increased temperatures (Koç, 2022b) and a decrease in precipitation (Giorgi & Lionello, 2008). Although it is estimated that many species will be significantly affected by these changes, it is estimated that the pressure on forests will be much more severe (Talu et al., 2011). Trees with a long life cycle are not as easy to adapt to rapid climate changes as other living things (Lindner et al., 2010). This is because global climate change will occur at an unnatural rate. Contrary to the climate changes that have occurred throughout history, the global climate change experienced today will take place in a short period. Therefore, it is estimated that most species will change significantly in the suitable habitat area, and the migration mechanism of plants with a long-life cycle will be insufficient to keep up with this change (Dyderski et al., 2018; Varol et al., 2022a,b). Thus, harm to essential roles and services and local extinctions are predicted (Keenan, 2012).

For these reasons, especially in recent years, many studies have been carried out on the possible effects of climate change on different ecosystems and living communities globally, the adaptation strategies of species, and possible changes in climate parameters. These studies focus on determining the effect of the possible change on species and developing species conservation strategies.

This study tried to determine how the distribution area of the species Anatolian chestnut, which is one of the utmost valuable broad-leaved tree species that occur in Türkiye, can be disturbed by a potential climate change globally. According to the Shared Socio-economic Pathways (SSPs), produced in the 2021 IPCC sixth assessment report (AR6) for the years 2040, 2060, 2080, and 2100 in the WorldClim database 585, and 245 scenarios of climate change globally, Bio1 (Annual Mean Temperature), Bio5 (Max Temperature of Warmest Month), Bio6 (Min Temperature of Coldest Month), Bio12 (Annual Precipitation) by using the 2021 IPCC AR6 for the years 2040, 2060, 2080, and 2100 in the WorldClim database (Mendoza-González et al., 2013; Varol et al., 2021), were modeled with ArcGIS 10.5 software. Thus, it is aimed to determine how the natural distribution areas of the species subject to the study will change with the effects of global climate change.

Methods

Study Area

In the current study, the Anatolian chestnut field distribution database within the boundaries of Türkiye is used (Euforgen, 2020). Modeling and mapping current (year 2020) and potential distribution regions were done with ArcGIS 10.5 software (ESRI, 2016). Positional information on the Anatolian chestnut used in the current project and the project location is given in Figure 1.

Anatolian chestnut establishes mix stands especially coniferous species in Marmara and northern Anatolia in Türkiye. In additional, it has a natural distribution locally in the Aegean region (Ovacık, Ödemiş, Simav, etc.) and the Mediterranean region (in Antalya (İbradı, Selge), Isparta (Merkez, Sütçüler), it is generally cultivated (Kulaç et al., 2014, 2017). It is locally located in Diyarbakır (Kurp-Islam village) as a small group.

Input Data

WorldClim data are widely used in species distribution modeling studies. Bioclimatic variables are expressed in a total of 19 different variables on this platform (Mendoza-González et al., 2013; Panagos et al., 2017). Since the purpose of modeling studies is to make the most accurate estimation with the least criteria, in this study, it is frequently used in such distribution modeling studies in order to make modeling with the least criteria and to maximize the success rates of the model. It is stated that it represents the future spread of chestnut in the best way (Qin et al., 2017); four bioclimatic variables were used. These are Bio1, Biol5, Biol6, and Biol12 representing annual mean temperature, max temperature of the warmest month, min temperature of the coldest month, and annual precipitation climate parameters, respectively (Table 1). The demonstration of stratocumulus by the aerial element of the Center National de Recherches Météorologiques model version 6 (CNRM—CM6-1) 2.5 minutes spatial resolution climate model (Varol et al., 2021) was used in the study.

