Role of Climate Change on Oriental Spruce (*Picea orientalis* L.): Modeling and Mapping

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Global climate change is a process with dramatic consequences for ecosystems, and changes that may occur in the potential distribution of plant communities especially draw attention. This study aimed to reveal the potential distribution modeling and mapping of the Oriental spruce (*Picea orientalis* L.), distributed in a limited area, using current and future (year 2100) climate scenarios in Turkey. The maximum entropy method for potential distribution and Chelsa V2.1 technical specification IPSL-CM6A-LR scenarios (SSP126-SSP370-SSP585) were preferred to reveal the effect of climate change. Results for the current were in the "excellent" category with training and test data AUC 0.981 and 0.977, respectively. The variables contributing to the model were the precipitation amount of the driest month, mean diurnal air temperature range, annual precipitation amount, and mean annual air temperature. Variables contributing to the current model were analysed using the SSP126, SSP370, and SSP585 scenarios of the year 2100. It was assessed that the potential distribution for 2100 decreases according to SSP126, was fragmented according to SSP370, and decreased according to the SSP585 scenario. As a result, the authors determined that the high potential distribution is reduced 61% when the current mapping of Oriental spruce is compared with the SSP585 mapping.

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INTRODUCTION

The current distribution of Oriental spruce (*Picea orientalis* L.), belonging to the Pinaceae family, covers a limited area in the Black Sea region of Türkiye and the Caucasus (Kayacik 1955). Although it is economically valuable, the area covered by Oriental spruce is approximately 2.3% of the total forest area in Türkiye (Konukcu 2001). However, because of its softwood structure (Yaşar *et al.* 2016), Oriental spruce is used in many areas such as the paper industry and cellulose production, building materials, sleepers, joinery and furniture, poles, chip and fibreboard, plywood, musical instruments, and resin production. Moist soils with temperate and cold climates are very suitable growing environments for Oriental spruce. Therefore, it is inevitable that the potential distribution of Oriental spruce will be affected by increasing temperatures or decreasing precipitation (climate change) on a global scale.

Climate change is a process that has led to dramatic consequences on ecosystems in recent years. Particularly, the changes that may occur in the potential distribution of plant communities has drawn increased attention (Özdemir *et al.* 2020). Global climate envelope models come to the fore to predict whether plant species distributions can survive the expected climate change with minimum damage (Randall *et al.* 2007). Global climate models are the most advanced systems used to make climate-related statistical evaluations and to determine how the climate will change. Chelsa climate envelope models, one of these systems, are important in modeling the potential distribution of plants in current and future years (Karger *et al.* 2017).

Potential distribution modeling methods are divided into two categories: connection and mechanical. Mechanistic methods require eco-physiological properties that are difficult to achieve for the target plant species. There is no need for such information in connection methods that are classified as presence-absent and working only with presence data (Özkan 2013). Maximum entropy (MaxEnt) software, which is one of the methods that works only with presence data, provides more accurate and reliable results than modeling methods that work with present-absent data (Elith *et al.* 2011). In addition, MaxEnt software helps take conservation measures by analyzing continuous and categorical data affecting plant species distribution and simulating changing climate conditions for future years (Phillips and Dudík 2008; Kıraç and Mert 2019; Suel 2019; Özdemir *et al.* 2020). Based on its accuracy and reliability, the MaxEnt method is frequently preferred in modeling the potential distribution of plant species.

This study aimed to reveal the potential distribution mapping of Oriental spruce, which is likely to be affected by changing climatic conditions currently and in the future (2100), using the MaxEnt method. For this purpose, current and future climate were preferred in the CHELSA V2.1 technical specification IPSL-CM6A-LR scenarios. This study has a unique value with its first numerical and model-based mapping of environmental and climatic changes affecting the distribution of Oriental spruce. Potential distribution maps of Oriental spruce created using modeling results according to different years and scenarios classified its distribution as low ($r < 0.5$) and high ($r > 0.5$) (Yi *et al.* 2019). As a result, priority areas have been determined for the protection, development, and sustainability of this species to meet the increase in demand for wood raw materials of Oriental spruce under changing climate conditions.

