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ORIGINAL PAPER

Identifying the suitable habitats for Anatolian boxwood (*Buxus sempervirens* L.) for the future regarding the climate change

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Abstract

Distribution of tree species is a function of climatic (such as temperature and precipitation) and topographic (such as altitude, slope, and exposure) parameters. It is thought that any change in climatic parameters would be one of the most effective factors to influence the distribution of species. The adaptation of populations would depend on the phenotypic variation, strength of selection, interspecies competition, and biotic interactions. Moreover, many ecologic and anthropogenic processes that are related with each other would affect the distance of distribution. Hence, the detailed and reliable information about the geographical distribution of species under changing climate conditions is of significant importance for various ecologic and protection practices. For this reason, the present study focused on the estimation and analysis of the potential distribution of Anatolian boxwood in different scenarios (SSPS245 and SSPS585) and the estimation and analysis of environmental factors influencing this distribution. Using the current and future (2040-2060-2080-2100) climate scenarios, the habitats that are suitable for the distribution of Anatolian boxwood in Turkey were modeled using the maximum entropy model and then mapped using ArcGIS software. In determining the potential distribution areas, 21 parameters (19 bioclimatic and 2 topographic variables) were used in 21 field-based formation points. The results showed that the most important variables affecting the distribution of species were annual mean temperature (Bio1), minimum temperature of the coldest month (Bio6), mean temperature of the coldest quartile (Bio11), precipitation of the driest month (Bio14), precipitation of the driest quartile (Bi017), and precipitation of the warmest quartile (Bio18). According to two future climate change scenarios, the estimation models showed that there might be decreases up to 6% in Anatolian Boxwood population in years 2040–2060 and, in year 2100; the potential area of distribution will shift to north and higher altitudes in comparison to the current ones and increase by 1–4%. The human help needed for maintaining the existence of new species in the suitable distribution areas suggests the necessity of reviewing and re-designing the current forestry plans and silvicultural practices within the context of climate change.

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1 Introduction

Climate change, which has a risen due to the use of raw materials in order to meet the increasing needs and demands of the population in the last century and the increasing use of fossil fuel in procuring the energy needed for processing these raw materials, is becoming an irreversible problem that the world should resolve (Clift 2007; Tran 2019; Wood and Roelich 2019). In this process, it is known that global climate changes will directly or indirectly affect almost all the organisms and ecosystems (Cetin 2016a, b; Meli et al. 2017; Gustavsson et al. 2017; Cetin 2020a, b). The limited migration mechanisms of plants and the insufficiency of adaptation of this mechanism to climate change make the plants one of the leading organisms to be affected by climate change at most. For this reason, it is estimated that the suitable habitats of species will significantly decrease (Cetin 2015a, b ; Wang et al. 2017; Andrews et al. 2017; Dyderski et al. 2018; Cetin 2019).

Forest ecosystems are remarkably affected by global climate change but they also affect the speed of global climate change. Forests are both the largest terrestrial carbon absorbers and the most effective and low-cost instruments to be used in balancing the global greenhouse gas emissions (Schmidt et al. 2011; Hadden and Grelle 2016). Besides that, the forests are significantly influenced by climate change (Huang et al. 2020; Zeren Cetin et al. 2020; Zeren Cetin and Sevik 2020) because, as with all other organisms, the most important factor shaping the phenotypic characteristics of plants is the climate (Cetin et al. 2018; Sevik et al. 2021; Cetin and Jawed 2022). The precipitation regimes, temperatures, growth periods, and increasing summer droughts changing with the global climate change might cause a change in the distribution of tree species (Huang et al. 2020). Moreover, also the insect damages and increasing forest fires due to the increasing temperatures (Ertugrul et al. 2017; Varol et al. 2017) also contribute to these changes. It was reported that, besides the negative reactions such as invasion by foreign species, such conditions causing reactions like local adaptation and migration (Aitken et al. 2008; Aitken and Whitlock 2013) would also have positive effects such as an increase in the wood production as a result of the increase in the area of forests (Lindner et al. 2010; Smith et al. 2012; Popp et al. 2017; Rogelj et al. 2018). It is estimated that climate change will cause decreases in distribution areas and habitat losses for certain species (Varol et al. 2021) but enlarge the distribution areas of some other species (Melles et al. 2011; Lopez-Sánchez et al. 2021). Furthermore, the projection that the areas, which are suitable for the spread of only one species, will become suitable for other species (McLane and Aitken 2012) corroborates the enlargement of other species' distribution areas. Dyderski et al. (2018) estimated the threat levels for 12 tree species (*Abies alba, Fagus sylvatica, Fraxinus excelsior, Quercus robur, Quercus petraea; Betula pendula, Larix decidua, Picea abies, Pinus sylvestris, Pseudotsuga menziesii, Quercus rubra,* and *Robinia pseudoacacia*) for the period 2061–2080 with three climate change scenarios (optimistic, neutral, and pessimistic scenarios) and determined that these tree species will react to these changes in different ways.

From the aspect of the effects of climate change, Turkey is among sensitive and "under-risk" countries (UNDP 2019). In future climate projections, it is projected that the annual temperature will increase in general in Turkey until 2100 (the increase may reach 6 °C especially in the Aegean region) and that higher levels of decrease in precipitation will be observed in northern regions in comparison to the southern regions (Dalfes et al. 2007; Talu et al. 2010). Because global climate change will occur at a speed that plants will have difficulty in adapting to, it is necessary to predetermine the future changes in order to take measures against the species and population losses especially for the species having limited distribution areas.

For this reason, the present study focused on the estimation and analysis of the potential distribution of Anatolian boxwood in different scenarios (SSPS245 and SSPS585) and the estimation and analysis of environmental factors influencing this distribution. For this purpose, the period between 2040 and 2100 (with 20-year parts) was analyzed using Shared Socioeconomic Pathways (SSPs) according to the 245 and 585 global climate change scenarios. In analyses, 19 bioclimatic variables including temperature and precipitation data and isothermality and Emberger climate classification calculated using temperature and precipitation (Poggio et al. 2018; Chang et al. 2020) were modeled using Maximum Entropy software.

2 Material and method

Anatolian boxwood (Fig. 1), which is endemic to western and eastern Europe, northwestern Africa, and southwestern Asia, spreads from England in the north to northern Morocco in the south and from the northern Mediterranean region to Turkey in south (Rushforth 1999). In this study, the database of *Buxus sempervirens* having a wide distribution area within Turkey was used (GBIF 2021). Distribution of *Buxus sempervirens* in Anatolia divides into several parts, and the most isolated societies are observed in Amanos Mountains and the mountains near Denizli. In Turkey, it was observed to have natural distribution in 21 locations including Kocaeli, Bolu, Kastamonu, Zonguldak, Trabzon, Rize, Artvin, Denizli, Osmaniye, Kahramanmaraş, and Hatay (Akkemik 2018).