The present time map for the chestnut and the variables explaining possible future changes were taken from the WorldClim project (version 2.1) website (Hijmans et al., 2005), reclassified in ten different intervals through ArcGIS 10.5, and made available for the creation of scenario maps throughout the twenty-first century. The latter was performed in two SSPs within two-time slices. These setups express the pollutant's molality and greenhouse gases caused by anthropogenic activity, affirmed by the sixth assessment report (Hausfather, 2019). The selected most extreme scenario achieved 8.5 W/m^2 by 2100 (SSPs 585), while the intermediate scenario increased to 4.5 W/m^2 (SSPs 245) simultaneously. Four-time slices were examined for each SSPs: average for 2021–2040, 2041-2060, 2061-2080, and 2081-2100. In total, two scenarios were forecasted for four different periods (SSPs 245 and SSPs 85 scenarios for 2040, 2060, 2080, and 2100 separately).

The climate parameters for the Anatolian chestnut, the subject of the study, are that the annual average rainfall is between 600 and 1500 mm, the annual average temperature is between 9°C and 15°C, and the annual maximum average temperature value is 27°C, and it also shows a natural distribution from 0 to 1200 meters above sea level (Gomes-Laranjo et al., 2006; Heiniger and Conedera, 1992). Based on these criteria, the climate parameters (Bio1, Bio5, Bio6, Bio12) of the SSPs 245 and SSPs 585 scenarios were analyzed using ArcGIS 10.5 software within the scope of the study. The obtained maps were reclassified according to the conformity classification criteria, and maps showing the changes in the current situation and the natural range until the end of 2040, 2060, 2080, and 2100 for Anatolian chestnut according to the climate change scenarios were obtained.

Results

According to the SSPs 245 scenario applied in this study, the model results gained according to the 2020 and future (years 2040, 2060, 2080, and 2100) projections are mapped in Figure 2, and the numerical values of the areas mapped in Figure 2 are given in Table 2.

