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INVESTIGATION AND EVALUATION OF STONE PINE (*Pinus pinea* L.) CURRENT AND FUTURE POTENTIAL DISTRIBUTION UNDER CLIMATE CHANGE IN TURKEY

AKYOL, A.; ORUCU, O. K. Investigation and evaluation of stone pine (*Pinus pinea* L.) current and future potential distribution under climate change in Turkey. **CERNE**, v. 25, n. 4, p.x-x, 2019.

HIGHLIGHTS

The most effective bioclimatic variable in the potential distribution of stone pine was minimum temperature of coldest month (Bio6).

The prediction model in 2050-2070 and RCP4.5-8.5 showed that the stone pine habitat would decrease.

According to prediction model, stone pine will shift geographical distribution towards north sites.

The most suitable potential habitats should be prioritized for afforestation investments.

ABSTRACT

Climate change has negative effects on especially plant species that have a limited habitat. In this context, the stone pine (*Pinus pinea* L.), which has a limited distribution, is prominent with its economic, ecological and aesthetical characteristics, and it is frequently preferred in afforestation. In this study, the habitats in Turkey that are suitable for distribution of *P. pinea* L. were modelled by using Maxent based on high-resolution environmental data. In total, 13 field-based occurrence points and 19 bioclimatic variables were used to model the potential distribution area under current and two prediction model (RCP4.5 and RCP8.5) for the years 2050 and 2070. According to the results, the most important bioclimatic variables effective on the potential distribution of *P. pinea* L. were found as the minimum temperature of coldest month (Bio6), annual precipitation (Bio12) and precipitation of wettest quarter (Bio16). Prediction models under two future climate change scenarios displayed that *P. pinea* L. will lose habitat and it will shift geographical distribution towards north and higher elevation sites. Considering especially the economic contributions provided by *P. pinea* L., these results necessitate consideration of the areas where the rate of potential distribution of the species is the highest in afforestation work aiming rural development. In addition to habitat losses, climate change affects many variables of the ecosystem.

Keywords:

Afforestation
Climate change
Geographical distribution
Bioclimatic variables
Habitat suitability
Maxent
Species distribution models

Historic:

Received 16/05/2019
Accepted 27/11/2019

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DOI:

10.1590/01047760201925042643

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INTRODUCTION

Turkey is a highly rich country in terms of diversity of plant species (Davis, 1982; Davis et al., 1988), and it contains many plant species which show a natural distribution and commercial importance. The number of people who live especially in rural areas and utilize these plants directly and indirectly is very high, and these species also have great significance in terms of rural development practices. In this context, stone pine (*Pinus pinea* L.), which is one of the species that are naturally distributed in the Mediterranean forest ecosystem, is frequently preferred and utilized afforestation practices. However, *P. pinea* L. does not have a broad distribution in the world. Approximately 70% of the *P. pinea* L. forests of the world are located in Spain, and most of these forests in Spain are plantations (Bravo-Oviedo and Montero, 2005). The countries where the species naturally grows are Spain, Portugal, Italy, France, Corsica, Turkey, Greece, Lebanon and Syria. In addition to these, it is known that plantations are made in countries like Albania, Croatia, Serbia, Russia, Ukraine, Cyprus, Israel, Libya, Morocco, South Africa, Tunisia, Argentina and Brazil. *P. pinea* L. locally is distributed in Bergama-Kozak, Aydın-Koçarlı, Muğla, Antalya-Manavgat, Gemlik, Artvin-Fıstıklı village, Trabzon-Kalenema, Kahramanmaraş-Hacıağalar and Önsen villages and Bartın-Çakraz and has a high economic value (Yalıtırık, 1988; Kılıcı et al., 2000; Batur, 2015; Güleç, 2015).

In recent years, in addition to socioeconomic studies related to non-wood forest products, ecological studies have increased (Ticktin, 2004). In addition to its good ecological adaptation to high temperatures and drought, *P. pinea* L. also tolerates water stresses to a significant extent thanks to its deep roots (Castillo et al., 2002; Teobaldelli et al., 2004). *P. pinea* L. is also a more durable species in comparison to other pine species in the Mediterranean forest ecosystem against diseases and pests (Yılmaz and Erbilgin, 2010). Stone pine is frequently preferred in afforestation practices due to its ecological, economic and aesthetical characteristics, and it is among the top species that provide important contribution to the national economy as a non-wood product (Kırdar et al., 2010; Kurt et al., 2016). As it is a highly valuable product in international markets, it provides producers with more income in comparison to other forest products (Mutke et al., 2005). Especially cone and pine nut production has very significant social and economic contributions in forest villagers. This is why *P. pinea* L. is planted in Turkey intensively for achieving multifunctional purposes such as pine nut production, production of wood for construction

and fuel and recreational uses (Moreno-Fernández et al., 2013; Üçler and Arpacı, 2017). Studies in recent years have demonstrated that it provides successful results in afforestation and rehabilitation of mining sites (Keskin and Makineci, 2009).