Species distribution models are used by the International Union for Conservation of Nature (IUCN) in protecting the species such as Anatolian boxwood (Chadburn and Barstow

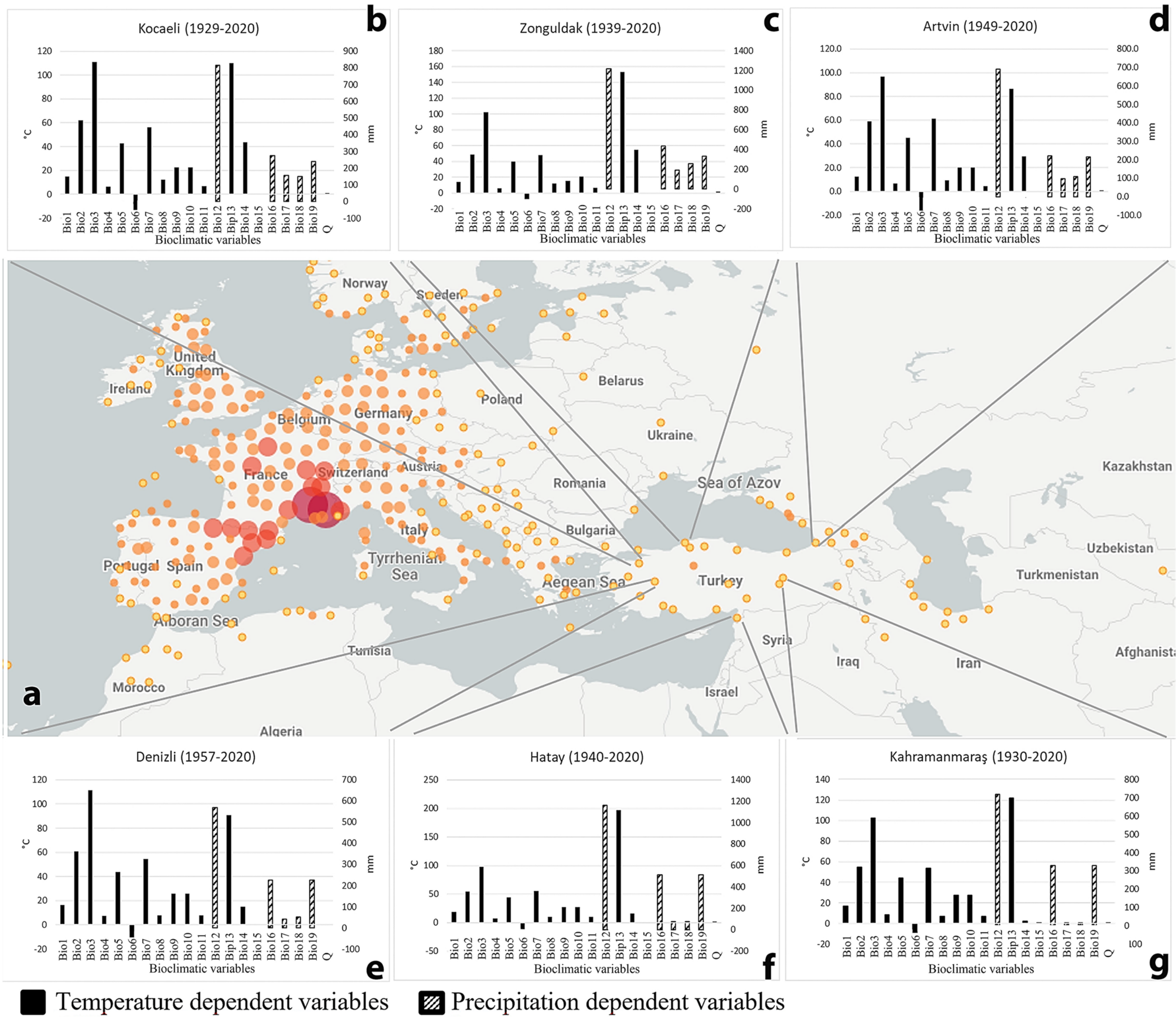

Fig. 1 Current distribution area of Anatolian boxwood (**a**), biovariables of some Anatolian boxwood distribution areas (**b**, **c**, **d**, **e**, **f**, **g**)

2018) having the least concern for existence (LC-Least Concern) from the environmental conditions changing with the effects of climate change, to determine the areas suitable for species, and protecting their own habitats (Fois et al. 2016; Safaei et al. 2018). In modeling the current and potential areas of Anatolian boxwood in the present study, the MaxEnt that is one of the species distribution models was preferred for its usability for both categorical and environmental layers, ability to predict the distribution of threatened species even at low sample sizes, usability of repetitive studies in testing the model, measurability of environmental variables' importance by using jackknife test, and usability for projecting the future under the effects of climate change (Phillips and Dudík 2008). Jackknife test examines the importance of individual variables for the MaxEnt estimations. The data were mapped using ArcGIS 10.5 software.

In analyzing 19 bioclimatic variables used for most accurately estimating the future distribution of Anatolian Boxwood, the representation of stratocumulus by the atmospheric component of the Centre National de Recherches Météorologiques model version 6 (CNRM-CM6-1) climate model with 2.5 min spatial resolution was used. Receiver operating curve analysis (ROC) was determined for determining the model quality of MaxEnt models, whereas receiver operating characteristic area under curve (AUC) that is widely preferred was used in comparing the performances of species distribution models (Lobo et al. 2008; Babar et al. 2012; Wang et al. 2017; Chang et al. 2020). While ROC draws the false-positive fraction and sensitivity values for all the existing probability thresholds, AUC allows measurement of the performance of a single model independently from a selection of specific thresholds. The accuracy classification for AUC is as follows: 1 > excellent > 0.9 > good > 0.8> intermediate > 0.7 > weak > 0.6 > failed (Tsai et al. 2012; Wingert et al. 2016). The final consensus map for the present plus the expected future explanatory variables downloaded from WorldClim v2.1 project were the base for building the scenario maps along the twenty-first century—reclassified in ten intervals by means of ArcGIS 10.5 (Varol et al. 2021). In both time intervals, the intermediate (SSPs 245- 4.5 W/m^2) and most extreme (SSPs 585- 8.5 W/m^2) having