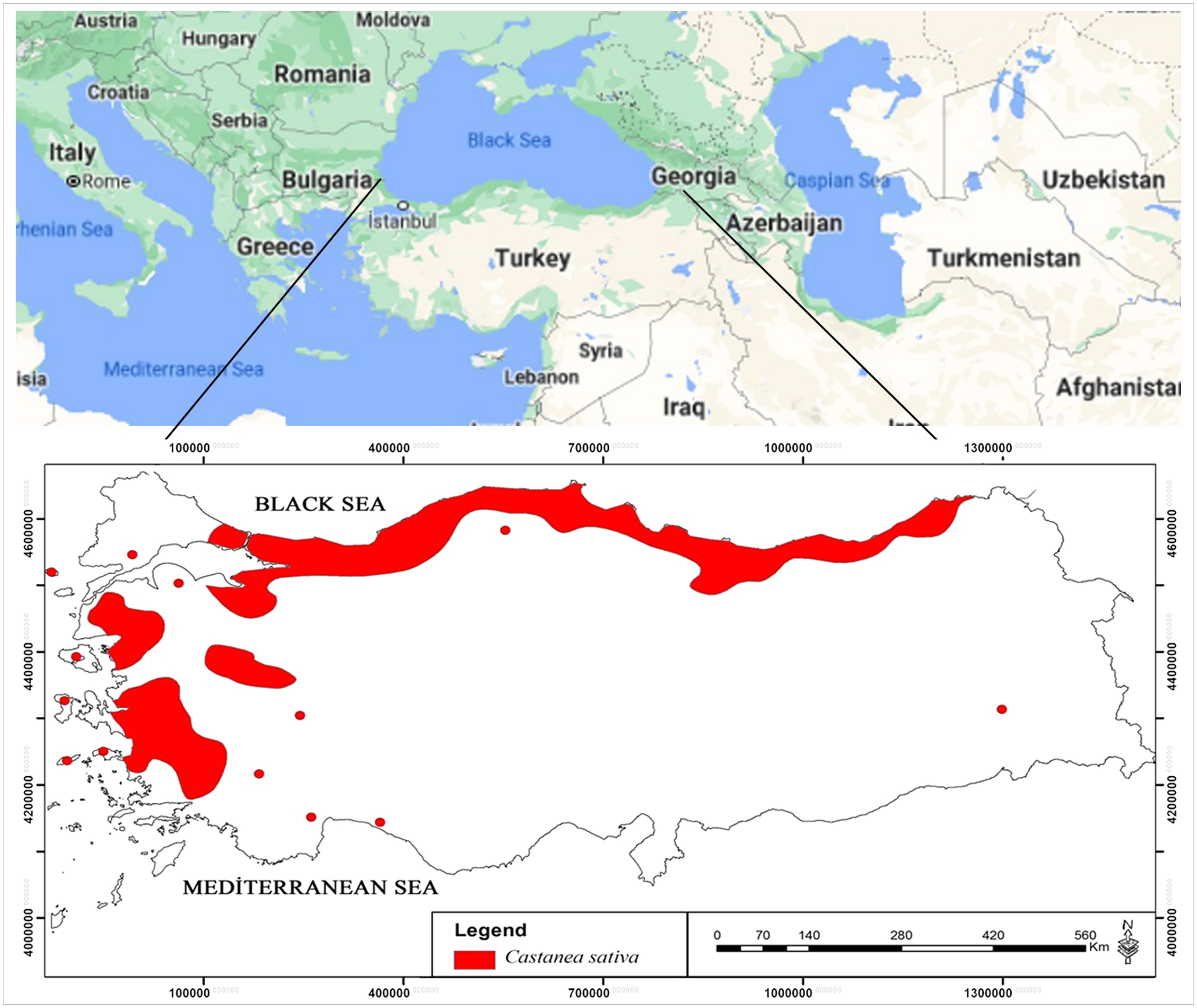

Figure 1.
Current (2020) Distribution Area of Anatolian Chestnut (Castane sativa*) in the Study Boundary.*

When Table 2 values are examined, the most suitable distribution area for Anatolian chestnut is approximately 44 880.6 ha, and the suitable distribution area is approximately 134 106.7 ha. According to the scenario of SSPs 245, the very suitable distribution areas are estimated to decrease to 28 409.5 ha in 2040, 8026.2 ha in 2060, 1504.6 ha in 2080, and 217.4 ha in 2100. It is estimated that today the suitable areas for growing Anatolian chestnuts will increase to 321 177.1 ha in 2040, and decrease to 56 726.1, 43 750.1, and 33 616.8 ha in 2060, 2080, and 2100, respectively.

Table 1.
The Variables of the WorldClim Bioclimatic Variables Used in the Study (Mendoza-González et al., 2013; Panagos et al., 2017)

Labels	Used Bioclimatic Variables
Bio1	Annual mean temperature
Bio5	Max temperature of warmest month
Bio6	Min temperature of coldest month
Bio12	Annual precipitation

If the total study is examined, 5.75% of them are very suitable for future studies, the working rate of the areas that are very suitable for growing Anatolian chestnuts will be 3.64% in 2040, 1.03% in 2060, 0.19% in 2080, and it is predicted to decrease to 0.03% in 2100. Therefore, it is predicted to decrease to 0.19 and 0.03% in 2100.

When compared to the total study area, 17.18% of the area under study is currently suitable for Anatolian chestnut growth. This ratio will increase to 41.15% in 2040, then decrease rapidly to 7.27% in 2060, and it is estimated to decrease to 5.61% in 2080 and to 4.31% in 2100.

As seen in Table 2, according to the scenario of SSPs 585, it is estimated that the Anatolian chestnut distribution region will decrease significantly in the following years. Today, the most suitable distribution

