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Potential change of chestnut (*Castanea sativa* Mill.) distribution areas in Kastamonu due to global climate change

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Abstract

Climate change, which is effective on a global scale, threatens almost all living things and ecosystems directly or indirectly. Forests are among the ecosystems that are predicted to be most affected by climate change. In this study, it was aimed to determine the current status of chestnut distribution areas in Kastamonu Forestry Regional Directorate, which is the Forestry Regional Directorate with the highest production in Türkiye, and the change in suitable distribution areas due to global climate change. In the study, in addition to the current suitable distribution areas of chestnut distribution areas and the current distribution area, the suitable distribution areas in 2040, 2070 and 2100 according to SSP 126, SSP 370 and SSP 585 scenarios were determined. The results of the study show that there will be a significant decrease in the suitable distribution areas of chestnut populations in Kastamonu due to the effects of climate change. Therefore, in order to prevent individual, population and species losses in the future, it is recommended to make necessary arrangements in forest management plans by taking the results of the study into consideration.

Keywords: Global climate change; *Castanea sativa*; Habitat distribution; Kastamonu; SSP scenarios

1. Introduction

Chestnut is an important forest tree species that has economic importance with its fruit and wood production, grows very fast, has a smooth and full body, and has valuable wood. Its wood is used in the construction and furniture industry, and is primarily preferred in the construction of scaffolding as well as watercraft such as furniture, boats, yachts and ships [1,2]. Chestnut has 5% - 6% tannin in the stem shells and is also used in the dye industry to obtain brown color due to tannin. The fruit contains high amounts of vitamin C and vitamins A, B1, B2, B3, B6 and E, as well as the minerals Ca, Mg, K, Mn, P, Na and Zn. Its fruits are transformed into about 150 different types of products such as chestnut sugar, chestnut candy, chocolate covered chestnuts, chestnut cream and puree. Therefore, chestnut is a highly valuable species in terms of both its wood and fruit [2,3].

However, it is stated that chestnut, which already has a very limited distribution area, is one of the species that will be most affected by global climate change [2]. As it is known, in the last century, developments in the field of industry, extraction of underground elements in order to meet the supply of raw materials and their release into the atmosphere have made environmental pollution [4-7], urbanization [8-10] and global climate change [11-13] global problems.

Among these problems, global climate change is defined as an irreversible problem that will directly or indirectly affect all ecosystems and that the world has to cope with [14-16]. It is emphasized that global climate change will cause permanent changes in climate. Changes in climate directly or indirectly affect all living things because all phenotypic

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characters of living things are shaped depending on the effect of climate [17-19]. Therefore, permanent changes in climate have the potential to affect all living things and ecosystems on Earth [20,21].

Türkiye is highly vulnerable to climate change and is among the "countries at risk" [2]. Global climate change will manifest itself with an increase in temperature and a decrease in precipitation [15]. Although it is estimated that many species will be significantly affected by these changes, the pressure on forests is predicted to be much more severe. It is not easy for trees that can live for many years to adapt to rapid changes in climate, and in this case, loss of individuals, populations and even species is inevitable [20-22].

For these reasons, especially in recent years, the number of studies on possible changes in climate parameters, possible effects of climate change on living organisms and ecosystems, adaptation of species and migration has increased significantly. It is emphasized that in order to reduce losses especially in forests, it is imperative to determine the suitable habitat changes that may occur in advance and to provide the migration mechanism needed by plants by human hands [2,16,22]. However, detailed studies are needed to plan appropriate silvicultural interventions. However, the studies carried out so far are generally conducted in large areas [23]. In this study, it was aimed to determine in detail how the suitable distribution areas of chestnut (*Castanea sativa*) may change due to global climate change in Kastamonu Regional Forest Directorate, which is the Regional Forest Directorate with the highest wood raw material production in Türkiye.

2. Material and Method

The study was conducted to model the changes in the potential distribution areas of chestnut (*Castanea sativa*), one of the most important tree species for Türkiye and the world, in Kastamonu due to global climate change. Within the scope of the study, firstly the current distribution area of the species subject to the study, then the current potential distribution area was determined, and then the potential distribution areas in 2040, 2070 and 2100 years were tried to be determined in Kastamonu. MaxEnt 3.4.1 software was used for modeling the potential distribution areas of the species and ArcGIS 10.5 software was used for map representation. In this study, 19 bioclimatic variables were used, which were preferred in many previous studies [22, 23], and the biological variables used are given in Table 1.