Considering exports numbers, it is seen that the income provided by *P. pinea* L. is increasing year to year (Şafak and Okan, 2004) and has reached approximately 100 million dollars according to 2018 data (OGM, 2018). This situation provides information on why public and private sector afforestation practices to be carried out with *P. pinea* L. are important and shows that this species will also be preferred intensively in the future in afforestation practices in rural development processes due to economic reasons. Indeed, 33750 hectares (ha) of the *P. pinea* L. forests in Turkey with a total area of approximately 92900 ha are natural, while 59150 ha consist of afforestation and plantation (OGM, 2006; Üçler and Arpacı, 2017). Hence, the forestry sector obtains many benefits from *P. pinea* L. afforestation in terms of both sustainable forest management and rural development.

While *P. pinea* L. is an economically valuable plant species, its geographical distribution in the future dependent on global warming and climate change is uncertain. It is known that climate plays a determining role in the large-scale distribution of species (Guisan and Thuiller, 2005). Additionally, it is one of the most important factors that affect the growth and reproduction of organisms (Lawler et al., 2009). It is expected that land, freshwater and seawater species will change their geographical distribution, seasonal activities, migration patterns, populations and species interactions in the future due to the ongoing climate change (IPCC, 2014). Therefore, species distribution models (SDMs) are used to determine the ecological needs of species and estimate their potential distribution ranges in terms of regional ecology and biogeography (Franklin, 2013). One of the most prevalently used models is the Maximum Entropy Model (Maxent). The Maximum Entropy Model is a method that aims to determine how different environmental variables affect the suitability of the habitat of a species. Maxent is a software that estimates the distribution of species by using the maximum entropy algorithm and occurrence records of species (Phillips et al., 2017). For this purpose, Maxent adopts a grid shape. If a certain grid area is determined as suitable, this means that the area has the most suitable climatic and environmental conditions for the species (Phillips et al., 2006; Zhang et al., 2019). The main reason for common

usage of Maxent is that it works only with occurrence data. This is because it is highly difficult to determine the gaps in absence data (Phillips and Dudík, 2008). In short, the model output of Maxent shows the predictability of the relative probability of a species' occurrence in an area (Sharma et al., 2018).

Projections about the climate conditions in the future estimate that there will be many substantial changes in the world such as increased average global temperature, reduced precipitation and alterations in annual patterns (Allison et al., 2009; Zank et al., 2014). As a result of this situation, while some species are expected to change their geographical distribution or adapt to new conditions, it is expected that some other species, especially those with limited habitats, will go extinct (Hughes, 2000; McLachlan et al., 2005; Parmesan, 2006; Root and Schneider, 2006; Schivo et al., 2019). Understanding species distributions based on changing environmental processes provides important information on the design of protection strategies for species (Guisan and Thuiller, 2005; Falcucci et al., 2007). While many researchers who are interested in the topic reveal whether or not climate change occurs on local, regional and global levels by using existing data on one hand, on the other hand, they continue to provide models and projections on climate change in future years by interpreting the existing situation (Coumou and Rahmstorf, 2012; Sisco et al., 2017; Şensoy and Ateşoğlu, 2019). Based on this approach, it is aimed to establish a connection between what kind of a distribution of species will show in the future and the course of climate change. By this, it is aimed to support protection and development activities for species that could be affected by climate change.

In this context, the objectives of this study are: (1) determining the most important environmental factors that affect the potential distribution of *P. pinea* L., (2) estimating the potential distribution of *P. pinea* L. under current and future RCP4.5-RCP8.5 models for the years 2050 and 2070, (3) providing reference data for planners in terms of usage, protection and development of *P. pinea* L. in afforestation activities with the purpose of rural development.