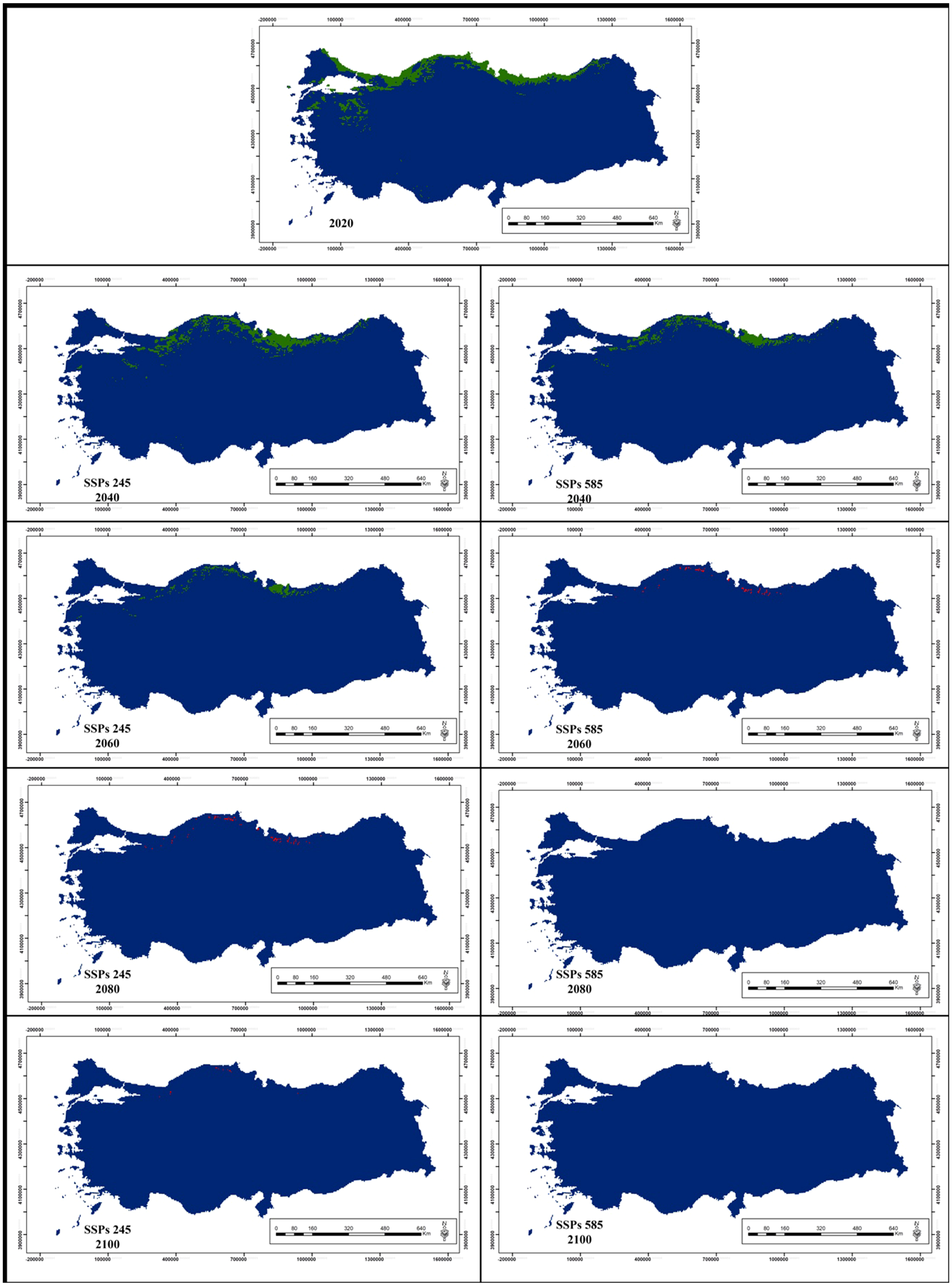

Figure 2.
Distribution of the Current and Future Status of the Areas Suitable for Anatolian Chestnut Distribution According to the SSPs 245 and SSPs 585 Scenarios.

Table 2.
Current and Future Status of the Suitable Areas for Anatolian Chestnut Distribution (Shown in Figure 2) According to the SSPs 245 and SSPs 585 Scenarios

			Years				
	Spatial Distribution	Relevance	2020	2040	2060	2080	2100
SSPs 245	Hectare (Ha)	Not suitable	60 1546.7	430 947.4	715 781.7	735 279.3	746 699.8
		Suitable	13 4106.7	321 177.1	56 726.1	43 750.1	33 616.8
		Very suitable	44 880.6	28 409.5	8026.2	1504.6	217.4
	Percent (%)	Not suitable	77.07	55.21	91.70	94.20	95.66
		Suitable	17.18	41.15	7.27	5.61	4.31
		Very Suitable	5.75	3.64	1.03	0.19	0.03
SSPs 585	Hectare (Ha)	Not suitable	60 1546.7	693 491.9	738 088.3	761 538.5	776 052.6
		Suitable	134 106.7	69 685.2	41 158.2	18 995.5	4481.4
		Very suitable	44 880.6	17 356.9	1287.5	0	0
	Percent (%)	Not suitable	77.07	88.85	94.57	97.57	99.43
		Suitable	17.18	8.93	5.27	2.43	0.57
		Very suitable	5.75	2.22	0.16	0	0