EXPERIMENTAL

Study Area and Data Collection

The wood raw material of Oriental spruce, one of Türkiye's main tree species, has a great economic value. For this reason, the demand for Oriental spruce wood raw material, which is generally distributed in the eastern Black Sea region in Türkiye, is constantly increasing. Although the potential distribution is in a limited area, numerical and model-based mapping methods are likely to yield more accurate and reliable results in larger areas (Özdemir 2024). Therefore, this study was conducted in the Black Sea region, which is one of the temperate and cold regions, corresponding to approximately 18% of Türkiye's surface area. The study area has a mountainous and rugged structure, with the lowest elevation starting at sea level (0 m) and the highest elevation being 3655 m. The main tree species of the study area, which has an area of approximately 134.8 km^2, are Oriental beech (*Fagus orientalis*), alder (*Alnus glutinosa*), and Oriental spruce (*Picea orientalis*), which are distributed in pure and mixed stands. In the study area, summer is cool, winter is mild in the coastal areas, and snowy and cold in the higher areas. This area receives perception every season, and there is no water shortage. In this context, to reduce the standard deviation of potential distribution modeling and mapping, presence data of the Oriental spruce were obtained from articles, master's, and doctoral theses on Oriental spruce in Türkiye (Ercanli 2003; Turna 2004; Tüfekçioğlu *et al.* 2008; Üçler *et al.* 2011; Yener 2013), and Global Biodiversity Information Facility (GBIF 2022) internet webpages. For this research conducted to determine the effect of climate change on Oriental spruce, there are 329 presence data shown in green (Fig. 1).