MATERIAL AND METHODS

Species occurrence and environmental data

This study used the Maxent model that utilizes the maximum entropy algorithm to estimate the potential distribution of *P. pinea* L. under current and projected future bioclimatic conditions. This model requires

the occurrence records of the species that are being modelled and data related to environmental and climatic variables for the habitat. To be used for the study as the species presence data, records obtained in the year 2019 from 13 regions where *P. pinea* L. is distributed in Turkey were utilized (Figure 1) (Table 1). For this purpose, geographical coordinates were obtained by using the Geographical Positioning System (GPS) and the relevant literature (Davis, 1982; Davis et al., 1988; GBIF, 2019; EUFORGEN, 2019).

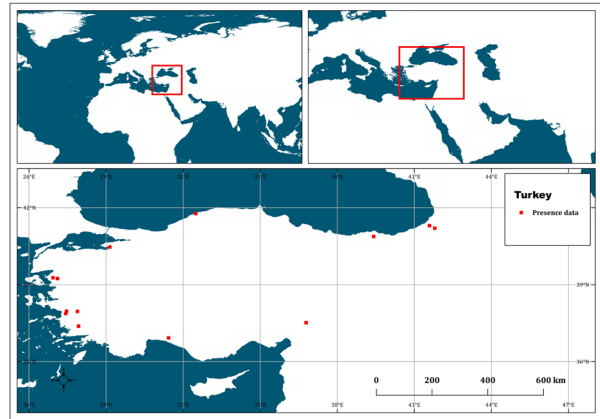


FIGURE 1 The location of *Pinus pinea* L. occurrence sites in Turkey.

Bioclimatic variables are values that are derived from monthly temperature and precipitation values to form more meaningful variables, and they are usually used in species distribution modelling and ecological modelling techniques. These variables represent annual trends (e.g., average annual temperature, annual precipitation), seasonality (e.g., annual range of temperature and precipitation) and extreme or restricting environmental factors (e.g., temperature of the coldest and hottest month or precipitation in dry and wet quarters). The bioclimatic variables were obtained for the current situation by WorldClim Version 1 (1960-1990) and the future by WorldClim Version 1.4 (2050 and 2070) (Bio1-19) (Table 2) from the WorldClim database at a high resolution (Hijmans et al., 2005; WorldClim, 2019). The 2050 bioclimatic data were the average values between 2041 and 2060, and the 2070 bioclimatic data were the average values between 2061 and 2080.

Modelling methods and statistical analysis

The study used the HadGEM2-ES (Hadley Global Environment Model 2 - Earth System) model as the climate model. HadGEM2-ES is a coupled Earth System Model that is used for centennial simulations. The HadGEM2-ES climate model comprises an atmospheric GCM at N96 and L38 horizontal and vertical resolution,

TABLE 1 Geographic coordinates and attribute information of presence data.

Sample	Province	District	X	Y	Altitude (m)	Temperature (°C)	Precipitation (mm)
1	Balikesir	Ayvalik	26.93431	39.27060	298	14.42	58.25
2	Izmir	Bergama	27.11072	39.23884	703	12.68	61.67
3	Aydin	Germencik	27.43111	37.87471	238	16.72	60.50
4	Aydin	Merkez	27.88460	37.95858	1113	12.08	67.08
5	Artvin	Borçka	41.59120	41.30053	418	11.12	113.33
6	Bursa	Gemlik	29.14985	40.46865	378	13.43	52.50
7	Bartın	Kurucaşile	32.49477	41.76757	146	12.92	65.92
8	Trabzon	Düzköy	39.41871	40.87739	582	11.48	68.58
9	Artvin	Merkez	41.79814	41.19936	471	11.40	89.58
10	K. Maraş	Merkez	36.78781	37.51881	829	15.54	57.75
11	Izmir	Tire	27.46449	37.96760	560	15.43	62.00
12	Antalya	Manavgat	31.43159	36.92492	261	17.43	79.67
13	Mugla	Yatağan	27.92916	37.38292	662	15.30	67.92

TABLE 2 Bioclimatic variables.