region for Anatolian chestnut growth is approximately 44 880.6 ha, and the suitable range is about 134 106.7 ha. According to the scenario of SSPs 245, the most suitable distribution regions will decrease to 17 356.9 and 1287.5 ha in 2040 and 2060, respectively. These areas will disappear entirely after 2080. It is estimated that the number of areas suitable for growing Anatolian chestnuts today will decrease to 69 685.2, 41 158.2, 18 995.5, and 4481.4 ha in 2040, 2060, 2080, and 2100, respectively.

Evaluating the total working area, 5.75% of the area subject to the study is very suitable today, while the ratio of the areas that are very suitable for Anatolian chestnut growth will decrease to 2.22% in 2040 and 0.16% in 2060 is foreseen. Compared to the total study area, 17.18% of the subject area is suitable for Anatolian chestnut growth, while this ratio will increase to 8.93% in 2040, 5.27% in 2060, and 2.43% in 2080. It is estimated to decrease to 0.57% in 2100.

In the other conformity modeling that draws a more pessimistic picture (in conformity modeling with the maximum temperature averages of the hottest months), the model results obtained according to the current and future (2040, 2060, 2080, and 2100) projections by the SSPs 245 scenario are mapped and shown in Figure 3. The numerical values of the areas mapped in Figure 3 are given in Table 3.

Based on the SSPs 585 scenario, the distribution of the Anatolian chestnut area will decrease significantly in the following years, as given in Table 3. Today, while the very suitable distribution area for Anatolian chestnut is approximately 44 880.6 ha, and the suitable range is about 134 106.7 ha, according to the scenario of SSPs 245, the most suitable distribution ranges will decrease to 17 356.9 ha in 2040 and 1287.5 ha in 2060. These areas will disappear entirely after 2080. It is projected that the suitable areas for Anatolian chestnut growth today will decrease to 69 685.2, 41 158.2, 18 995.5, and 4481.4 ha in 2040, 2060, 2080, and 2100, respectively.

As can be seen in Table 3, considering the maximum temperature averages, based on the scenario of SSPs 245, the area of Anatolian chestnut distribution is estimated to decrease significantly in the following years, and from 2080 there will be no suitable areas for this species distribution. Today, the most suitable distribution area for growing Anatolian chestnut is approximately 44 880.6 ha, according to the SSPs 585 scenario, while these areas are predicted to decrease to 17 356.8 ha in 2040, 1287.4 ha in 2060, and will completely disappear from 2080. Compared to the total study area, 5.75% of the area subject to study is suitable for growing Anatolian chestnuts today. It is estimated that the ratio of areas very suitable for growing Anatolian chestnuts to the working area will decrease to 2.22% in 2040 and to 0.16% in 2060.

Discussion and Conclusion

In the study, the changes in suitable areas for Anatolian chestnut cultivation have been examined in the future, depending on the predicted temperature and precipitation changes due to global climate change. As a result of the study, different scenarios were evaluated, but it is predicted that in all scenarios, especially after the years 2060–2080, the suitable distribution areas for Anatolian chestnut growth will decrease significantly and even disappear from 2080, according to some scenarios. Even according to the best scenario, the areas suitable for growing Anatolian chestnuts are predicted to fall to one-fifth of today's levels.

Global climate change is considered a process that will lead to significant changes in climate parameters. It is predicted that global climate change will increase the rates of natural calamities and ecological degradation such as drought, desertification, forest fires, floods, and erosion, and the most important effects will be temperature increase and decrease in water resources (Chugunkova and Pyzhev, 2020; Talu et al., 2011).

