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Original Article

Potential Changes in the Suitable Distribution Areas of *Fagus orientalis* Lipsky in Kastamonu Due to Global Climate Change

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ABSTRACT

The present study aims to determine the current distribution areas of *Fagus orientalis* Lipsky and the changes in suitable distribution areas due to global climate change within the borders of Kastamonu Forest Regional Directorate of Forestry. In the present study, the current suitable distribution areas of *Fagus orientalis* and the suitable distribution areas in the years 2040, 2070, and 2100 according to socioeconomic pathway 126, socioeconomic pathway 370, and socioeconomic pathway 585 scenarios were determined. The study results indicate that the suitable distribution areas of *Fagus orientalis* populations in Kastamonu will change depending on the effects of climate change and that the change will be in the form of an increase in general.

Keywords: Beech, *Fagus orientalis* Lipsky, global climate change (GCC), SSP scenarios

Introduction

The world's population, which has reached approximately 8 billion nowadays, is concentrated in urban areas as a result of rural-to-urban migration due to industrialization (Dogan et al., 2023; Ghoma et al., 2022). Changing habits, desires, and needs due to technological advancements and also the production activities performed in order to meet them have disrupted the natural balance of the world. Human-induced environmental pollution has become one of the most important problems worldwide, and it has caused degradation in its structure by leading to pollution in soil (Cetin et al., 2022), water (Ucun Ozel et al., 2019), and air (Key et al., 2022). The remarkable increase in the concentrations of some substances in the air in relation to air pollution has led to global climate change (GCC) (Savas et al., 2021) and, together with urbanization, has made GCC the most important irreversible problem of the world nowadays (Sulhan et al., 2022).

Climate is a factor that directly or indirectly affects all living organisms (Ozel et al., 2022) because all phenotypic characteristics of living organisms are shaped under the effects of genetic structure (Kurz et al., 2023) and environmental conditions (Allen et al., 2010; Hoffmann et al., 2022; Tandogan et al., 2023; Tauqeer et al., 2022). Among environmental conditions, the most important and dominant parameters are climatic parameters (Koç, 2022). Thus, permanent changes in climate will not only affect humans but also all living organisms and ecosystems on the earth (Ghoma et al., 2022).

The group of organisms that would be affected by the potential changes in climate the most are plants because of their limited migration mechanism (Varol et al., 2021). Since plants' natural migration mechanism is not capable of keeping up with the pace of GCC, many plant species and populations might become extinct due to the effects of GCC (Tekin et al., 2022). During the process of GCC, it is estimated that suitable habitat areas would remarkably change for most plant species, and the migration mechanism of plants would not be able to adapt to this change (Dyderski et al., 2018).

Particularly because trees that are the main components of forests have long life cycles, it is emphasized that forests will experience the effects of GCC at a destructive level, and population and species losses will be observed in large areas. It is stated that it is necessary to determine the changes in suitable habitats in advance and to provide the migration mechanism, which plants need, by human intervention in order to reduce these losses (Cobanoglu et al., 2023a; Varol et al., 2022a, 2022b). However, detailed studies are needed to plan accurate silvicultural

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interventions. But most of the previous studies have been carried out in large areas to date (Cantürk & Kulaç, 2021). The present study aims to determine in detail how the suitable distribution areas of beech species might change due to GCC in the Kastamonu Regional Directorate of Forestry, which has the highest level of production in Türkiye.

Material and Methods

The present study was carried out in order to model the potential shift in the distribution areas of the oriental beech (*Fagus orientalis*), one of the most important tree species in Türkiye and Kastamonu, in response to GCC. This study is one of the most detailed and practice-oriented studies carried out on a small scale and can serve as an exemplary work on this subject.

Within the scope of this study, the current distribution area of the species was determined first, followed by the determination of the potential distribution area under current conditions. Then, the potential distribution areas for 2040, 2070, and 2100 were determined for Kastamonu province. MaxEnt 3.4.1 (Phillips & Dudik, 2008) was used in modeling the potential distribution of the species, whereas ArcGIS 10.5 (ESRI, 2017) was used for map representations. Nineteen bioclimatic variables, which were preferred in many previous studies (Canturk & Kulac, 2021), were used in this study, and the biological variables used are presented in Table 1.