Codes	Bioclimatic Variables
Bio1	Annual Mean Temperature
Bio2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
Bio3	Isothermality (Bio2/Bio7) (* 100)
Bio4	Temperature Seasonality (standard deviation * 100)
Bio5	Max Temperature of Warmest Month
Bio6	Min Temperature of Coldest Month
Bio7	Temperature Annual Range (Bio5-Bio6)
Bio8	Mean Temperature of Wettest Quarter
Bio9	Mean Temperature of Driest Quarter
Bio10	Mean Temperature of Warmest Quarter
Bio11	Mean Temperature of Coldest Quarter
Bio12	Annual Precipitation
Bio13	Precipitation of Wettest Month
Bio14	Precipitation of Driest Month
Bio15	Precipitation Seasonality (Coefficient of Variation)
Bio16	Precipitation of Wettest Quarter
Bio17	Precipitation of Driest Quarter
Bio18	Precipitation of Warmest Quarter
Bio19	Precipitation of Coldest Quarter

and an ocean GCM with a 1-degree horizontal resolution (increasing to 1/3 degree at the equator) and 40 vertical levels. The Earth system components are terrestrial and ocean carbon cycle and tropospheric chemistry. Terrestrial vegetation and carbon are represented by the dynamic global vegetation model of TRIFFID which simulates the coverage and carbon balance of 5 types of vegetation (broadleaf tree, needleleaf tree, C3 grass, C4 grass and shrub) (ENES, 2019).

The modelling process utilized the climate change scenarios reported in the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC5) Representative Concentration Pathways (RCP) RCP 4.5 and RCP 8.5. RCPs are used in climate modelling processes and research with the purpose of defining the climate scenarios that are considered to be possible based on the greenhouse gas emission amounts in the near future (Moss et al., 2008).

This study used Maxent 3.4.1 that uses the maximum entropy algorithm to estimate the potential distribution of *P. pinea* L. in Turkey under the current and future bioclimatic conditions (Elith, et al., 2011). The performance of a Maxent model may be tested by Receiver Operating Characteristic (ROC) analyses (Fielding and

Bell, 1997). The Area Under ROC Curve (AUC) value that is obtained may be interpreted as the estimated probability of the presence of a randomly selected grid cell in a model. AUC defines the success of the model with all possible thresholds. If this value is $AUC > 0.5$, the model is shown to have a better performance than a random estimation (Phillips, 2010). The closer the AUC value is to 1, the better the distinction is, and the more sensitive and descriptive is the model (Phillips et al., 2006; Oliveira et al., 2010). $AUC \geq 0.9$ =very good, $0.9 > AUC \geq 0.8$ =good and $AUC < 0.8$ =weak (Gassó et al., 2012). In order to determine environmental variables, the Jackknife option which allows measurement of the effects of environmental variables was selected in the Maxent modelling program (Sarikaya et al., 2018). This option allows determination of the significance of the effect of each independent variable in forming the model. The values 0 and 1 were used while creating the potential distribution maps, and accordingly, while 1 showed the most suitable area where the species may be found, 0 meant that the presence of the species in that area was impossible (0-0.5 unsuitable habitat, 0.5-0.75 suitable habitat, 0.75-1 highly suitable habitat). Modelling was restricted to the area covered by the northern latitudes of 35°-43° and eastern longitudes of 26°-46° considering the geographical borders of Turkey.

RESULTS

Model performance and contribution of environmental variables

According to the model, due to the $AUC > 0.5$, the model performed better than a random estimate. The obtained 0.925 AUC value proved the sensitivity of the model (Figure 2). These results showed that the performance of the model was very good, that is, the model had a high power of estimation.

Jackknife is an option that allows measurement of the effects of environmental variables in the Maxent modelling software. Accordingly, the Jackknife option

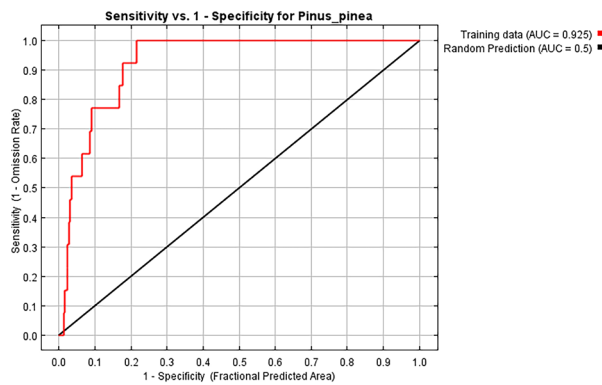


FIGURE 2 AUC values of the MaxEnt model

was selected for *P. pinea* L., and a Jackknife of regularized training gain created (Figure 3). Three environmental variables that affected the species' distribution the most by themselves could be listed in order from the most to the least effective were the minimum temperature of coldest month (Bio6), annual precipitation (Bio12) and precipitation of wettest quarter (Bio16). That is, Bio6, Bio12 and Bio16 were the most significant bioclimatic variables for prediction of the current potential distribution of *P. pinea* L.