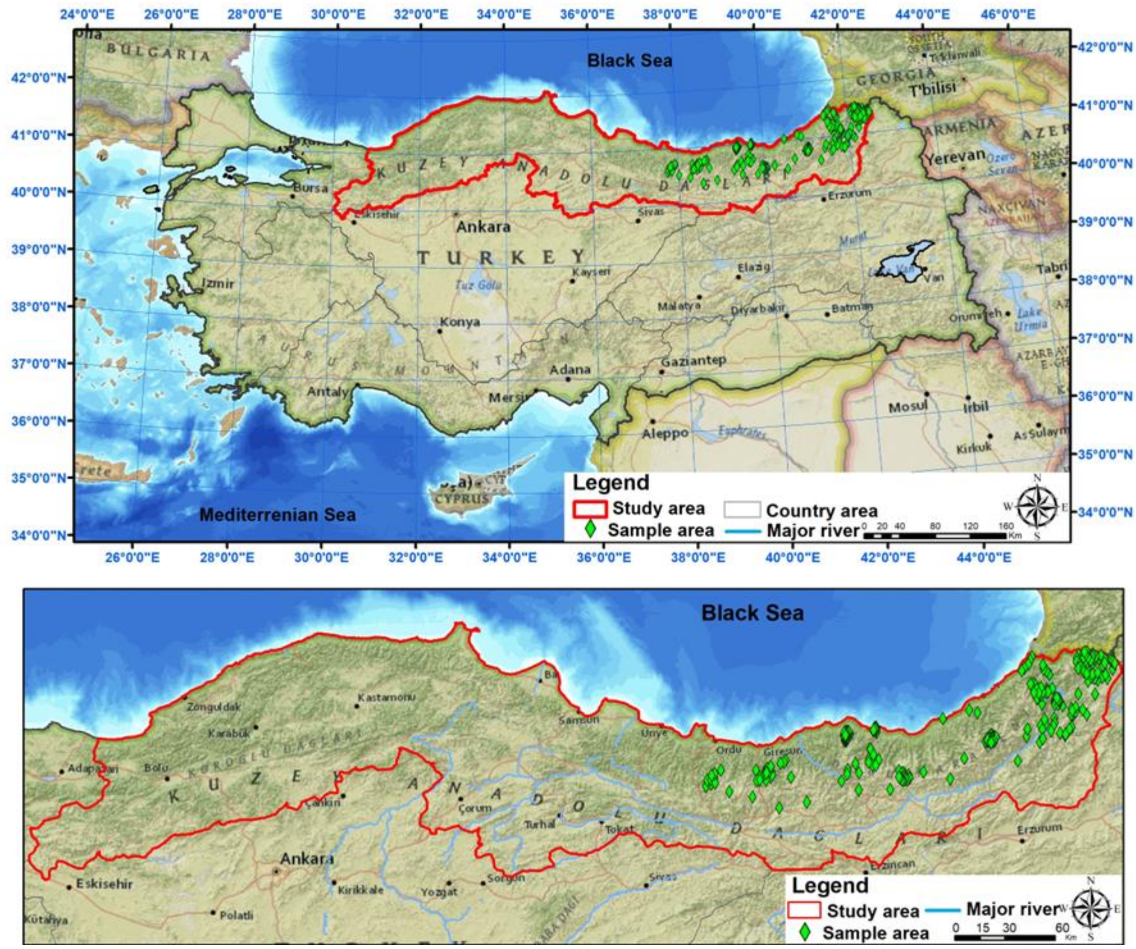

Fig. 1. Location map of the study area and Oriental spruce presence data

Numerical-based Environmental and Chelsa Climate Variables

Base maps were first created for numerical and model-based potential distribution maps. The digital elevation model (30 arc-second ~1 km) was downloaded to the world scale from the internet address https://www.usgs.gov/ and resized according to the study border. The "Lambert Conformal Conic ED50" coordinate system was introduced to the digital elevation model map obtained according to the working boundary. Using the digital elevation model, environmental variables that could be effective on the distribution of Oriental spruce were created with the help of various formula, index, or toolbox in the ArcMap 10.8 software. In addition, environmental variables, such as stand type, area (ha), age classes, cover, and bedrock, were obtained from the General Directorate of Forestry and the General Directorate of Exploration and Mineral Research.

High-resolution information on climate change is important for plant species distribution. Worldclim and Chelsa climate envelope models are generally preferred, as they provide high resolution in species distribution modeling (Karger *et al.* 2017). While more accurate results are obtained with Worldclim climate variables in small-scale areas, Chelsa climate variables come to the fore in large-scale area. Because the study area has a large scale, Chelsa climate envelope models were preferred. Chelsa climate envelope models V2.1 (current and future) are available at www.chelsa-climate.org. High resolution Chelsa climate variables (30 arc-second ~1 km) from version 2.1 were downloaded in ESRI Grid format. In addition, IPSL-CM6A-LR (SSP126-SSP370-SSP585) scenarios for the year 2100 in Version 2 were preferred to reveal the effect of changing climate conditions over a long period of time on the potential distribution of Oriental spruce. All variants of SSP126-SSP370-SSP585 climate scenarios are based on daily, monthly, and annual times. The variables of these times have their characteristics and can be calculated separately (Karger *et al.* 2017).

Species Distribution Modeling (Maximum Entropy) and Mapping

MaxEnt version 3.4.4 (Phillips and Dudík 2008) was used to model and map the Oriental spruce, which exists with a limited potential distribution area (Özkan *et al.* 2015; Süel *et al.* 2018). The purpose of the MaxEnt method is to explain that it is a measure of variable uncertainty limited by environmental and climatic changes. In fact, it is a measurement of how many alternatives can be classified to obtain information about a situation. More precisely, MaxEnt, which is the Similarity software, is the probability of finding target types at that pixel for each pixel in the work area and simulating this probability for the entire work area (Yost *et al.* 2008). This software works with a regular distribution and calculates to what extent the variable distribution changes with the specified degree and repetition. The results of this analysis, called gain, are described as covariance calculation. This value is 0 before starting the calculation, and it increases with each iteration it calculates (Elith *et al.* 2011). It is repeated until the gain value reaches the maximum value or becomes lower than the previous gain value.

As with other species distribution modeling methods, the accuracy of the model obtained from the MaxEnt method must be checked. In this context, AUC (Area Under Cover) values and Jackknife training graphics obtained in the model results need to be analysed. In a study conducted by Swets (1988), these AUC values were classified as "excellent" (AUC > 0.90), "very good" (0.90 > AUC > 0.81), "good" (0.80 > AUC > 0.71), "low" (0.70 > AUC > 0.61), and "unsuccessful" (AUC < 0.60). In the Jackknife chart, care should be taken to ensure that the contribution level of the variables contributing to the model alone does not exceed the contribution to the entire model. In this study, the cross-validation option was applied by accepting the test percentage and number of repetitions of the model as 10 (Phillips 2005). These processes were continued until the model that best explained the relationship between the dependent and independent variables was obtained. To determine the variables contributing to the model, the elimination process was carried out according to their contribution rates.