Shared socioeconomic pathways (SSPs) include five main SSPs (SSP 119, SSP 126, SSP 245, SSP 370, and SSP 585) (Saha et al., 2021). Shared socioeconomic pathway 126, SSP 370, and SSP 585 scenarios were used in the present study. The atmospheric component of the Center National de Recherches Météorologiques model version 6 (CNRM-CM6-1), with a spatial resolution of 2.5 minutes, was used to represent stratocumulus in the study. Receiver operating characteristic (ROC) and area under the curve (AUC) values and the jackknife test were used for model validation (Varol et al., 2022a, 2022b). Ethic committee approval was not required for the study.

Table 1.
Bioclimatic Variables Used in Modeling

Codes	Bioclimatic Variables	Unit
Bio1	Annual mean temperature	°C
Bio2	Mean diurnal range [mean of monthly (max imum temperature–minimum temperature)]	°C
Bio3	Isothermality (Bio2/Bio7) (×100)	-
Bio4	Temperature seasonality (standard deviation × 100)	(coefficient of variation °C)
Bio5	Maximum temperature of warmest month	°C
Bio6	Minimum temperature of coldest month	°C
Bio7	Temperature annual range (Bio5–Bio6)	°C
Bio8	Mean temperature of wettest quarter	°C
Bio9	Mean temperature of driest quarter	°C
Bio10	Mean temperature of warmest quarter	°C
Bio11	Mean temperature of coldest quarter	°C
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	-

Results

Given the ROC curve obtained as a result of the modeling process conducted within the scope of the present study, the validation value of the training data was determined to be 0.799 (AUC > 0.5), while that of the test data was determined to be 0.796 (AUC > 0.5). These results indicate that the model has a high predictive power (Figure 1).

Examining the achievement table created for *F. orientalis* using the jackknife option in the model, it was determined that the environmental variables that had the highest effect on the species' distribution individually in the training data were "temperature annual range" [Bio7] and "temperature seasonality (standard deviation × 100)" [Bio4]. Among the environmental variables, other highly effective variables included "precipitation of wettest quarter" [Bio16] and "mean diurnal range [mean of monthly (maximum temp–minimum temp)]" [Bio2]. This finding reveals that the species is significantly affected by temperature and precipitation. The current distribution areas, suitable distribution areas given by the model, and distribution areas of *F. orientalis* in relation to GCC are shown in Figure 2.

The suitable distribution areas of *F. orientalis* in the SSP 126 scenario are expected to increase slightly when compared to both the current and the suitable distribution areas in the years 2040 and 2070. This increase will be observed mainly in the southern parts of the province, especially in the Ilgaz Mountain range. It is estimated that some of the fragmented distribution areas in the middle parts of the province would no longer be suitable as of the year 2100. The change rates of the suitable distribution areas of *F. orientalis* in the years 2040, 2070, and 2100 when compared to the current distribution areas in the SSP 126 scenario are presented in Table 2.

Examining the values presented in Table 2, it can be seen that *F. orientalis* has a potential distribution area of 3454.8 km^2, of which 0.6 km^2 is highly suitable, 1421.6 km^2 is quite suitable, and 2032.6 km^2 is suitable today. On the other hand, the total current distribution area of *F. orientalis* was calculated to be 1733.2 km^2. Considering the future changes in the suitable distribution areas of *F. orientalis* in the SSP 126 scenario, it is predicted that there will be a general increase in the total suitable distribution area. While the current suitable distribution area of *F. orientalis* is 3454.8 km^2, this area is predicted to be 3677.7 km^2 as of the year 2040, 3697.0 km^2 as of the year 2070, and 3588.2 km^2 as of the year 2100. However, the suitability will slightly deteriorate; the highly suitable areas, which are currently 0.6 km^2, will disappear, and the very suitable areas, which are currently 1421.6 km^2, will decrease to the level of 1211.1 km^2 as of the year 2040. The changes in the suitable distribution areas of *F. orientalis* relative to the current situation in the SSP 370 scenario are given in Table 3.