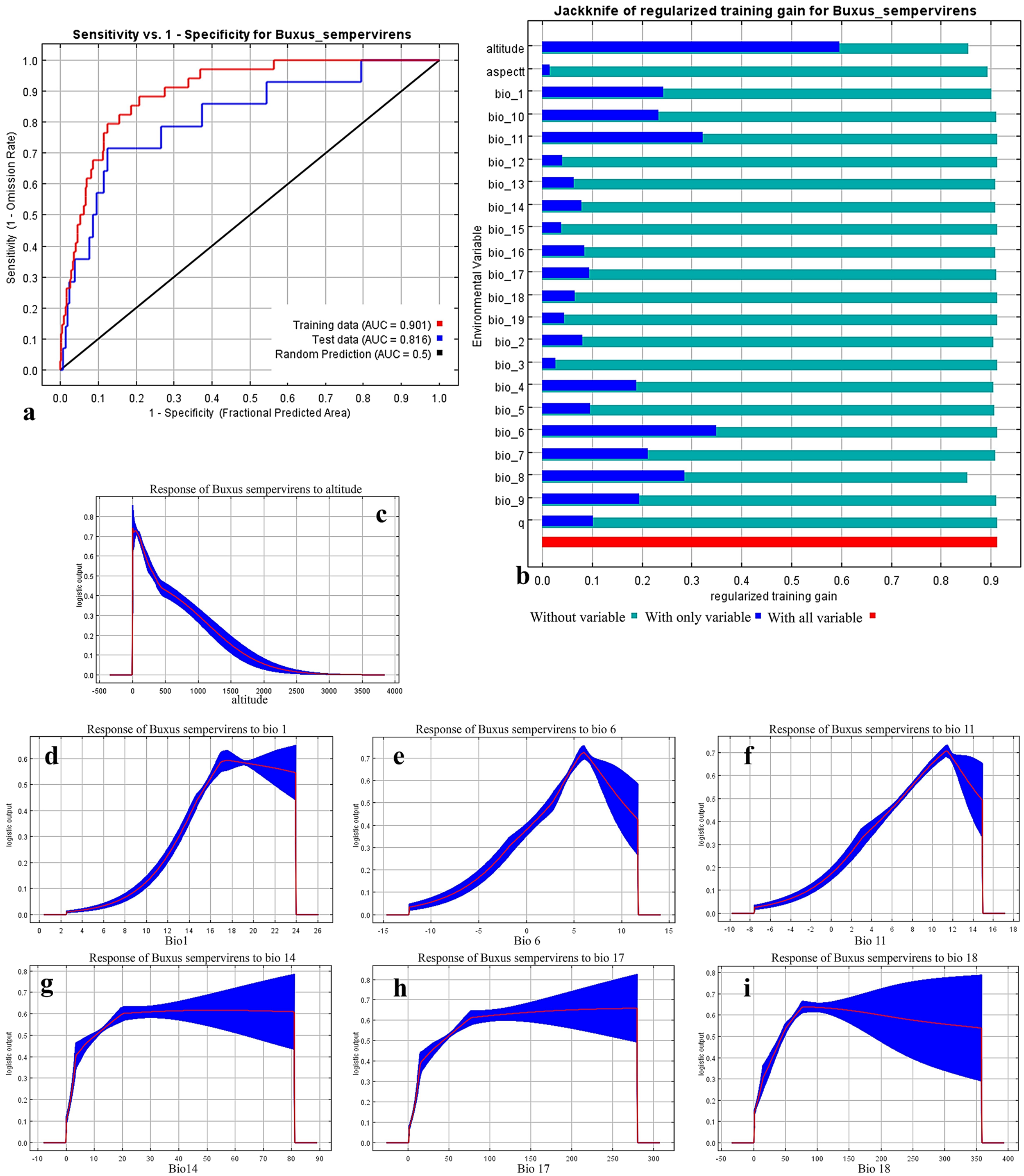

Fig. 2 ROC curve-AUC value of the model (**a**), impact of environmental variables (**b**), response curves (**c**, **d**, **e**, **f**, **g**, **h**, **i**)

different radioactive strains in year 2100 (Burgess et al. 2020) were selected and SSPs (Shared Socioeconomic Pathways) were performed. Each of SSPs was run for four different periods as 2021–2040, 2041–2060, 2061–2080, and 2081–2100.

3 Results

3.1 Potential habitat suitability of Anatolian boxwood and variables contribution

Together with high estimation performances calculated to be 0.901 (AUC>0.5) for training data and to be 0.816 (AUC>0.5) for test data in ROC curve of models, the contributions of variables used in determining the habitats that are suitable for *Buxus sempervirens* L. are shown in Fig. 2. The results of the jackknife test showed that the variable with the highest level of contribution to the distribution of species was the altitude having importance higher than 50%. Following the altitude, the highest mean contributions (>20%) were expressed by environmental variables of Min Temperature of Coldest Month (Bio6), Mean Temperature of Coldest Quarter (Bio11), and Annual Mean Temperature (Bio1). For the test data, the environmental variable individually showing the highest contribution to the distribution of species was the altitude (59.2%). Considering the SSPs245 and SSPs 585 scenarios for the year 2100, besides the altitude, the variables to show the highest contribution were found to be Bio14 (Precipitation of Driest Month), Bio17 (Precipitation of Driest Quarter), and Bio18 (Precipitation of Warmest Quarter) (Table 1). These results revealed that, as the temperatures increase, the species would be affected significantly by the precipitation regime. While the global warming values increased from 4.5 to 8.5 W/m^2, no change was observed in the contribution of Bio14 to the model, whereas the contribution of Biol18 decreased as the contribution of Biol7 increased.

The curves of the responses of four variables to the habitat suitability of *Buxus sempervirens* L are shown in Fig. 2. Given the probabilities of temperature variables, it can be stated that *Buxus sempervirens* L. will show higher rates of distribution with a mean annual temperature range of (Bio1) 16.0–22.0 °C, Bio6 range of 5.0–14.5 °C, and Bio11 range of 9.0–17.0 °C. Having the optimal altitude of 0–550 m in Turkey, Anatolian boxwood shows its highest distribution possibility at the altitude range of 0–350 m, but it can find suitable habitats up to the altitude level of 2000 m. This wide range of altitude might result in an expansion of suitable habitat, which will shrink before 2060, until the year 2100 (Table 2). Hence, it can be understood that global warming will cause an expansion in optimal distribution altitude of this species that is vulnerable to frost, suitable for a warm climate, and growing under shadow (Akkemik 2018). According to the response curves illustrating the relationships between environmental factors and species' existences (Abolmaali et al. 2018), *Buxus sempervirens* L. prefers the habitats with absolute and local maximum values of >10 mm for the mean precipitation of driest month (Bio14), > 50mm for the mean value of driest quarter (Bio17), and > 50 mm of the precipitation of warmest quarter (Bio18) (Fig. 2g, h, i).

Table 1 Average contribution and permutation importance of the environmental variables for SSPs245 and SSPs585

Variables	Contribution percentage		Permutation importance	
	SSPs245	SSPs 585	SSPs245	SSPs 585
Bio14	4.5	4.3	4.6	3.1
Bio17	3.0	8.9	7.3	24.9
Bio18	8.1	0.1	13.8	0.3
Altitude	56.3	58.6	36.8	35.6

3.2 Potential future distribution of *Buxus sempervirens* L.

The model results of future (2040, 2060, 2080, and 2100) projections of *Buxus sempervirens* L. are illustrated in Fig. 3 according to the SSPs245 and SSPs 585 scenarios.