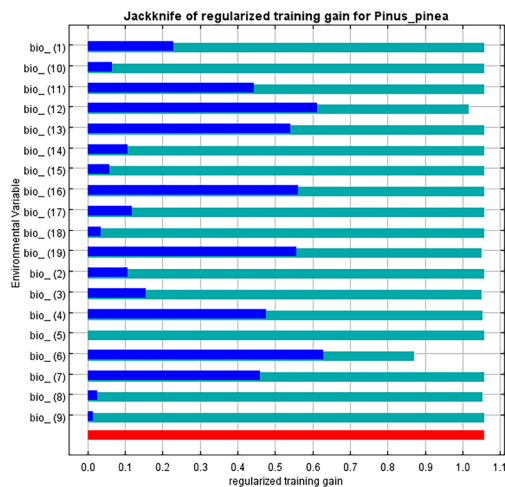


FIGURE 3 Jackknife test for relative importance of bioclimatic variables

Predicted current and future potential *P. pinea* L. distribution

In the Maxent model, the probability of a species to be present in an area is determined by a value in the range of 0-1. As the values approach 1, the probability of the species to be present in that area potentially increases. For this reason, in this study, as the economic value of *P. pinea* L. is high, and it is frequently preferred in afforestation, the areas where the presence potential

of the species was higher than 0.5 were considered in determining the current and potential distribution for the species. Afforestation activities are ecologically and economically risky investments, and the most important way of reducing investment risk is determination of the areas where the species could be potentially found to the highest degree. Therefore, for afforestation investments those are to be made especially for purposes of rural development, including the areas that are designated with the color red in Figure 4 in planning processes as a priority will increase the ecological success of afforestation activities, and therefore, their economic success (Carvalho et al., 2017).

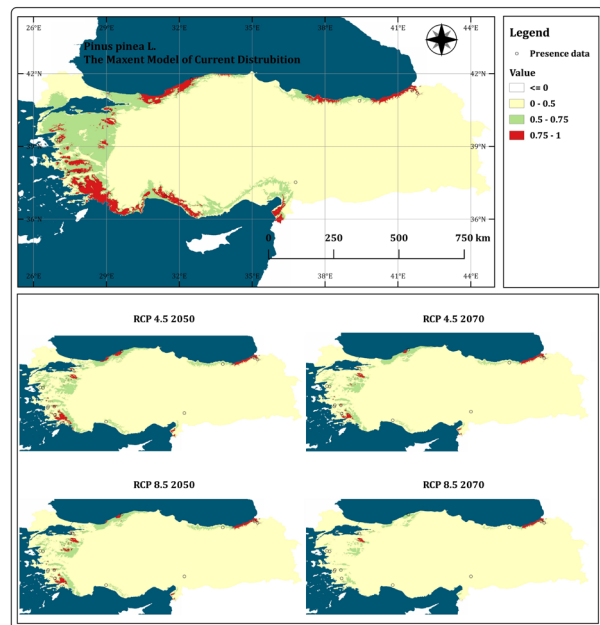


FIGURE 4 *Pinus pinea* L. bioclimatic habitat suitability maps in Turkey (Current, HadGEM2-ES RCP 4.5-8.5 2050, HadGEM2-ES RCP 4.5-8.5 2070). (0-0.5 unsuitable habitat, 0.5-0.75 suitable habitat, 0.75-1 highly suitable habitat).

Figure 4 shows the estimations on the predicted current and future potential distribution of *P. pinea* L. reflected by the Maxent model by using QGIS version 3.6.2. Based on the data in the model, the potential distribution of *P. pinea* L. in the years 2050 and 2070 will decrease under the RCP 4.5 and RCP 8.5 climate change scenarios. Table 3 shows the amounts and ratios of the future habitat losses of *P. pinea* L. According to Table 3, the suitable habitat conditions which are 125427 km² today are estimated to be 55331 km² (RCP 4.5) and 47726 km² (RCP 8.5) for the year 2050. These values were estimated for the year 2070 as respectively 40037 km² and 17793 km². These data show that in the years 2050 and 2070 and in both scenarios, the suitable habitat areas of *P. pinea* L. will decrease.

TABLE 3 Predicted current and future potential *P. pinea* L. habitat distributions.