Examining the changes in the suitable distribution areas of *F. orientalis* in the SSP 370 scenario, it is estimated that the total suitable

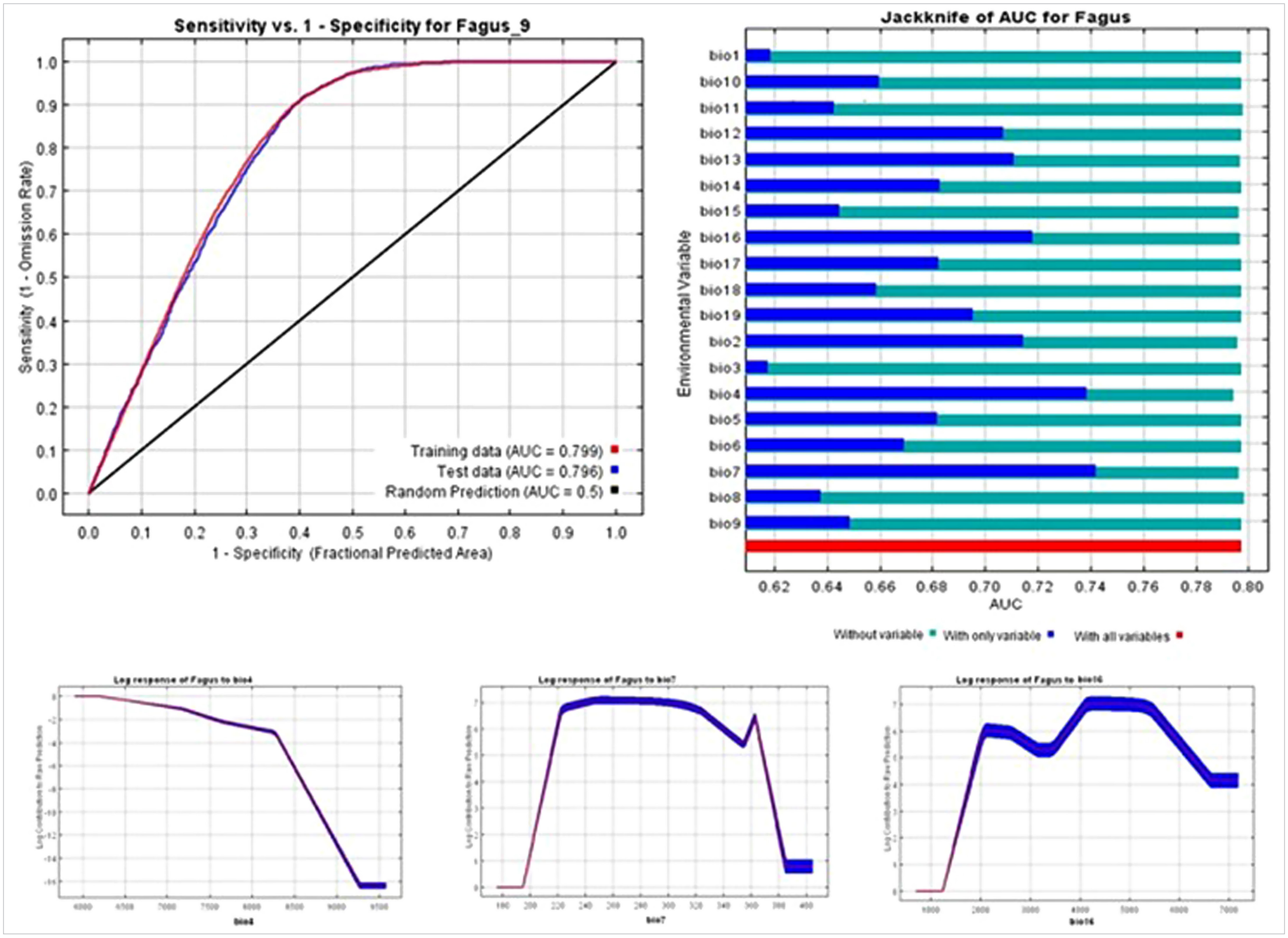

Figure 1.
Effects of Environmental Factors on the Distribution Area of Fagus orientalis. *AUC = area under receiver operating characteristic curve.*

distribution area will increase in comparison to the present day as of the year 2040 and will rise from 3454.8 km^2 in the present day to 3462.0 km^2 in the year 2040 and to 3761.4 km^2 in the year 2070. However, it is predicted that it will decline to 3607.6 km^2 by the year 2100. Nonetheless, it is projected that suitable distribution areas would decline slightly; highly suitable areas, which are currently 0.6 km^2, would disappear, and the very suitable areas would decrease from 1421.6 km^2 to 1352.7 km^2 as of the year 2040, to 1195.0 km^2 as of the year 2070, and to 1157.7 km^2 as of the year 2100. The rate of change in the suitable distribution areas of *F. orientalis* in comparison to the current according to the SSP 585 scenario is given in Table 4.