Examining the maps showing the potential future distribution of *Buxus sempervirens* L., it is estimated according to the SSPs 245 scenario for the year 2100 that there will be shrinkages in distribution areas of *Buxus sempervirens* L. in Northeastern Anatolia and Mersin-Hatay region of Southern Anatolia and the pressure of global climate change will be felt more by the populations in these regions. In the Marmara region, a general decrease until 2080 and then an increase are projected. It is thought that, in this process, the distribution areas in Eastern Anatolia region that are currently at a limited level will completely be extinct. According to the SSPs 585 scenario, the distribution areas of this species in Eastern Anatolia will significantly shrink towards the year 2100 and the distribution of this species will stop at various points, and there will be significant losses in the Central Anatolia region. Partial increases are projected for Thrace and Aegean regions.

Comparing the potential distribution and the climate map projected for the period 2041–2060 under both intermediate and the most extreme scenarios, it was determined that the habitat suitable for Anatolian Boxwood will decline (Fig. 3 and Table 2).

Having current potential distribution area of 7.581.893 ha, *Buxus sempervirens* L. will have suitable distribution area of 7.899.044 ha in 2040, 7.453.050 ha in 2060,

Table 2 Areal and proportional changes according to model

Models	Potential distribution (current)	Years			
		2040	2060	2080	2100
SSPs245	7.581.893 ha (100%)	7.899.044 ha (104,18%)	7.453.050 ha (98,30%)	7.788.372 ha (102,72%)	7.652.922 ha (100,94%)
SSPs585		7.122.685 ha (93,94%)	7.139.203 ha (94,16%)	7.383.674 ha (97,39%)	7.889.133 ha (104,05%)

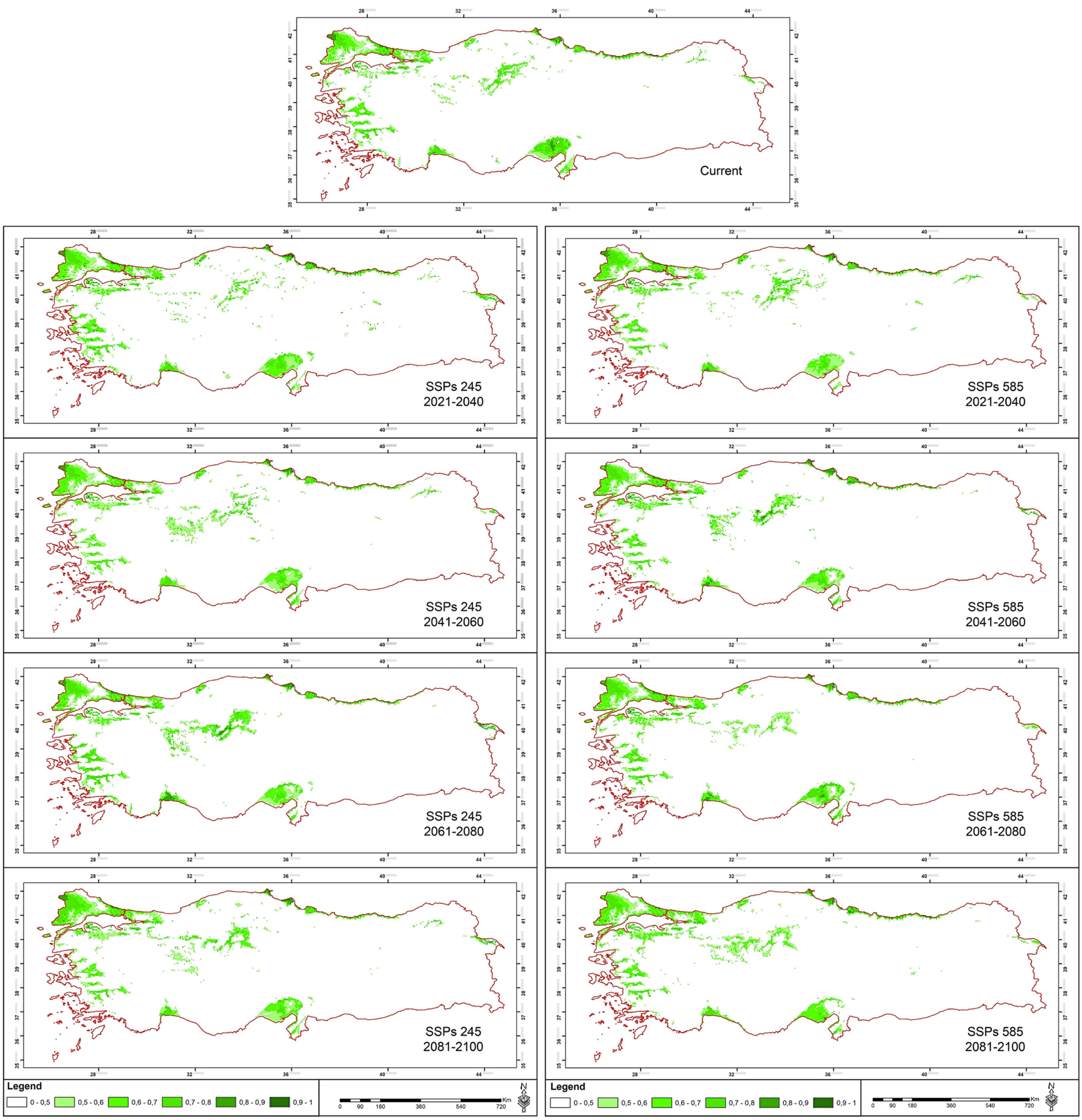

Fig. 3 Current distribution of *Buxus sempervirens* L in Turkey according to the modeling results for SSPs245 and SSPs585

7.788.372 ha in 2080, and 7.652.922 ha in 2100 according to SSPs 245 model. According to SSPs 585 model, it was calculated that the species will have a suitable distribution area of 7.122.685 ha in year 2040, 7.139.203 ha in year 2060, 7.383.674 ha in year 2080, and 7.889.133 ha in year 2100. Hence, in case of the increase of global warming from 4.5 W/m^2 to 8.5 W/m^2, it is estimated that non-suitable distribution area of Anatolian boxwood will incline by 9.8%, 4.2%, and 5.2% in years 2040, 2060, and 2080, respectively, whereas approx. 3% increase is projected for the suitable habitat areas.