RESULTS AND DISCUSSION

Analyses for the potential distribution modeling were started with 329 presence data of Oriental spruce. A total of 28 environmental and 19 Chelsa climate variables were produced to the extent of study area border. Modeling processes were applied to the cross-validation option, assuming the test percentage and number of repetitions were 10, and analyses were performed with 500 iterations. Of the 47 different variables produced for the study area, variables with at least a percentage contribution and low permutation importance were removed from the model and the modeling process continued until 2 variables remained. According to the modeling results, the best model was selected with the training data set AUC 0.981 and the test data set AUC 0.977 (Fig. 2a). When the obtained model training and test data AUC values were compared according to Swets (1988) and Yesilnacar (2005) classification, it was determined that they were in the "excellent" category. The standard deviation in the average omission of current potential distribution model of Oriental spruce, which is in the excellent category, was 0.004 (Fig. 2b).

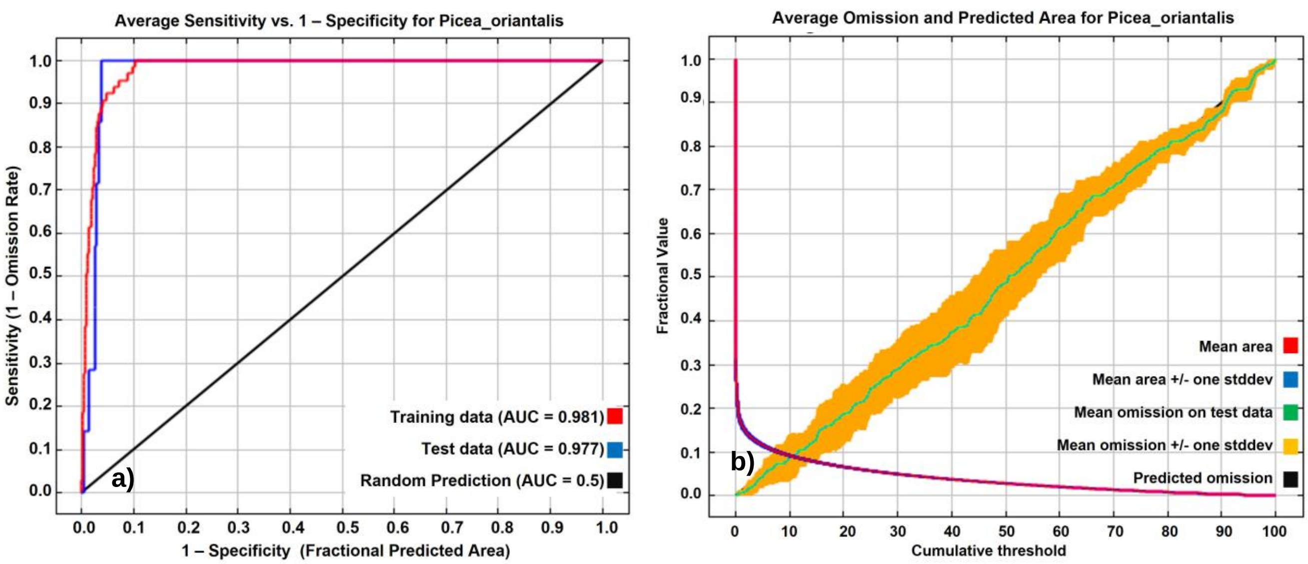

Fig. 2. Current potential distribution model of Oriental spruce: a) Training data set and test data set AUC graph, and b) Average omission chart

The variables that structure the model with low standard deviation were mean annual air temperature (bio1), mean diurnal air temperature range (bio2), annual precipitation amount (bio12), and precipitation amount of the driest month (bio14). In addition, after the current potential distribution modeling process of Oriental spruce was completed, the accuracy of the model obtained was checked. In this context, Pearson correlation analysis was applied among the environmental variables and Chelsa climate variables produced for the study area. Principal component analysis was applied to reveal the most effective variables on the distribution of Oriental spruce among environmental variables and climate variables that are highly correlated ($r < 0.80$) with each other. As a result of the principal components analysis, it was determined that the most effective climate variables on the Oriental spruce were the variables that contributed to the model. Thus, with the results of statistical analysis, it was determined that the model results are accurate and reliable. According to model result, the climate variables that alone contributed the most to the Jackknife graph were bio14, bio2, bio12, and bio1, respectively.