Given the changes in the suitable distribution areas of *F. orientalis* by the SSP 585 scenario presented in Table 4, it is estimated that the total suitable distribution area will increase as of the year 2040 when compared to the present day. While the current suitable distribution area of *F. orientalis* is 3454.8 km^2, this area is predicted to be 3540.6 km^2 in 2040, 3648.7 km^2 in 2070, and 3622.3 km^2 in 2100. However, it is expected that the suitability of the area will deteriorate to some extent; the highly suitable areas, which are currently 0.6 km^2, will disappear and the very suitable areas, which are 1421.6 km^2, will decrease to 1198.9 km^2 by 2040.

Discussion

The results of the present study indicate that the suitable distribution areas of beech populations in Kastamonu province will change due to the effects of climate change, and this change will occur in the form of a general increasing trend. However, examining the maps, it can be seen that, although there will be an increase in the total spatially suitable distribution areas, these areas will shift, which means that some of the current beech distribution areas will no longer be suitable in the future. In this case, population losses will be inevitable.

Similar results were achieved in different studies examining this subject. In a study carried out in Türkiye, it was estimated that there might be an increase by more than 66% in the suitable distribution areas of *Abies bornmulleriana* at the altitudes of 200–400 m in the year 2040, while the suitable distribution areas at the altitudes of 1800–2000 m might decrease down to 38.5% of the current level by the year 2100 (Tekin et al., 2022). It is predicted that the distribution areas of *Tilia cordata* in the western Marmara region will almost completely disappear, significant decreases will occur in the distribution areas of *Tilia tomentosa* in southern Anatolia (Hatay) and the Black Sea region, and there will be large losses in the distribution areas of *Tilia platypyllos* in eastern Anatolia (Canturk & Kulac, 2021).