Table 1 Bioclimatic variables used in modeling

Codes	Bioclimatic variables	Unit
Bio1	Annual Mean Temperature	ºC
Bio2	Mean Diurnal Range (Mean of monthly [max temp - min temp])	ºC
Bio3	Isothermality (Bio2/Bio7) (* 100)	-
Bio4	Temperature Seasonality (standard deviation *100)	(coeff. of var. ºC)
Bio5	Max Temperature of Warmest Month	ºC
Bio6	Min Temperature of Coldest Month	ºC
Bio7	Temperature Annual Range (Bio5-Bio6)	ºC
Bio8	Mean Temperature of Wettest Quarter	ºC
Bio9	Mean Temperature of Driest Quarter	ºC
Bio10	Mean Temperature of Warmest Quarter	ºC
Bio11	Mean Temperature of Coldest Quarter	ºC
Bio12	Annual Precipitation	mm
Bio13	Precipitation of Wettest Month	mm
Bio14	Precipitation of Driest Month	mm
Bio15	Precipitation Seasonality (coefficient of variation)	percent
Bio16	Precipitation of Wettest Quarter	mm
Bio17	Precipitation of Driest Quarter	mm
Bio18	Precipitation of Warmest Quarter	mm

Bio19	Precipitation of Coldest Quarter	mm
Q	Emberger climate classification	-

Socio-economic pathways (SSPs) include five main SPPs (SSP 119, SSP 126, SSP 245, SSP 370, SSP 585) [24]. In this study, SSP 126, SSP 370 and SSP 585 scenarios were used. These scenarios and the method used in the study are among the methods and scenarios frequently used in similar studies [16,21].

2.1. Findings

The validation values of the training data and test data in the ROC curve obtained as a result of the modeling performed within the scope of the study were determined as 0.976 (AUC>0.5) and these results show that the model has a very high predictive power (Figure 1).