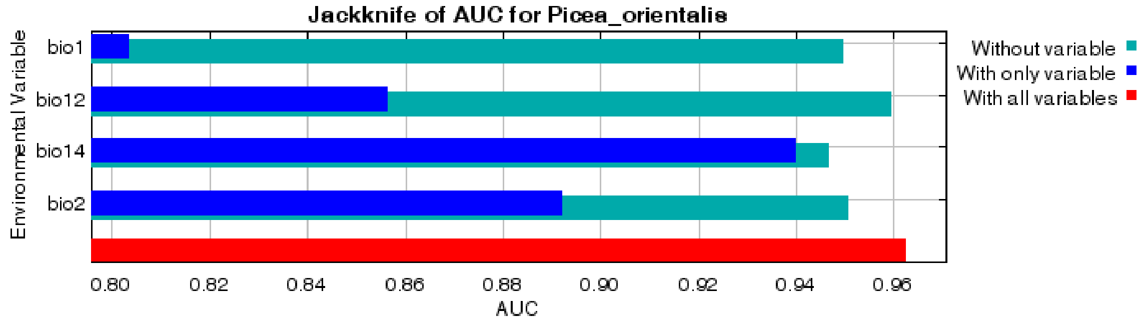

Fig. 3. Jackknife graph of current potential distribution model of Oriental spruce

Marginal response graphs of the variables contributing to the model were also examined. Areas with a variable value of up to 150 mm of precipitation amount of the driest month, which alone contributes the most to the formation of current potential distribution model of Oriental spruce, are suitable (Fig. 4a). It is the driest summer season, with low precipitation and high temperatures throughout the study area. Ata (1980) found in his study that Oriental spruce saplings were negatively affected by the decrease in precipitation in the summer and the burning and drying temperatures. Barber *et al.* (2000) found that temperature-induced drought stress disproportionately affected the fastest-growing white spruce. They also found that drought is an important factor limiting carbon uptake and distribution of forests in North America due to global climate warming. In this context, the increase in temperature or decrease in precipitation during the growth period of plant species in forest areas affects their productivity (Boisvenue and Running 2006). Yener (2013) found that the climate variables that have an impact on the productivity of pure Oriental spruce stands distributed on the sea-facing slopes of the Eastern Black Sea region are variables such as temperature and precipitation during the growth period.

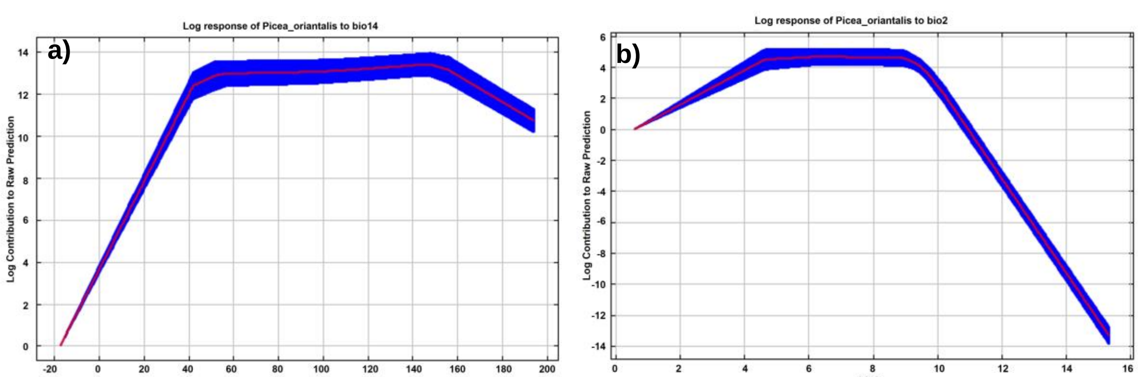

Fig. 4. Oriental spruce contributing to current potential model: a) precipitation amount of the driest month (bio14), and b) mean diurnal air temperature range (bio2) graph

According to the mean diurnal air temperature range variable that contributes to the model, it has been determined that areas within the study area where the daily average temperature differs between 1 °C and 9.5 °C are suitable for species distribution, and areas after these values are unsuitable (Fig. 4b). Atalay (1976) found that the daily temperature difference at the seaside of pure eastern spruce forests, which are distributed in different growing environments, is 4 °C to 6 °C in summer and 6 °C to 8 °C in winter. Akalp (1978) stated that the daily temperature requirement is low, and humidity is high for the best development and productivity of the Oriental spruce. Yener (2013) found that the daily average temperature difference in pure Oriental spruce stands located far from the seaside varies between 7 °C to 9 °C. Therefore, the variable value results of precipitation amount of the driest month and mean diurnal air temperature range, which contribute the most to current potential distribution model of Oriental spruce, are in the same direction as the literature.