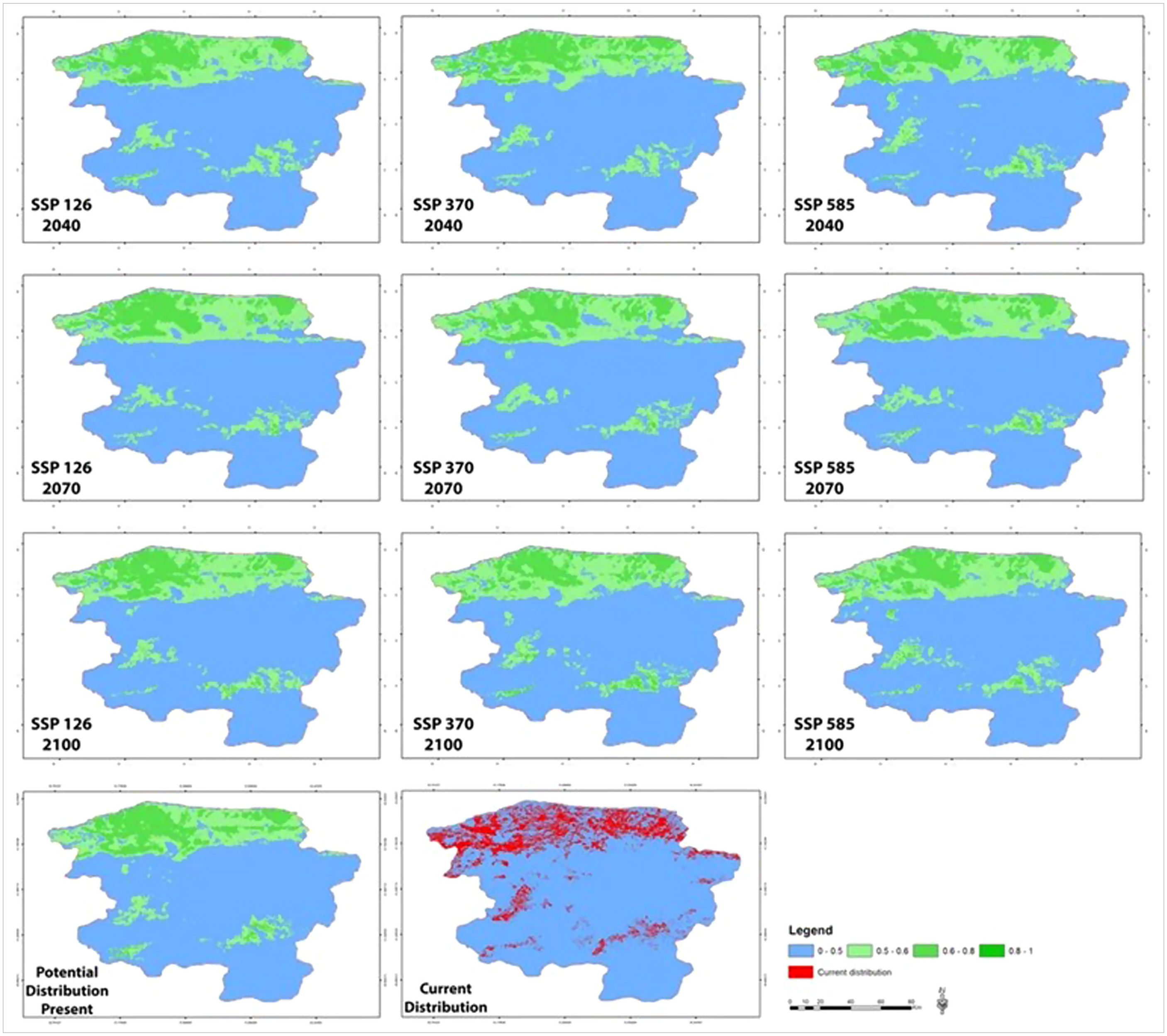

Figure 2.
Current Distribution Areas, Suitable Distribution Areas Given By the Model, and Distribution Areas of Fagus orientalis. *SSP = shared socioeconomic pathway.*

The effects of GCC might cause population losses in *Carpinus betulus* at altitudes lower than 1600 m by more than 25% and in *Carpinus orientalis* at altitudes lower than 1000 m by more than 30% until the year 2100 (Varol et al., 2021). The loss in the potential distribution areas of *Pinus pinea* might hit almost 85% (Akyol & Örücü, 2020), and it is estimated that the suitable distribution area of *Quercus libani*, which is currently around 72,819 km^2, might decrease to 63,390 km^2 by the year 2070 (Çoban et al., 2020).

Similar results were achieved in studies carried out in different regions of the world. Significant decreases in the distribution areas of *Fagus sylvatica* (Thurm et al., 2018), *Larix decidua, Picea abies, Betula pendula*, and *Pinus sylvestris* (Dyderski et al., 2018) are predicted in Europe. Moreover, it is emphasized that this decrease will be seen not only in natural forests but also in plantation areas (Quinto et al., 2021). Furthermore, it is also stated that this change will occur more recently in some regions. For instance, it is mentioned that habitat loss in mountainous areas in Mexico might reach 77% in different species by the year 2060 (Gómez-Pineda et al., 2021).

However, previous studies emphasized that there could be significant increases in suitable distribution areas for some species. For instance, Hirata et al. (2017) reported that there could be an increase by almost 50% in potential distribution areas for *Pinus* species until the year 2070. López-Tirado et al. (2021) suggested that potential distribution areas for *Cedrus libani* will increase substantially, while Ouyang et al. (2022) stated that the most suitable distribution areas for *Eucalyptus grandis* will expand toward lower altitudes until the 2070s. However, it is not

Table 2.
Change in the Suitable Distribution Areas of Fagus orientalis *by the Socioeconomic Pathway 126 Scenario*

Suitability	2020 Current (km²)	2020 Potential (km²)	SSPs 126 2040 (km²)	2070 (km²)	2100 (km²)
0–0.5	11319	9597.4	9374.5	9355.2	9464
0.5–0.6	1733.2	2032.6	2466.6	2413.2	2330.8
0.6–0.8		1421.6	1211.1	1283.8	1257.4
0.8–1		0.6	0	0	0
Total (km²)	13052.2	13052.2	13052.2	13052.2	13052.2

Note: SSP = shared socioeconomic pathway.