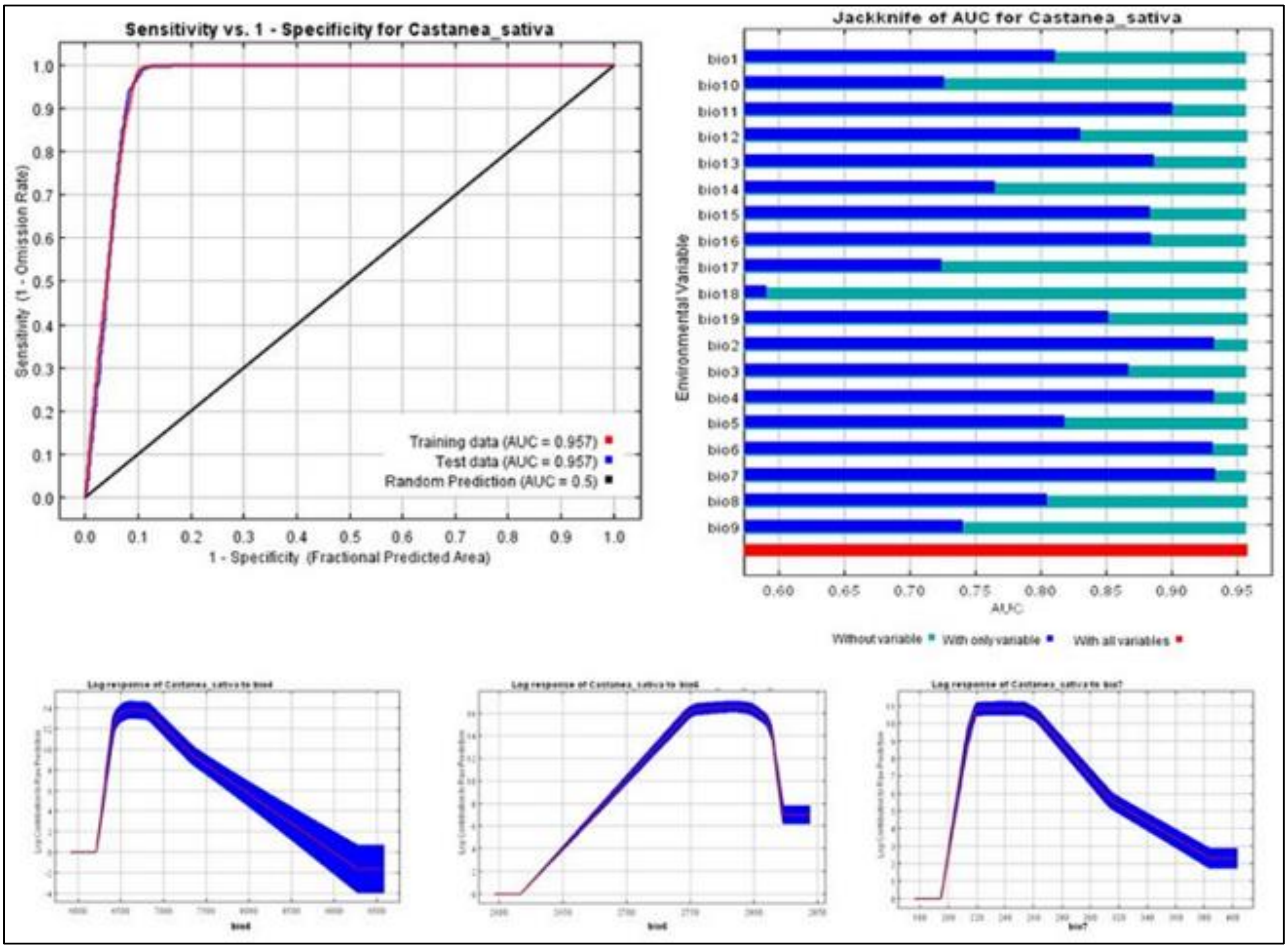

Figure 1 Effects of environmental factors on the distribution area of *C. sativa*

According to the gain table created for *Castanea sativa* with the Jacknife option in the model, the environmental variables that affect the distribution of the species individually in the training data at the highest level are "Mean Diurnal Range" [Bio2], "Temperature Seasonality" [Bio4], "Min Temperature of Coldest Month" [Bio6] and "Temperature Annual Range" [Bio7]. This situation reveals that the species is significantly affected by temperature. Current distribution areas of *Castanea sativa*, suitable distribution areas according to the model and distribution areas depending on global climate change are shown in Figure 2.