In the annual precipitation amount graph, which contributes to the current potential distribution model of Oriental spruce, it has been determined that areas with an annual precipitation amount of up to 2300 mm are suitable and areas with a precipitation amount greater than this value are unsuitable (Fig. 5a). Türkiye’s Black Sea region is divided into 3 regions: eastern, western, and central black sea. The average annual rainfall in the Western Black Sea region ranges between 1000 to 1500 mm. In the central Black Sea region, this value is between 450 to 700 mm. In the Eastern Black Sea region, the average annual rainfall ranges between 1500 to 2500 mm (Öztürk *et al.* 2017). According to model results, the target plant species is likely to be generally distributed in the eastern Black Sea region. Akgül (1989) found that the annual precipitation amount in the natural growing areas of Oriental spruce ranges between 700 to 2000 mm. In a study conducted by Yener (2013), it was stated that the Oriental spruce species had the best development in areas with nutrient and average water capacity where the annual precipitation amount was between 230 to 400 mm. In the study conducted by Jansson *et al.* (2013), it was determined that Oriental spruce grows best in wet and swampy soils above the water capacity.

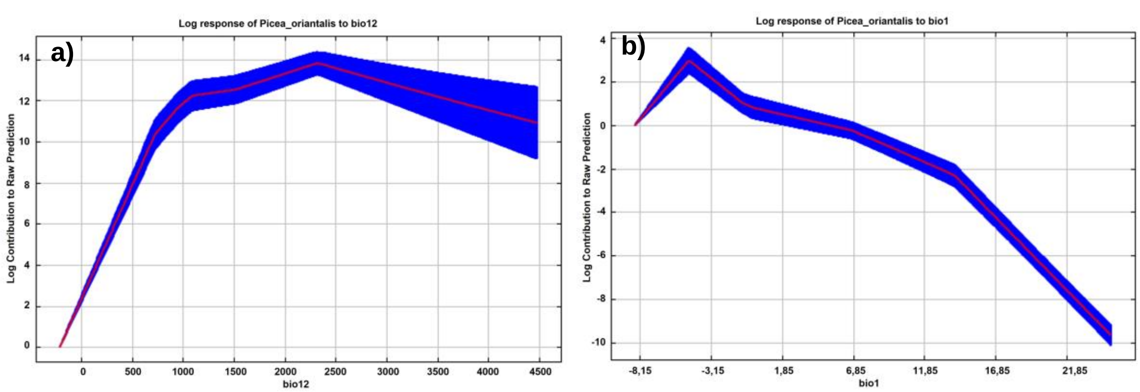

Fig. 5. Oriental spruce contributing to current potential model: a) annual precipitation amount (bio12), and b) annual mean temperature (bio1) graph

Areas with annual mean temperature values between -8 and 14.5 °C, which contribute the least to current potential distribution model of Oriental spruce, have a high relationship, and areas before or after these values have a low relationship (Fig. 5b). Atalay (1976) obtained from field studies that depending on the altitude in the study area, the annual mean temperature of Oriental spruce at 1000 m altitude ranges between 3 to 7 °C, and at 1500 m it was between 2 and 4 °C. Perry *et al.* (1994) stated that the natural environments of spruce species in forest ecosystems are between -5 °C and 3 °C in annual mean temperature. Tüfekçioğlu *et al.* (2008) stated that in general, Oriental spruce is distributed in pure and mixed forms in areas where the annual mean temperature is 5 °C to 10 °C. Yener (2013) found that Oriental spruce photosynthesized at temperatures as low as -6 °C and -7 °C during their vegetation period in their general distribution area. In this context, the variable value results of the annual precipitation amount and annual mean temperature, which contribute the least to the current potential distribution model of Oriental spruce, were the same results as the literature.