Table 3.
Change in the Suitable Distribution Areas of Fagus Orientalis *by the Socioeconomic Pathway 370 Scenario*

Suitability	2020 Current (km²)	2020 Potential (km²)	SSP 370 2040 (km²)	2070 (km²)	2100 (km²)
0–0.5	11,319	9597.4	9590.2	9290.8	9444.6
0.5–0.6	1733.2	2032.6	2109.3	2566.4	2449.9
0.6–0.8		1421.6	1352.7	1195.0	1157.7
0.8–1		0.6	0	0	0
Total (km²)	13,052.2	13,052.2	13,052.2	13,052.2	13,052.2

Note: SSP = shared socioeconomic pathway.

Table 4.
Change in the Suitable Distribution Areas of Fagus orientalis *by the Shared Socioeconomic Pathway 585 Scenario*

Suitability	2020 Current (km²)	2020 Potential (km²)	SSP 585 2040 (km²)	2070 (km²)	2100 (km²)
0–0.5	11,319	9597.4	9511.6	9403.5	9429.9
0.5–0.6	1733.2	2032.6	2341.7	2358.4	2437
0.6–0.8		1421.6	1198.9	1290.3	1185.3
0.8–1		0.6	0	0	0
Total (km²)	13,052.2	13,052.2	13,052.2	13,052.2	13,052.2

Note: SSP = shared socioeconomic pathway.

possible to naturally transport species to new suitable distribution areas, and therefore, migration mechanisms need to be facilitated by humans (Tekin et al., 2022). As a result, detailed studies that can guide forestry and management plans, as in this study, are necessary.

Ayan et al. (2022); Altitude is the most important factor that will affect the distribution area. This situation is applicable to many of the apricot woodlands around the world. The main reason for this situation is the moisture demand in the distribution area of the beech. Humidity is one of the most important factors determining the distribution area of beech (Dagtekin et al., 2019; Martin-Benito et al., 2018). In studies on GCC, it is predicted that the most important changes in the coming years will be in temperature, precipitation, and, accordingly, the humidity parameters (Cetin et al., 2023; Isinkaralar, 2023; Laporta et al., 2023; Zhang et al., 2023).

Global climate change is considered to be a process that will affect the lives of organisms in many ways because all the phenotypic characteristics of living organisms are shaped under the effects of climate (Key et al., 2022). It is stated that changes in climate parameters, i.e., GCC, will affect the spread of fungi and insects (Anderegg et al., 2022; Morera et al., 2022) in forestlands, increase the number and amount of forest fires (Ertugrul et al., 2021), and directly or indirectly influence forests by affecting water and nutrient availability and precipitation regimes (Peñuelas et al., 2018).

Global climate change might accelerate plant growth due to increased CO_2 concentration (Brundu & Richardson, 2016; Walker et al., 2019), but it might also result in various stress factors in many species, such as increased ultraviolet B radiation (Ozel et al., 2021), temperature increase, and drought (Koç, 2021), especially causing significant damage in plants under drought stress (Cobanoglu et al., 2023b; Ghoma et al., 2022).

As a result, GCC can be regarded as an irreversible process that can directly or indirectly affect all organisms and ecosystems on the earth (Tekin et al., 2022; Yayla et al., 2022). The group that would be affected by this process the most are plants, which do not have an effective movement capacity (Varol et al., 2021). In addition to laying the foundation of the food pyramid, plants fulfill many economic, ecological, and social functions that are vital to other organisms, particularly humans (Kuzmina et al., 2023). Therefore, taking measures to minimize the effects of GCC on plants is crucial for humans. It is possible to reduce the effect of this process on forests and minimize the loss of species and population by predicting future changes and taking action accordingly. Therefore, detailed studies on different species and populations, as in the present study, are recommended for planning silvicultural and management plans based on the results of these studies.

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