4 Discussions

The results of this study show that, as a result of climate change, significant changes will occur in the potential distribution areas of Anatolian boxwood. These changes will occur in form of a general decrease in 2040–2060 first. The studies carried out to date reported that significant changes will occur in the natural distribution areas of species under the effects of global climate change, and these changes will generally occur in the form of shrinkages in distribution areas. It was determined that the populations of *Fagus sylvatica* L. and *Picea abies* (L.) Karst. in Europe will significantly decrease due to climate change (Hanewinkel et al. 2013; Ruiz-Labourdette et al. 2013; Eurostat 2018) and the decrease in potential distribution area of *F. sylvatica* might reach 56% (Thurm et al. 2018). Gomez-Pineda et al. (2020) reported that, in Mexico, the loss of habitat might reach 46–77% for different species in mountainous areas until and the species to be affected at most will be *Pinus hartwegii* and *Abies religiosa*. Ning et al. (2021) estimated that the suitable habitat of *Pinus armandii* in China's Hengduan Mountains will slowly disappear. Taylor Aiken et al. (2017) stated that the fundamental tree species in the forests of Acadian region of Canada have difficulty in maintaining their lives and existence and, thus, they will start losing their "boreal" character. According to different RCP scenarios, Li et al. (2020) Reported that 23–57% of the trees in China will become vulnerable or be at risk within the scope of universal migration until 2070 and the species migrating from dry zones and monsoon regions will be subjected to a higher level of species loss when compared to Alpine regions under climate change. It was found that, in this process, certain species are under the risk of extinction and, even in the most conservative case (RCP2.6), 18% of trees will be defenseless or under threat. There also are studies emphasizing that global climate change will significantly influence not only the natural forests but also the plantation areas (Quinto et al. 2021).

The results of the present study revealed that, in Turkey, the potential distribution area of *Buxus sempervirens* L. in year 2100 will be 1–4% higher in comparison to the current situation. It might seem positive for the species at the first glance but, considering the fact that the potential distribution area of the species will shrink in the period 2040–2060, it can be seen that it will be difficult for the new species to settle in the suitable distribution areas and human help will be needed for growing the species in these areas. Similar results were obtained in studies carried out on different tree species, and it was recommended to transfer the species to new suitable distribution areas by humans. Hirata et al. (2017) emphasized that according to RCP 8.5 scenario, potential distribution areas of pine species may increase by 50% in 2070s. It was determined by Lopez-Tirado et al. (2021) that potential distribution areas of *Cedrus libani* will significantly expand. Using the future climate scenarios, Ouyang et al. (2021) estimated that the most suitable distribution areas for *Eucalyptus grandis* are expected to increase until 2070s, that the suitable distribution areas in Sichuan Basin will expand towards lower altitudes to south, and that the suitable areas in China's southeastern hills will shift to the areas with high sun radiation and lower seasonal temperature changes. Gomez-Pineda et al. (2020) determined that, in Mexico, the suitable distribution areas of *Pinus oocarpa* will significantly expand at low altitudes, but the coniferous trees will need human help in migrating to higher altitudes in order to compensate the populations with climates that they have adapted to. The authors also stated that the conventional on-site protection measurements are largely equal to the inaction and, thus, they cannot protect the current forest compositions. Hence, it can be concluded that *Buxus sempervirens* L., which might show distribution at altitudes higher than 550 m in the future, will need human help. It was reported that, in forestry practices, climate change might cause significant losses in current *Abies religiosa* forests in Canada if the assisted migration management system is not involved in the forestation programs (Gomez-Pineda et al. 2021). Hence, in order for the forests to be subjected to minimum damage during the global climate change process, detailed studies should be carried out on this subject and the migration mechanism, which the plants having no effective migration mechanism that can adapt to the global climate change will need, should be provided by humans.

Besides that, the severity and processes of the effects of climate change on species will significantly vary and the stress factors that the climate change will create on the tree species might also remarkably differ. Within the scope of this study, it was determined that the environmental variables influencing the distribution of Buxus sempervirens L. at most were altitude, Minimum Temperature of Coldest Month, Mean Temperature of Coldest Quarter, Annual Mean Temperature, Precipitation of Driest Month, Precipitation of Driest Quarter, and Precipitation of Warmest Quarter. These factors might have different levels of effects on each species. Ouyang et al. (2021) stated that the dominant ecological factors influencing the distribution of Eucalyptus grandis were sun radiation, altitude, seasonal temperature and precipitation change, maximum temperature of the warmest month, annual mean temperature, slope, isothermality, current water content of soil, the driest quarter, and mean daily temperature range. Varol et al. (2021) specified the three environmental variables influencing the distribution of Fraxinus excelsior L. at most were precipitation in driest month, precipitation in driest quarter, and precipitation in warmest quarter. Bouchard et al. (2020) determined that the tree species in eastern Canada will be vulnerable mainly to the estimated temperature increases, whereas the forests in western Canada will be more affected by the droughts. Accordingly, it can be stated that the effects of global climate change will vary between the regions (Taylor Aiken et al. 2017). The different effects of global climate change process on the forests suggest that the silvicultural interventions that species need will also vary, which silvicultural interventions will offer the highest level of benefit will vary depending on the ecologic context of the forest and the adaptation capability of the species (Webster et al. 2018). Hence, the existing forestry plans and silvicultural practices should be analyzed, and they should be re-designed considering the effects of global climate change (Vilà-Cabrera et al. 2018).

The fact that the species will be affected by the stress factors, which will arise during the global climate change process, at different levels, depends largely on their genetic structure (Diaz et al. 2021) because all the phenotypic characters of organisms are shaped by the mutual interaction between genetic structure and environmental conditions (Cesur et al. 2021) and it is known that the species with different genetic structures and even a single species' origins having different genetic structures have different levels of reactions to environmental stress factors (Sevik et al. 2020; Ozel et al. 2021). The previous studies showed that global climate change resulted in rapid genetic, epigenetic, and metabolomic changes in plants. This process causes changes in morphology, physiology, reproduction, and death rates, and certain species become more vulnerable to these changes in comparison to the other species. As a reaction to climate change, many other adverse effects such as a decrease in CO_2 absorption in case of an increase in emissions of biogenic volatile organic compounds or increasing risk of fire or during drought periods were observed. It was revealed that the projected increase in heavy rains will cause uncertain changes in food cycles, soil fertility, and food flows in mid- and long-term (Peñuelas et al. 2018).

Thus, the effects of this process on the species depend on the indirect results of global climate change, as well its direct effects. It was concluded in the previous studies that climate change will directly affect the forest tree species and pose a secondary threat by influencing the distribution of certain insects and fungi; for these reasons, the pure forests in several regions might face the risk of extinction in the future (Iverson et al. 2016; Oberle et al. 2018; Toczydlowski et al. 2020). Besides that, the factors such as changes in water and food availability and the loss of soil due to leakage and erosion depending on the changes in precipitation regime (Peñuelas et al. 2018), geographic obstacles, anthropogenic effects (such as the change of agricultural and pasture areas) or competitive species might cause important changes in the distribution of species (Akyol and Örücü 2019; Varol et al. 2021).