The potential distribution map of the species is presented in Fig. 6, based on the variable value results that are effective in current model of Oriental spruce. In general, it was determined that the eastern region of the Black Sea, which constitutes the study area, is the area with high potential distribution of the Oriental spruce. In addition, some areas with southern aspect and low elevation located in the northwestern part of the study area are suitable areas for the growing environment of Oriental spruce. Kayacik (1955) and Konukcu (2001) stated in their studies that Oriental spruce has a potential distribution only in the eastern Black Sea region. However, it was clearly seen that these studies were not numerical, and model based. Therefore, in these studies conducted in smaller-scale areas, no mapping could be revealed about the potential distribution of Oriental spruce. As a result, in addition to being numerical and model-based, it will contribute to the literature that the current distribution of the Oriental spruce can be expanded according to this mapping with the climate variables that are effective in its potential distribution.

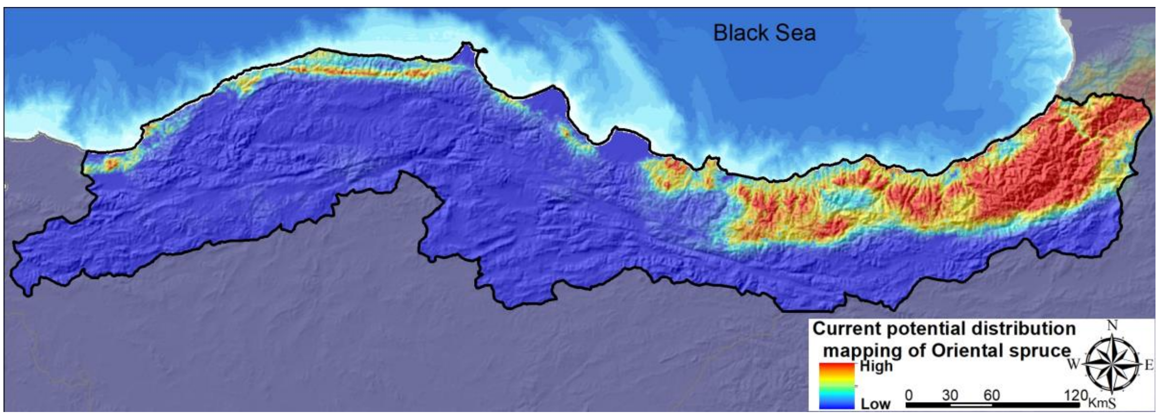

Fig. 6. Current potential distribution map of Oriental spruce

After obtaining the potential distribution model of current Oriental spruce, it was aimed to determine the potential distribution of the target species under changing climatic conditions in 2100. For this purpose, SSP126, SSP370, and SSP585 envelope models belonging to the IPSL-CM6A-LR scenario, one of the Chelsa global climate models for the year 2100, were used. According to the modeling results simulated according to the SSP126 envelope model for the year 2100, it was determined that there were decreases in the mapping of the potential distribution of Oriental spruce (Fig. 7a). In the SSP370 envelope model map for the year 2100, it was revealed that the areas with high distribution potential of Oriental spruce will be fragmented (Fig. 7b). Finally, according to the SSP585 envelope model for the year 2100, it was determined that the areas with high potential distribution of the Oriental spruce will decrease extremely and even disappear (Fig. 7c). Tüfekçioğlu *et al.* (2008) stated through literature studies and field observations that climate change will affect Oriental spruce forests. According to meteorological station data in the area, they estimated that the temperature would increase 2 to 4 °C and the amount of precipitation would increase 200 to 300 mm. It is predicted that increasing temperatures will cause Oriental spruce ecosystems to be exposed to more stress and may increase bark beetle outbreaks. Therefore, they estimated that the Oriental spruce belt within the small-scale area would probably shift upwards by 400 to 800 m and narrow.

Finally, the potential maps of Oriental spruce Chelsa SSP126, SSP370, and SSP585 envelope models were classified as low and high (Fig. 7d). According to this classification, 28% of the Oriental spruce study area current, 24% in the SSP126 scenario, 19% in the SSP370 scenario, and 11% in the SSP585 scenario were determined as areas with high potential distribution. When the current mapping of Oriental spruce was compared to the SSP585 scenario mapping, it was determined that the high potential distribution decreased 61%. Climate change that may occur due to factors, such as temperature or precipitation, has an impact on plant species with ecological and economic value such as Oriental spruce. According to the Chelsa climate scenarios of year 2100, the potential distribution of Oriental spruce is predicted to have irreversible consequences.