Türkiye is among the countries highly vulnerable and "countries at risk" to climate change (UNDP, 2019). Türkiye's average annual temperature will rise throughout the whole of the period by the time 2100 all the countrywide for future climate projections; especially in the Aegean region, it is predicted that the amount of temperature increase may rise to 6°C (Dalfes et al., 2007). The estimation of the summer rainfall in Türkiye's southern half will significantly decline than the northern side (Talu et al., 2011). Since the natural distribution areas of Anatolian chestnut are centered in Türkiye's northern coastal areas, these types are expected to be affected most by this process.

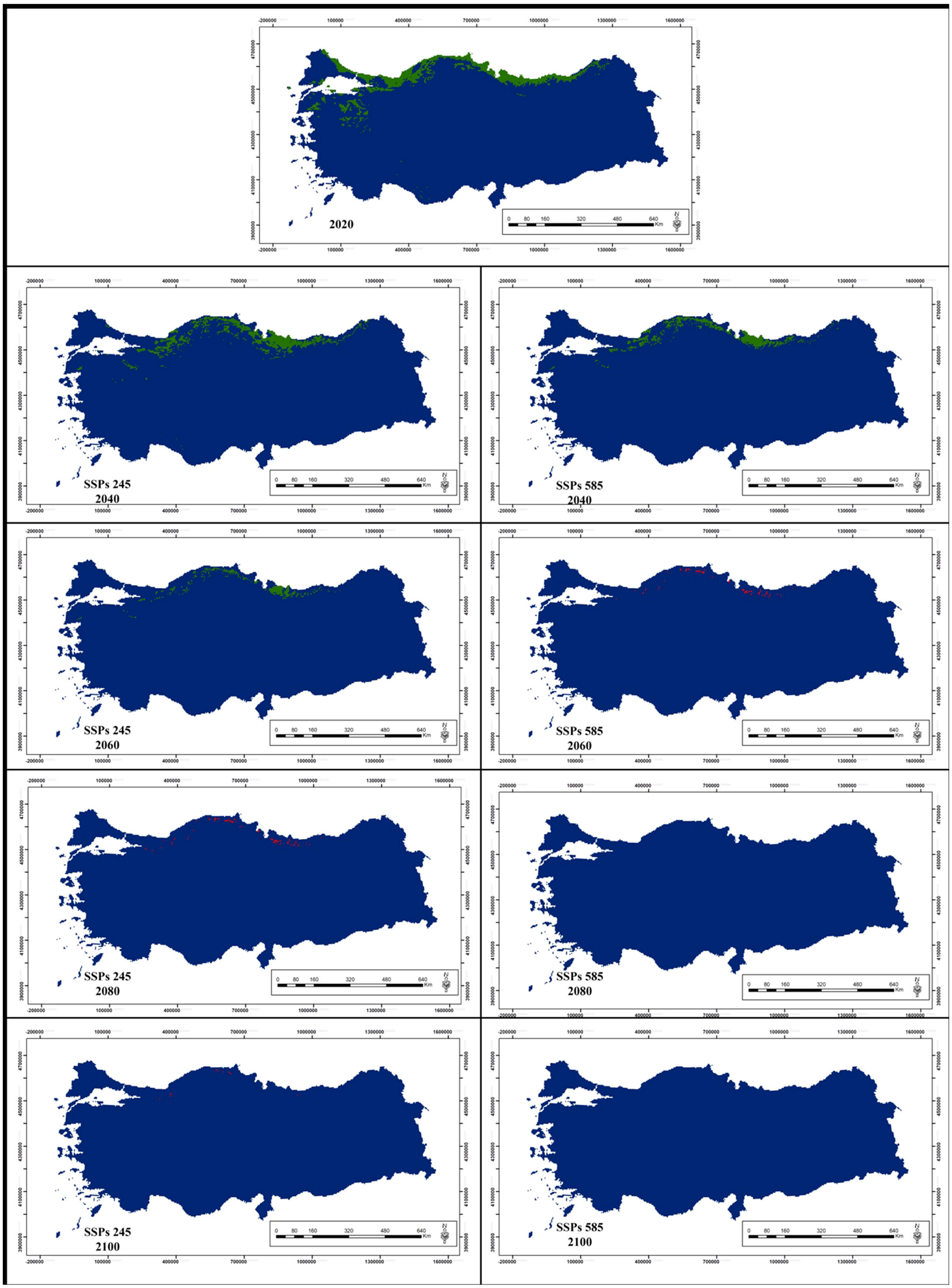

Figure 3.
Distribution of the Current and Future Conditions of the Areas Suitable for the Spread of Anatolian Chestnut According to the Suitability Model, Including the Maximum Temperature Averages of the Hottest Months and the SSPs 245 and SSPs 585 Scenarios.

Table 3.
Distribution of the Current and Future Conditions of the Areas Suitable for the Spread of Anatolian Chestnut According to the Suitability Model (Shown in Figure 3), Including the Maximum Temperature Averages of the Hottest Months and the SSPs 245 and SSPs 585 Scenarios

			Years				
	Spatial Distribution	Relevance	2020	2040	2060	2080	2100
SSPs 245	Hectare (Ha)	Not suitable	735 653.4	752 124.4	772 507.8	779 029.1	780 316.7
		Suitable	44 880.6	28 409.6	8026.2	1504.9	217.3
	Percent (%)	Not suitable	94.25	96.36	98.97	99.81	99.97
		Suitable	5.75	3.64	1.03	0.19	0.03
SSPs 585	Hectare (Ha)	Not suitable	735 653.4	763 177.2	779 246.6	780 534	780 534
		Suitable	44 880.6	17 356.8	1287.4	0	0
	Percent (%)	Not suitable	94.25	97.78	99.84	100	100
		Suitable	5.75	2.22	0.16	0	0

Studies have shown that European beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* L. Karst.) populations in Europe may decrease with the climate change effect by 2100 (Eurostat, 2020; Hanewinkel et al., 2013; Ruiz-Labourdette et al., 2013). Similar results have been obtained in studies on different tree species. The studies also claimed that there might be a 56% reduction in the potential distribution range of European beech (*F. sylvatica*) (Thurm et al., 2018).