<i>Pinus pinea</i> L.	Distribution (km ²)	The ratio of the surface area of Turkey (%)
Current	125427	16.08
RCP 4.5 2050	55331	7.09
RCP 4.5 2070	40037	5.13
RCP 8.5 2050	47726	6.12
RCP 8.5 2070	17793	2.28

DISCUSSION

Accordingly, the potential distribution of *P. pinea* L. in the years 2050 and 2070 will decrease under the RCP 4.5 and RCP 8.5 scenarios. These estimates show that the geographical distribution of *P. pinea* L. will decrease in the future, and in both climate scenarios, the potential losses of habitat may reach significant levels. While climate change and increased land usage have been defined as the main reasons of habitat loss (Khanum et al., 2013; Kumar, 2012; Newbold et al., 2015), habitat losses and fragmentations are seen as some of the most important factors in loss of biological diversity (Jiao et al., 2016; Linshan et al., 2017).

While the current ratio of the geographical distribution of *P. pinea* L. to the geographical area of Turkey is 16.08%, it is expected to be 2.28% in the year 2070 under the RCP 8.5 scenario (Table 3). This indicates that the habitat losses of *P. pinea* L. in the future may reach a serious extent in the future based on climatic change. In contrast, some studies have found that the geographical distributions of some plant and insect species will increase based on climate change (West et al., 2015; Sarikaya et al., 2018; Wei et al., 2018). It has also been projected that these species that are not invasive species today may turn into invasive species due to habitat losses and climatic change. For example, *Leptoglossus occidentalis* (Heidemann, 1910) (Heteroptera: Coreidae), which is a seed pest that used to not have a record in Turkey, was seen in recent years especially in the western regions of Turkey and recorded (Arslangündoğdu and Hizal, 2010). This demonstrates that climate change not only result in habitat losses, but they also affect many variables in the ecosystem. Other similar studies have supported this situation (Süel et al., 2018; Koç et al., 2018; Mert and Kırac, 2019).

Considering Figure 4, the current situation and future predictions together, it may be seen that the habitat losses of *P. pinea* L. were estimated to occur especially in the southern and western parts of Turkey. According to these results, climate change is shifting the distribution of *P. pinea* L. more towards the north and higher altitudes. Some other studies on the effects of climate change on plants reached similar results, and it was reported that especially plants distributed in the

Mediterranean region are under risk of extinction of they cannot adapt to climate change (Moiseev and Shiyatov, 2003; IPCC, 2014; Khanum et al., 2013; Mert et al., 2016; Dülgeroğlu and Aksoy, 2018). However, it is also known that the endemic species in the Mediterranean region are more tolerant against the stress created by difficult habitat conditions, and they are affected less by natural and anthropogenic factors such as fire (Medail and Verlaque, 1997; Rundel et al., 2018; Dülgeroğlu and Aksoy, 2018). For this reason, it is important to take the appropriate precautions for future years and making plans by considering this issue in afforestation activities towards rural development in terms of the success of such afforestation activities and the continuity of the high added value provided by the species. But, According to a study in the Western Mediterranean, it is noteworthy that the society is not ready for the effects of climate change (Korkmaz, 2018).

CONCLUSION

P. pinea L. is a species with high economic value that is frequently used in afforestation processes for various purposes. There is a need for further studies for investigating the geographical distribution of this species, which is used especially for rural development purposes, depending on forest ecosystem characteristics for the species to be able to sustain the ecological, economic and social benefits that are expected of it in the future. The results we obtained showed that *P. pinea* L. in Turkey will shift its geographical distribution in the future and experience losses of habitat. It is predicted that these habitat losses will occur especially in the western and southern part of Turkey. This situation has significance for protection and development of *P. pinea* L., which is a species with limited distribution. Therefore, the most suitable potential areas should be prioritized for afforestation activities to be carried out with this species in the present and the future. This also helps in conservation efforts (in situ or ex situ). Nevertheless, studies have demonstrated that changes in climate not only result in habitat losses, but they also negatively affect many variables in the ecosystem, change the biology and ecology of different species and lead to loss of biological diversity. This issue necessitates carrying out more detailed and comprehensive studies on climate change and interactions of species by integrating the topic of climate change into planning processes in ecosystems where biological diversity is high like especially forest ecosystems and protected areas. Hence, it will be possible to protect and sustain the ecological, economic

and social benefits obtained from various species, especially regarding protection of biological diversity.

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