Global climate change will affect the species not only from the spatial aspect but also in terms of health, quality, and development (Daniel et al. 2017). In a study carried out on *Chukrasia tabularis, Toona ciliata,* and *Lagerstroemia speciosa* in Bangladesh, it was determined for all three species that the radial tree growth will decrease by 20% according to RCP 8.5 scenario and by 11.3% and 9% according to RCP 6.0 and RCP 4.5 scenarios. It was emphasized that this might have significant effects especially on the carbon balance of tropical forests (Rahman et al. 2018).

5 Conclusions

In order to ensure the minimum effect on species by the global climate change, it is necessary to estimate the possible future changes and to take measures in parallel with the potential changes. For instance, in the areas that will be affected more by climate change, it might be recommended to establish mixed forests with the species that can better adapt to both current and future conditions. Thus, even if the species losses will occur, the continuity of forest can be ensured. Moreover, there also is an advantage that the mixed forests are more resistant to many factors. The resistance of species to external factors remarkably varies depending on the intraspecific genetic diversity. Genetic diversity is one of the most important defense mechanisms against the potential future threats that cannot be predicted today. Hence, maximum attention should be paid to protecting the genetic diversity in forests.

In conclusion, it was determined for the areas that are suitable for the distribution of *Buxus sempervirens* L. that there may be decreases up to 6% in the period of 2040–2060, but the potential distribution area might be 1–4% larger in 2100 in comparison to the current area. Given these results, it can be stated that human help will be needed for ensuring the adaptation of species to the future changes in their distribution areas. Hence, the pluralist plans should be prepared that will ensure the continuity of forests by considering the changes that might occur in distribution areas of other species. Moreover, it is deemed necessary to warrant the seed sources and re-determine the seed transfer zones and consider them in forestation projects in order to minimize the negative effects of global climate change process.

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Author contribution Halil, Tugrul, Hakan, Ugur, and Ilknur designed the study and performed the experiments; and Tugrul, Ugur, Ilknur, and Mehmet performed the experiments, analyzed the data, and wrote the manuscript

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Data availability All data are given in manuscript. Data came from the Turkish State of Meteorological Service, https://www.mgm.gov.tr/eng/forecast-cities.aspx. The authors thank the supported by the Republic of Turkey Ministry of Agriculture and Forestry, General Directorate of Forest Engineering and the General Directorate of Meteorology for their prompt responses to our requests.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

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References

Abolmaali SMR, Tarkesh M, Bashari H (2018) MaxEnt modeling for predicting suitable habitats and identifying the effects of climate change on a threatened species, Daphne mucronata, in central Iran. Ecol Inform 43:116–123

Aitken SN, Whitlock MC (2013) Assisted gene flow to facilitate local adaptation to climate change. Annu Rev Ecol Evol Syst 44:367–388

Aitken SN, Yeaman S, Holliday JA, Wang T, Curtis-McLane S (2008) Adaptation, migration or extirpation: climate change outcomes for tree populations. Evol Appl 1(1):95–111

Akkemik Ü (Ed) (2018) Natural-Exotic Trees and Shrubs of Turkey. General Directorate of Forestry Publications, Ankara. 684 p

Akyol A, Örücü ÖK (2019) Investigation and evaluation of stone pine (Pinus pinea L.) current and future potential distribution under climate change in Turkey. Cerne 25(4):415–423

Andrews T, Betts RA, Booth BB, Jones CD, Jones GS (2017) Effective radiative forcing from historical land use change. Clim Dyn 48(11):3489–3505

Babar S, Amarnath G, Reddy CS, Jentsch A, Sudhakar S (2012) Species distribution models: ecological explanation and prediction of an endemic and endangered plant species (Pterocarpus santalinus Lf). Curr Sci:1157–1165

Bouchard F, Fortier D, Paquette M, Boucher V, Pienitz R, Laurion I (2020) Thermokarst lake inception and development in syngenetic ice-wedge polygon terrain during a cooling climatic trend, Bylot Island (Nunavut), eastern Canadian Arctic. Cryosphere 14(8):2607–2627

Burgess MG, Ritchie J, Shapland J, Pielke R (2020) IPCC baseline scenarios have over-projected CO2 emissions and economic growth. Environ Res Lett 16(1):014016

Cesur A, Zeren Cetin I, Abo Aisha AES, Alrabiti OBM, Aljama AMO, Jawed AA, Cetin M, Sevik H, Ozel HB (2021) The usability of Cupressus arizonica annual rings in monitoring the changes in heavy metal concentration in air. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-021-13166-4

Cetin M (2015a) Using GIS analysis to assess urban green space in terms of accessibility: case study in Kutahya. Int J Sustain Dev World Ecol 22(5):420–424

Cetin M (2015b) Determining the bioclimatic comfort in Kastamonu City. Environ Monit Assess 187(10):1–10

Cetin M (2016a) A change in the amount of CO2 at the center of the examination halls: case study of Turkey. Stud Ethno-Med 10(2):146–155

Cetin M (2016b) Determination of bioclimatic comfort areas in landscape planning: a case study of Cide Coastline. Turk J Agric-Food Sci Technol 4(9):800–804

Cetin M (2019) The effect of urban planning on urban formations determining bioclimatic comfort area's effect using satellitia imagines on air quality: a case study of Bursa city. Air Qual Atmos Health 12(10):1237–1249

Cetin M (2020a) The changing of important factors in the landscape planning occur due to global climate change in temperature, rain and climate types: a case study of Mersin City. Turk J Agric-Food Sci Technol 8(12):2695–2701. https://doi.org/10.1007/s11869-020-00858-y

Cetin M (2020b) Climate comfort depending on different altitudes and land use in the urban areas in Kahramanmaras City. Air Qual Atmos Health 13(8):991–999

Cetin M, Jawed AA (2022) Variation of Ba concentrations in some plants grown in Pakistan depending on traffic density. Biomass Convers Biorefin:1–7

Cetin M, Sevik H, Yigit N, Ozel HB, Aricak B, Varol T (2018) The variable of leaf micromorphogical characters on grown in distinct climate conditions in some landscape plants. Fresenius Environ Bull 27(5):3206–3211

Chadburn H, Barstow M (2018) Buxus sempervirens. The IUCN Red List of Threatened Species 2018: e.T202944A68067753. https://doi.org/10.2305/IUCN.UK.2018-1.RLTS.T202944A68067753.en. Accessed 01/05/2021

Chang YL, Peng MW, Chu GM, Wang M (2020) Maxent modelling for predicting impacts of climate change on the potential distribution of Anabasis aphylla in northwestern China. Appl Ecol Environ Res 18:1637–1648

Clift R (2007) Climate change and energy policy: the importance of sustainability arguments. Energy 32(4):262–268

Dalfes HN, Karaca M, Sen OL (2007) Climate change scenarios for Turkey in Climate change & Turkey: impact, sectoral analyses, socio-economic dimensions. Ankara, United Nations Development Programme (UNDP) Turkey Office. https://scholar.google.com/scholar?hl=tr&as_sdt=0%2C5&q=Climate+change+scenarios+for+Turkey+In+Climate+change+%26+Turkey%3A+Impact%2C+sectoral+analyses%2C+socioeconomic+dimensions.%22+Ankara%3A+United+Nations+Development+Programme+%28UNDP%29+Turkey+Office+%28200&btnG=. Accessed 25 June 2021