Changes that may occur due to climate change will result in the transformation of suitable distribution areas for some tree species into suitable distribution areas to spread other tree species. A study conducted under three scenarios of climate change aimed to predict the variations in the predicted intervals and risk levels for 12 European forest tree species until 2061–2080 with three scenarios, pessimistic, average, and optimistic. The study results have shown that tree species will react differently to predicted climate change, and species can be separated into three groups. The "winners" were determined as European beech (*F. sylvatica*), silver fir (*Abies alba*), European ash (*Fraxinus excelsior*), Sessile oak (*Quercus petraea*), and European oak (*Quercus robur*), and the "losers" as Scots pine (*Pinus sylvestris*), silver birch (*Betula pendula*), European larch (*Larix decidua*), and Norway spruce (*Picea abies*) (Dyderski et al., 2018). The study results show that Anatolian chestnut will be among the losers in Turkey. Studies generally reveal that species-suitable distribution areas will shift upwards (Tekin et al., 2022; Varol et al., 2022a,b). In this case, it is estimated that the distribution areas of species such as pine and oak, which spread at low altitudes in chestnut distribution areas and are more resistant to drought, will expand their distribution in chestnut areas.

It is known that global climate change will affect almost all living things and ecosystems directly or indirectly (Gustavsson et al., 2017; Koç, 2022c; Meli et al., 2017). However, the living things that will feel this effect most are plants. This is because plants have a limited migration mechanism, and this migration mechanism cannot keep up with the pace of climate change. Therefore, it is estimated that most of the species' suitable areas will be significantly decreased (Booth, 2017; Dyderski et al., 2018; Wang et al., 2017).

The development of living things is possible when various external conditions are within a suitable range of values. Climatic (Cetin et al., 2018a,b; Sevik et al., 2020a,b) and edaphic (Kravkaz et al., 2018a,b) factors are the most influential factors in the development and spread of plants to the earth. These factors significantly affect plant growth, morphological, anatomical, and phenological structure (Cesur et al., 2021; Koç, 2021; Koç et al., 2022; Koç & Nzokou, 2022; Ozkazanc et al., 2019; Sevik et al., 2019; Yucedag et al., 2019). Therefore, considering that climate change will primarily affect the temperature and precipitation, which are the most important of these factors, it is natural that the plants are affected by this process.