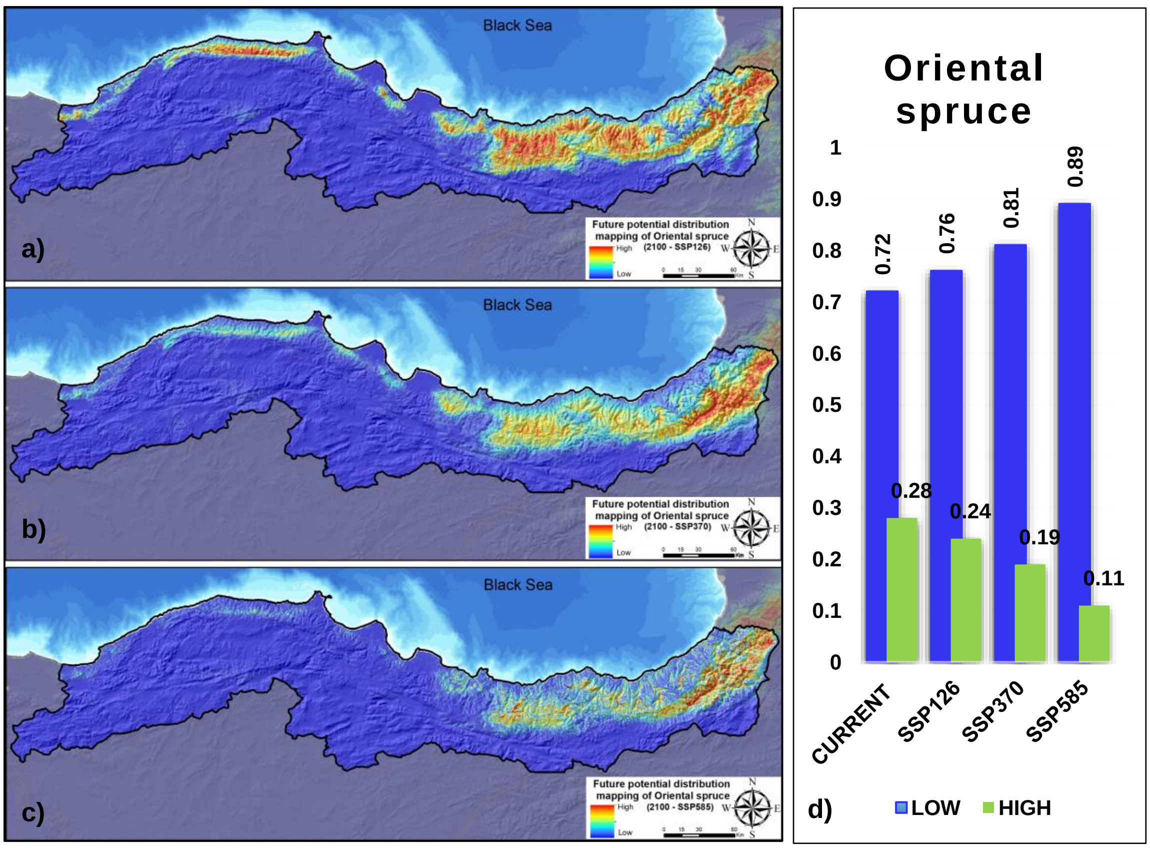

Fig. 7. The potential distribution of Oriental spruce in the year 2100 under scenarios a) SSP126, b) SSP370, and c) SSP585, along with d) potential distribution rates

CONCLUSIONS

1. The method and climate envelope models used in this work to reveal the climate change on the potential distribution of Oriental spruce are a guide for species distribution modeling.
2. Priority should be given to the areas shown in the potential distribution maps of the Oriental spruce, which will enable it to overcome the negative effects of climate change, one of the threats of the 21st century, with the least damage (Fig. 7c).

3. This numerical and model-based study provides important outputs for management plans to meet the wood raw material demand of Oriental spruce, which has a wide usage area, in conservation, development, sustainability, and the forest industry.
4. Finally, modeling and mapping of the potential distribution of Oriental spruce under the influence of climate change can later be integrated with studies on different subjects, such as biodiversity and species distribution mapping, and will contribute to researchers.

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