Daniel CJ, Ter-Mikaelian MT, Wotton BM, Rayfield B, Fortin MJ (2017) Incorporating uncertainty into forest management planning: Timber harvest, wildfire and climate change in the boreal forest. For Ecol Manag 400:542–554

Diaz DG, Ignazi G, Mathiasen P, Premoli AC (2021) Climate-driven adaptive responses to drought of dominant tree species from Patagonia. New For:1–24

Dyderski MK, Paź S, Frelich LE, Jagodziński AM (2018) How much does climate change threaten European forest tree species distributions? Glob Chang Biol 24(3):1150–1163

Ertugrul M, Varol T, Kaygin AT, Ozel HB (2017) The relationship between climate change and forest disturbance in Turkey. Fresenius Environ Bull 26(6):4064–4074

Eurostat (2018) Air Emissions Accounts by NACE Rev. 2 Activity. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_ac_ainah_r2&lang=en. Accessed 20/04/2021

Fois M, Cuena-Lombrana A, Fenu G, Cogoni D, Bacchetta G (2016) The reliability of conservation status assessments at regional level: past, present and future perspectives on Gentiana lutea L. ssp. lutea in Sardinia. J Nat Conserv 33:1–9

GBIF (2021) Global Biodiversity Information Facility, https://www.gbif.org/occurrence/map?has_coordinate=true&has_geospatial_issue=false&taxon_key=2984671&occurrence_status=present. Accessed 20/04/2021

Gomez-Pineda E, Sáenz-Romero C, Ortega-Rodríguez JM, Blanco-García A, Madrigal-Sánchez X, Lindig-Cisneros R et al (2020) Suitable climatic habitat changes for Mexican conifers along altitudinal gradients under climatic change scenarios. Ecol Appl 30(2):e02041

Gomez-Pineda E, Blanco-García A, Lindig-Cisneros R, O'Neill GA, Lopez-Toledo L, Sáenz-Romero C (2021) Pinus pseudostrobus assisted migration trial with rain exclusion: maintaining Monarch Butterfly Biosphere Reserve forest cover in an environment affected by climate change. New For:1–16

Gustavsson L, Haus S, Lundblad M, Lundström A, Ortiz CA, Sathre R et al (2017) Climate change effects of forestry and substitution of carbon-intensive materials and fossil fuels. Renew Sust Energ Rev 67:612–624

Hadden D, Grelle A (2016) Changing temperature response of respiration turns boreal forest from carbon sink into carbon source. Agric For Meteorol 223:30–38

Hanewinkel M, Cullmann DA, Schelhaas MJ, Nabuurs GJ, Zimmermann NE (2013) Climate change may cause severe loss in the economic value of European forest land. Nat Clim Chang 3(3):203–207

Hirata A, Nakamura K, Nakao K, Kominami Y, Tanaka N, Ohashi H et al (2017) Potential distribution of pine wilt disease under future climate change scenarios. PLoS One 12(8):e0182837

Huang S, Zheng X, Ma L, Wang H, Huang Q, Leng G et al (2020) Quantitative contribution of climate change and human activities to vegetation cover variations based on GA-SVM model. J Hydrol 584:124687

Iverson L, Knight KS, Prasad A, Herms DA, Matthews S, Peters M et al (2016) Potential species replacements for black ash (Fraxinus nigra) at the confluence of two threats: Emerald ash borer and a changing climate. Ecosystems 19(2):248–270

Li J, Fan G, He Y (2020) Predicting the current and future distribution of three Coptis herbs in China under climate change conditions, using the MaxEnt model and chemical analysis. Sci Total Environ 698:134141

Lindner M, Maroschek M, Netherer S, Kremer A, Barbati A, Garcia-Gonzalo J et al (2010) Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. For Ecol Manag 259(4):698–709

Lobo JM, Jiménez-Valverde A, Real R (2008) AUC: a misleading measure of the performance of predictive distribution models. Glob Ecol Biogeogr 17(2):145–151

Lopez-Sánchez CA, Castedo-Dorado F, Cámara-Obregón A, Barrio-Anta M (2021) Distribution of Eucalyptus globulus Labill. in northern Spain: Contemporary cover, suitable habitat and potential expansion under climate change. For Ecol Manag 481:118723

Lopez-Tirado J, Vessella F, Stephan J, Ayan S, Schirone B, Hidalgo PJ (2021) Effect of climate change on potential distribution of Cedrus libani A. Rich in the twenty-first century: an Ecological Niche Modeling assessment. New For 52(3):363–376

McLane SC, Aitken SN (2012) Whitebark pine (Pinus albicaulis) assisted migration potential: testing establishment north of the species range. Ecol Appl 22(1):142–153

Meli P, Holl KD, Rey Benayas JM, Jones HP, Jones PC, Montoya D, Moreno Mateos D (2017) A global review of past land use, climate, and active vs. passive restoration effects on forest recovery. PLoS One 12(2):e0171368

Melles SJ, Fortin MJ, Lindsay K, Badzinski D (2011) Expanding northward: influence of climate change, forest connectivity, and population processes on a threatened species' range shift. Glob Chang Biol 17(1):17–31

Ning H, Ling L, Sun X, Kang X, Chen H (2021) Predicting the future redistribution of Chinese white pine Pinus armandii Franch. Under climate change scenarios in China using species distribution models. Glob Ecol Conserv 25:e01420

Oberle B, Covey KR, Dunham KM, Hernandez EJ, Walton ML, Young DF, Zanne AE (2018) Dissecting the effects of diameter on wood decay emphasizes the importance of cross-stem conductivity in Fraxinus americana. Ecosystems 21(1):85–97

Ouyang L, Arnold RJ, Chen S, Xie Y, He S, Liu X, Zhang W (2021) Prediction of the suitable distribution of Eucalyptus grandis in China and its responses to climate change. New For:1–19

Ozel HB, Cetin M, Sevik H, Varol T, Isik B, Yaman B (2021) The effects of base station as an electromagnetic radiation source on flower and cone yield and germination percentage in Pinus brutia Ten. Biol Futura. https://doi.org/10.1007/s42977-021-00085-1

Peñuelas J, Sardans J, Filella I, Estiarte M, Llusià J, Ogaya et al (2018) Assessment of the impacts of climate change on Mediterranean terrestrial ecosystems based on data from field experiments and long-term monitored field gradients in Catalonia. Environ Exp Bot 152:49–59

Phillips SJ, Dudík M (2008) Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography 31(2):161–175

Poggio L, Simonetti E, Gimona A (2018) Enhancing the WorldClim data set for national and regional applications. Sci Total Environ 625:1628–1643