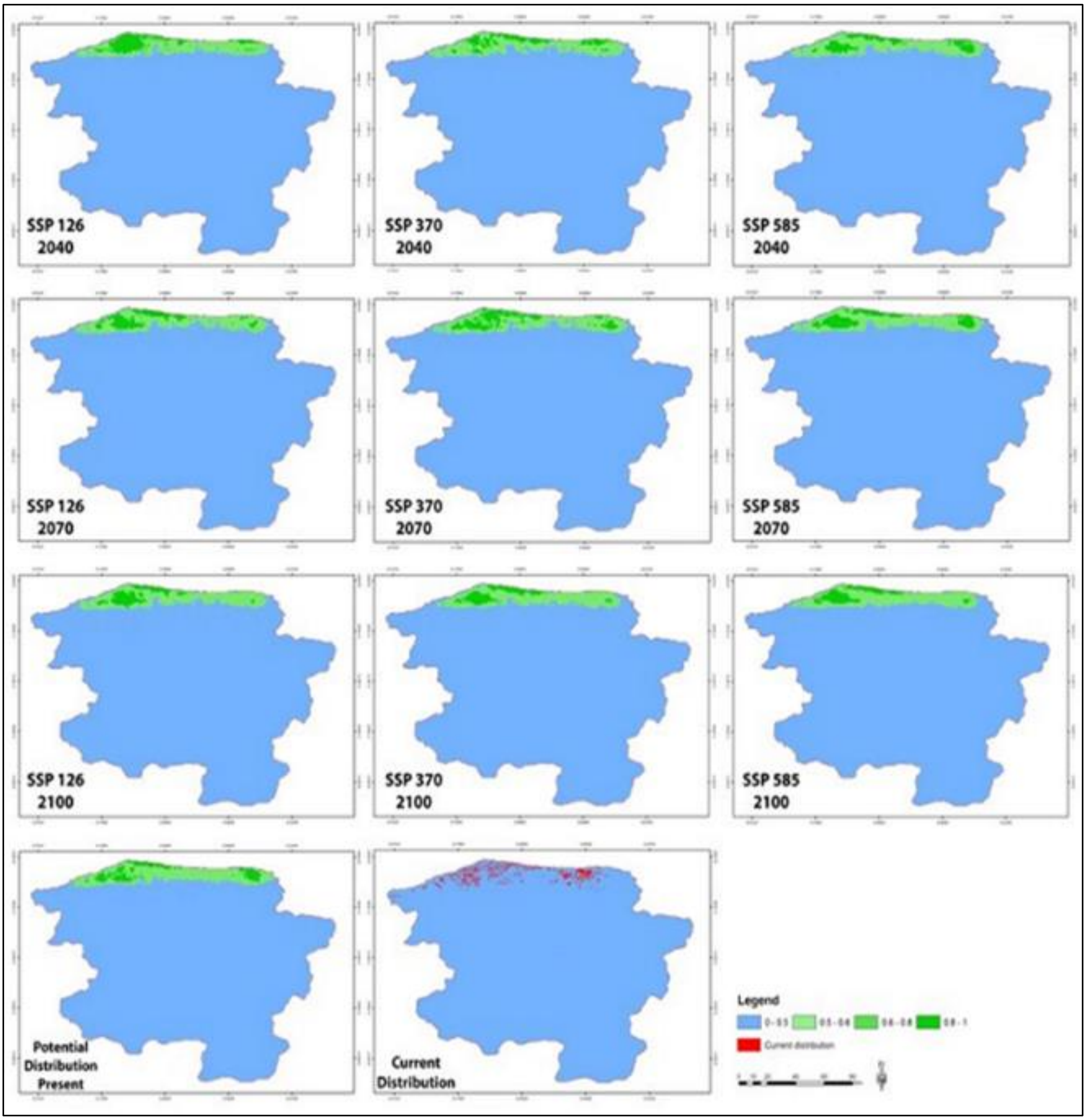

Figure 2 Distribution areas depending on global climate change

According to all scenarios, it is predicted that there will be a decrease in the suitable distribution areas of *C. sativa* starting from 2040. This decrease is predicted to manifest itself from 2040 onwards and in 2100, according to all scenarios, there will be a loss of suitable distribution area compared to today. The scenario that predicts the highest loss in 2100 compared to today is the SSP 370 scenario. According to the SSP 126 scenario, the rate of change in the suitable distribution areas of *C. sativa* in 2040, 2070 and 2100 compared to today is given in Table 2.

When the table values are analyzed, it is calculated that *C. sativa* has a total potential distribution area of 868.6 km^2 in Kastamonu, of which 678.0 $km^2$is suitable and 190.6 km^2 is highly suitable, whereas the current distribution area of C. sativa is 170.4 km^2. According to the SSP 126 scenario, when the change in the suitable distribution areas of *C. sativa* in the near future is analyzed, it is predicted that there will be a decrease in the total suitable distribution area. While the suitable distribution area of *C. sativa* is 678.0 km^2 today, this area is projected to be 567.2 km^2 in 2040, 585.3 km2 in 2070 and 624.5 km^2 in 2100. The highly suitable distribution area, which is approximately 190.6 km^2 today, is calculated to be 230.5 km^2 in 2040, 201.5 km^2 in 2070 and 180.9 km2 in 2100. The species does not have very suitable distribution areas in Kastamonu and will not occur in the future according to the SSP 126 scenario. Therefore, the total suitable distribution area, which is 868.6 km^2 today, is predicted to be 797.7 km^2 in 2040, 786.8 km2 in 2070 and 805.4 km^2 in 2100 according to the SSP 126 scenario. Table 3 shows the change in the suitable distribution areas of *C. sativa* according to the SSP 370 scenario compared to the present day.