However, the effect of global climate change on species is mainly uncertain since many variables are expected to affect each other (Knüsel et al., 2019). While these factors are mainly environmental factors, such as climatic and edaphic factors, microecological conditions are also important factors affecting the distribution area of the species (Cetin et al., 2018a; Dogan et al., 2022; Zeren Cetin et al., 2022). Since global climate change will significantly change the climatic factors, there will be significant individual and population losses in Anatolian chestnut, as in other species. In this process, the genotypes that are best resistant to the adverse effects of global climate change (e.g., the genotypes that can tolerate drought the best) will survive. Similarly, individuals and populations in the areas where micro-climatic conditions are suitable will continue to survive. However, in any case, population and individual losses are inevitable.

According to the scenarios examined in the article, it is revealed that Anatolian chestnut will decrease considerably and even come to the edge of extinction, especially after 2080. However, this scenario also occurs under the influence of many other factors. For example, it is clear that the impact of global climate change on pure and mixed stands will not be the same. Similarly, it can be said that natural populations with high genetic diversity will be much more resistant than plantation areas with much narrower genetic diversity because genetic diversity is the most critical defense mechanism of species against unpredictable biotic and abiotic risk factors (Hrivnak et al., 2017; Kardos et al., 2021; Topacoglu et al., 2017). In addition, it is possible that various fungal and insect damages, which have been effective in recent years, will increase even more in chestnut trees, whose resistance level will decrease due to the adverse effects of global climate change.

Natural forests are affected directly or indirectly by the climate change factor. While these direct factors affect forest tree species, indirect factors have been revealed by studies that both cause and spread some pests and fungal diseases, causing damage to forests in some provinces or regions and extinction risk in the following decades (Oberle et al., 2018; Toczydlowsk et al., 2020).

Suggestions

It is known that climate change will have significant effects on approximately all living things and ecosystems. To reduce this impact, it is necessary to eliminate the factors that trigger climate change by taking measures globally, especially using fossil fuels and carbon emissions.

Forest ecosystems are one of the ecosystems where the effects of climate change will be felt the most. The main reason for this effect at that high level is that the plants do not have an efficient and rapid migration ability. Therefore, many plant species' inability to adapt quickly enough to the impacts that will occur due to climate change to be experienced may cause a significant reduction in the populations of some species and even complete extinction for species with limited distribution areas. In this process, to minimize the effects on the species, it is vital to predict potential changes in the future from now and take precautions in terms of the changes. For example, in areas where climate change effects will be more affected, it may be recommended to create mixed forests with better-adapted species or varieties to current and projected conditions. Mixed forests are more resilient to various factors than pristine forests and are advantageous in ensuring the continuity of the forest, even in the loss of species. Also, determining and using the origin of each species most resistant to drought stress will contribute.

As another suggestion, it should be ensured that genetic diversity is kept at a high level. Species have different resistance levels to external factors, both within and between species, because of their genetic differences. The primary defense mechanism for forests against future dangers is that they have a high genetic diversity. For these reasons, it is vital to carry out activities to keep this genetic diversity in forests at the highest level.

As concluded, it was determined that suitable areas for Anatolian chestnut growth might disappear entirely in the future. Anatolian chestnut is a vital forest tree as well as an agricultural plant. Therefore, they can be planted in areas that will bear suitable conditions in the future, and their survival can be ensured. Besides, the drought effect, which is one of the most critical outcomes of climate change, can be overcome by irrigation in plantation areas. However, determining the most suitable species and origins, namely the species and origins of Anatolian chestnut resistant to drought, and using them in afforestation studies can be a smart solution.

This study and the various studies results carried out to date show that the species' distribution areas will shift upwards with the effects of global climate change. In this case, it is suggested that proper chestnut genotypes should be planted in an upper altitude range from today's distribution areas.

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