Popp A, Calvin K, Fujimori S, Havlik P, Humpenöder F, Stehfest E et al (2017) Land-use futures in the shared socio-economic pathways. Glob Environ Chang 42:331–345

Quinto L, Navarro-Cerrillo RM, Palacios-Rodriguez G, Ruiz-Gomez F, Duque-Lazo J (2021) The current situation and future perspectives of Quercus ilex and Pinus halepensis afforestation on agricultural land in Spain under climate change scenarios. New For 52(1):145–166

Rahman M, Islam M, Bräuning A (2018) Tree radial growth is projected to decline in South Asian moist forest trees under climate change. Glob Planet Chang 170:106–119

Rogelj J, Popp A, Calvin KV, Luderer G, Emmerling J, Gernaat D et al (2018) Scenarios towards limiting global mean temperature increase below 1.5 C. Nat Clim Chang 8(4):325–332

Ruiz-Labourdette D, Schmitz MF, Pineda FD (2013) Changes in tree species composition in Mediterranean mountains under climate change: Indicators for conservation planning. Ecol Indic 24:310–323

Rushforth K (1999) Trees of Britain and Europe; Collins: New York, USA. Google Scholar. https://scholar.google.com/scholar?hl=tr&

as_sdt=0%2C5&q=+Trees+of+Britain+and+Europe%3B+Collins%3A+New+York%2C+USA&btnG=. Accessed 25 June 2021

Safaei M, Tarkesh M, Bashari H, Bassiri M (2018) Modeling potential habitat of Astragalus verus Olivier for conservation decisions: a comparison of three correlative models. Flora 242:61–69

Schmidt J, Leduc S, Dotzauer E, Schmid E (2011) Cost-effective policy instruments for greenhouse gas emission reduction and fossil fuel substitution through bioenergy production in Austria. Energy Policy 39(6):3261–3280

Sevik H, Cetin M, Ozel HU, Ozel HB, Mossi MMM, Zeren Cetin I (2020) Determination of Pb and Mg accumulation in some of the landscape plants in shrub forms. Environ Sci Pollut Res 27(2):2423–2431

Sevik H, Cetin M, Ozel HB, Erbek A, Zeren Cetin I (2021) The effect of climate on leaf micromorphological characteristics in some broad-leaved species. Environ Dev Sustain 23(4):6395–6407

Smith AL, Hewitt N, Klenk N, Bazely DR, Yan N, Wood S et al (2012) Effects of climate change on the distribution of invasive alien species in Canada: a knowledge synthesis of range change projections in a warming world. Environ Rev 20(1):1–16

Talu N, Özden MS, Özgün S, Dougherty W, Fencl A (2010) Turkey's national climate change adaptation strategy and action plan (Draft). TR Ministry of Environment and Urbanization. General Directorate of Environmental Management, Department of Climate Change, Ankara

Taylor Aiken G, Middlemiss L, Sallu S, Hauxwell-Baldwin R (2017) Researching climate change and community in neoliberal contexts: an emerging critical approach. Wiley Interdiscip Rev Clim Chang 8(4):e463

Thurm EA, Hernandez L, Baltensweiler A, Ayan S, Rasztovits E, Bielak K et al (2018) Alternative tree species under climate warming in managed European forests. For Ecol Manag 430:485–497

Toczydlowski AJ, Slesak RA, Kolka RK, Venterea RT (2020) Temperature and water-level effects on greenhouse gas fluxes from black ash (Fraxinus nigra) wetland soils in the Upper Great Lakes region, USA. Appl Soil Ecol 153:103565

Tran QM (2019) Projection of fossil fuel demands in Vietnam to 2050 and climate change implications. Asia Pacific Policy Stud 6(2):208–221

Tsai P, Torabinejad M, Rice D, Azevedo B (2012) Accuracy of cone-beam computed tomography and periapical radiography in detecting small periapical lesions. J Endod 38(7):965–970

UNDP (2019) Small Island nations at the frontline of climate action. Retrieved from http://www.undp.org/content/undp/en/home/news-centre/news/2017/09/18/small-island-nations-at-the-frontline-of-climate-action-.html. Accessed 20/04/2021

Varol T, Ertugrul M, Ozel HB (2017) Drought-Forest Fire Relationship. In: Fuerst-Bjelis B (ed) Mediterranean Identities-Environment, Society, Culture, Section 3, Chapter 12. Intech Open, Crotia, p 283–303. https://doi.org/10.5772/66587. https://books.google.com.tr/books?hl=tr&lr=&id=RwWQDwAAQBAJ&oi=fnd&pg=PA283&dq=Drought-Forest+Fire+Relationship.+Journal+of+Mediterranean+Identities%E2%80%94Environment,+Society,+Culture&ots=tj98gVycpo&sig=qhSfjaQeXRpQarAYn0SLb1bGGk&redir_esc=y#v=onepage&q=Drought-Forest%20Fire%20Relationship.%20Journal%20of%20Mediterranean%20Identities%E2%80%94Environment%2C%20Society%2C%20Culture&f=false. Accessed 25 June 2021

Varol T, Canturk U, Cetin M, Ozel HB, Sevik H (2021) Impacts of climate change scenarios on European ash tree (Fraxinus excelsior L.) in Turkey. For Ecol Manag 491(2021):119199. https://doi.org/10.1016/j.foreco.2021.119199

Vilà-Cabrera A, Coll L, Martínez-Vilalta J, Retana J (2018) Forest management for adaptation to climate change in the Mediterranean basin: a synthesis of evidence. For Ecol Manag 407:16–22

Wang TT, Chu GM, Jiang P, Niu PX, Wang M (2017) Effects of sand burial and seed size on seed germination, seedling emergence and seedling biomass of Anabasis aphylla. Pak J Bot 49(2):391–396

Webster M, Gerland S, Holland M, Hunke E, Kwok R, Lecomte O et al (2018) Snow in the changing sea-ice systems. Nat Clim Chang 8(11):946–953

Wingert NC, Gotoff J, Parrilla E, Gotoff R, Hou L, Ghanem E (2016) The ACS NSQIP risk calculator is a fair predictor of acute periprosthetic joint infection. Clin Orthop Relat Res 474(7):1643–1648

Wood N, Roelich K (2019) Tensions, capabilities, and justice in climate change mitigation of fossil fuels. Energy Res Soc Sci 52:114–122

Zeren Cetin I, Sevik H (2020) Investigation of the relationship between bioclimatic comfort and land use by using GIS and RS techniques in Trabzon. Environ Monit Assess 192(2):1–14. https://doi.org/10.1007/s10661-019-8029-4

Zeren Cetin I, Ozel HB, Varol T (2020) Integrating of settlement area in urban and forest area of Bartin with climatic condition decision for managements. Air Qual Atmos Health 13(8):1013–1022. https://doi.org/10.1007/s11869-020-00871-1

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