Table 2 Change in suitable distribution areas of *C. sativa* according to SSP 126 scenario

Compliance	**2020 available (Km^2)**	**2020 potential (Km^2)**	**ssps126**		
			2040 (Km^2)	**2070 (Km^2)**	**2100 (Km^2)**
0-0.5	12881,8	12183,6	12254,5	12265,4	12246,8
0.5-0.6	170,4	678,0	567,2	585,3	624,5
0.6-0.8		190,6	230,5	201,5	180,9
0.8-1		0	0	0	0
Total (Km^2)	13052,2	13052,2	13052,2	13052,2	13052,2

Table 3 Change of suitable distribution areas of *C. sativa* according to SSP 370 scenario

Compliance	**2020 available (Km^2)**	**2020 potential (Km^2)**	**ssps126**		
			2040 (Km^2)	**2070 (Km^2)**	**2100 (Km^2)**
0-0.5	12881,8	12183,6	12265,4	12248	12268,7
0.5-0.6	170,4	678,0	605,9	571,1	612,9
0.6-0.8		190,6	180,9	233,1	170,6
0.8-1		0	0	0	0
Total (Km^2)	13052,2	13052,2	13052,2	13052,2	13052,2

When the change in the suitable distribution areas of *C. sativa* according to the SSP 370 scenario is analyzed, it is predicted that the total suitable distribution area will decrease in 2040 compared to today and will continue to decrease until 2070. According to the calculations made, according to the SSP 370 scenario, the area of suitable distribution, which is 678.0 km^2 today, is predicted to be 605.9 km^2 in 2040, 571.1 km^2 in 2070 and 612.9 km2 in 2100. The highly suitable distribution area, which is approximately 190.6 km^2 today, is calculated to be 180.9 km^2 in 2040, 233.1 km^2 in 2070 and 170.6 km^2 in 2100. The species does not have very suitable distribution areas in the study area and will not occur in the future according to the SSP 370 scenario. Therefore, the total suitable distribution area in Kastamonu, which is 868.6 km2 today, is predicted to be 786.8 km^2 in 2040, 804.2 km^2 in 2070 and 783.5 km^2 in 2100 according to the SSP 370 scenario. According to the SSP 585 scenario, the rate of change of the suitable distribution areas of *C. sativa* compared to the present day is given in Table 4.

Table 4 Change of suitable distribution areas of *C. sativa* according to SSP 585 scenario

Compliance	**2020 available (Km^2)**	**2020 potential (Km^2)**	**Ssps585**		
			2040 (Km^2)	**2070 (Km^2)**	**2100 (Km^2)**
0-0.5	12881,8	12183,6	12253,9	12237,1	12251,3
0.5-0.6	170,4	678,0	602,6	587,2	621,3
0.6-0.8		190,6	195,7	227,9	179,6
0.8-1		0	0	0	0
Total (Km^2)	13052,2	13052,2	13052,2	13052,2	13052,2

When the table showing the change in the suitable distribution areas of *C. sativa* in Kastamonu according to the SSP 585 scenario is analyzed, it can be said that the total suitable distribution area will decrease in 2040 compared to today. According to the calculations made, according to the SSP 585 scenario, it is estimated that the suitable distribution areas, which are 678.0 km^2 today, will be 602.6 km^2 in 2040, 587.2 km^2 in 2070 and 621.3 km^2 in 2100. The highly suitable distribution areas, which are approximately 190.6 km^2 today, are estimated to be 195.7 km^2 in 2040, 227.9 km^2 in 2070 and 179.6 km^2 in 2100. On the other hand, it is predicted that the areas of very suitable distribution are not present today and will not be present in the future. Therefore, according to the SSP 585 scenario, the total suitable distribution area, which is 868.6 km^2 today, is estimated to be 798.3 km^2 in 2040, 815.1 km^2 in 2070 and 800.9 km^2 in 2100.

3. Results and Discussion

In this study, the change of suitable areas for chestnut in Kastamonu in the coming years depending on the temperature and precipitation changes predicted to occur due to global climate change was examined. As a result of the study, different scenarios were evaluated, but in all scenarios, it is revealed that after 2040, the areas suitable for growing chestnut in Kastamonu will decrease significantly. Similar results were obtained in studies carried out to determine chestnut distribution areas throughout Türkiye. As a result of a study conducted by Çobanoğlu et al. [2], different scenarios were evaluated, but it was determined that in all scenarios, especially after the years 2060-2080, the distribution areas suitable for chestnut growth will significantly decrease in Türkiye, and according to some scenarios, it will disappear completely after 2080. Even according to the best scenario, it is predicted that the areas suitable for chestnut cultivation will decrease to one-fifth of today's levels, and according to some scenarios, they will completely disappear by 2080 [2].

Global climate change is considered as a process that will lead to significant changes in climate parameters. It is predicted that global climate change will increase the rates of climate-related natural disasters and ecological degradation such as forest fires, drought, floods, desertification and erosion [20-23]. However, it is stated that the process in which the effects of global climate change will emerge in a multifaceted manner will affect many interrelated factors. For example, while the increase in CO2 concentration will lead to rapid growth [25], it will also result in UV-B increase [26,27], temperature increase [14] and drought [28] which are important stress factors in many species.

All phenotypic characters of living organisms are shaped by their genetic structure [29-33] and environmental factors [34-47]. Climate is one of the most important environmental factors [19,22]. It is stated that changes in climatic parameters, i.e. global climate change, will directly or indirectly affect forests by increasing the spread of insects and fungi [48], forest fires [43,49], alien species invasions [11], affecting water and nutrient availability, precipitation regime [50].

It is emphasized that the most important effects of the global climate change process will be temperature increase and decrease in water resources [12-14]. This situation will cause significant stress in plants because drought stress is one of the stress factors that affect plant development and survival the most [51-53]. In future climate projections, it is predicted that Türkiye's annual temperature will increase throughout the country until 2100, and this increase may reach up to 6 ºC in some regions. It is also predicted that the northern half of Türkiye will experience a much larger decrease in summer precipitation than the southern half. Chestnut is one of the species expected to be most affected by this process since its natural distribution areas are concentrated in the northern coastal part of Türkiye [2].

Similar results were obtained in studies on different tree species. Studies have shown that *Fagus sylvatica* L. and *Picea abies* (L.) Karst. populations in Europe will decrease due to climate change [54], there may be a 56% decrease in the potential distribution area of *F. sylvatica* [55], and habitat loss in different species in mountainous areas in Mexico may reach 77% by 2060 [56].

In fact, changes that may occur due to climate change will result in the transformation of suitable areas for some tree species into suitable areas for other tree species [57]. However, the limited migration mechanism of plants will cause plants to be unable to migrate to newly formed suitable areas. In this case, population and species loss will be inevitable [16,21].

As a result, it is stated that global climate change is an irreversible process that can directly or indirectly affect all living things and ecosystems on Earth. Global climate change is defined as the most important problem worldwide [11,58,59]. The living group that will be most affected by this process is plants, which do not have an effective mobility [22,23]. In addition to forming the basis of the food pyramid, plants fulfill many economic, ecological and social functions that are vital for other living things, especially humans [60-67]. Therefore, taking measures to ensure that plants are minimally affected by the effects of global climate change is of vital importance for humans. Reducing the impact of this process in forests and minimizing species and population losses is possible by predicting possible future changes from today and taking precautions and planning according to the changes that may occur. Therefore, it is recommended that detailed studies such as this study should be carried out and silviculture and management plans should be made taking into account the results of these studies [16,21].

4. Conclusion

It is known that climate change will have significant impacts on almost all living things and ecosystems. In order to mitigate this impact, first of all, measures should be taken on a global scale to eliminate the factors that trigger climate change, especially the use of fossil fuels and carbon emissions. In addition, measures such as reducing water consumption, using energy efficiently, focusing on renewable energy sources, preventing waste of resources and increasing recycling should be implemented rapidly.

The results of the study reveal that there will be significant changes in the distribution areas of chestnut populations in Kastamonu. It does not seem possible for the species to adapt to these changes without human intervention. Therefore, it is recommended to make necessary arrangements in forest management plans by taking the results of the study into consideration.

The different impacts of global climate change on forests mean that species need different silvicultural interventions. Which silvicultural interventions will provide the greatest benefit for which species should be determined based on the ecological context of the forest and the species' ability to adapt. Existing management plans and silvicultural practices should therefore be reviewed and redesigned to take into account the impacts of global climate change.

Besides being an important forest tree, chestnut is also an agricultural plant. Therefore, chestnut can be planted in areas with suitable conditions in the future to ensure its continued existence. In addition, drought, one of the most important impacts of climate change, can be overcome by irrigation in plantation areas. However, determining the most suitable species and origins for this process, that is, drought-resistant chestnut species and origins, and using them in afforestation studies can be seen as a wise solution.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they no conflict of interest. The none of the authors have any competing interests in the manuscript.

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