Turkish Journal of Botany

Volume 47 | Number 5 Article 5

9-26-2023

Increasing temperatures can pose an opportunity to recover endemic and endangered oriental sweetgum tree (Liquidambar orientalis Mill.) from extinction

OKAN ÜRKER

NURBAHAR USTA BAYKAL

EREN ADA

Recommended Citation

ÜRKER, OKAN; BAYKAL, NURBAHAR USTA; and ADA, EREN (2023) "Increasing temperatures can pose an opportunity to recover endemic and endangered oriental sweetgum tree (Liquidambar orientalis Mill.) from extinction," *Turkish Journal of Botany*: Vol. 47: No. 5, Article 5. https://doi.org/10.55730/1300-008X.2774

Available at: https://journals.tubitak.gov.tr/botany/vol47/iss5/5

Turkish Journal of Botany

http://journals.tubitak.gov.tr/botany/

Research Article

Turk J Bot
(2023) 47: 363-371
© TÜBİTAK
doi:10.55730/1300-008X.2774

Increasing temperatures can pose an opportunity to recover endemic and endangered oriental sweetgum tree *(Liquidambar orientalis* Mill.*)* from extinction

Okan ÜRKER[1,2,*], **Nurbahar USTA**[3], **Eren ADA**[4]

[1]Eldivan Vocational School of Health Services, Çankırı Karatekin University, Çankırı, Turkiye
[2]NATURA The Society for the Conservation of Nature and Culture, Ankara, Turkiye
[3]Department of Biology, Ecology Division, Hacettepe University, Ankara, Turkiye
[4]Department of Biological Sciences, University of Rhode Island, Kingston, RI, USA

Received: 17.05.2023 • **Accepted/Published Online:** 10.08.2023 • **Final Version:** 26.09.2023

Abstract: Evidence suggests that past climatic oscillations caused many species to drastically change their distribution range and had significant impacts on their survival capabilities. There is significant evidence suggesting that today's changing climate threatens many species to face a rapid extinction period in the coming decades and centuries. Understanding the changing range patterns provides significant input on biodiversity and conservation biology studies. However, warming climatic conditions may also present an opportunity for some species to expand their habitats—particularly those adapted to warmer environments. In this study, we asked how near-future climate change will affect the distribution range of the oriental sweetgum tree (*Liquidambar orientalis* Miller, 1867) which is a deciduous tertiary relict endemic species that forms the riparian forest ecosystems across southwestern Türkiye and Rhodes Island (Greece). Oriental sweetgum is on the verge of extinction due to past climate changes and current anthropogenic pressures such as deforestation and improper farming practices as well as insufficient conservation policies and efforts in place. As a result, sweetgum trees only survive in fragmented forest patches. To understand the species' possible response to globally rising temperatures, we explored the ecological and climatic factors that drive the distribution changes using a species distribution modeling approach. We predicted species' past (Mid-Holocene, approximately 6000 years ago), current, and future (2070) distribution ranges using maximum-entropy (MaxEnt) niche models built with WorldClim Version 1.4 climatic data. We found that regular water and warmer temperatures are particularly crucial for this species. The models showed a past (Mid-Holocene) expansion in suitable habitats in response to warmer conditions followed by a contraction as temperatures cooled down to the current climate. Most importantly, our future predictions showed that the species can possibly expand its distribution range to newly suitable habitats exhibiting a similar past response to the increasing temperatures. In this scenario, however, we suggest that it is extremely important to take necessary restoration and conservation steps for fragmented sweetgum forests to ensure species survival in the next centuries. We also believe that further research must be conducted to better understand species' ecological requirements and to provide crucial knowledge for future conversation approaches.

Key words: Oriental sweetgum tree, *Liquidambar orientalis*, climate change, conservation biology, species distribution models (SDMs)

1. Introduction

The genus Liquidambar is known by fossil records from the Cretaceous to the Quaternary (age range: 99.7 to 0.781 million years ago) (Behrensmeyer and Turner, 2013) and much more widespread in the Tertiary. However, it has disappeared from the European continent due to extensive glaciation in the north and the east-west oriented Alps and Pyrenees which served as a barrier against southward migration. It has also disappeared from western North America and unglaciated far-eastern parts of Russia. In the last glacial periods, the distribution of the genus shifted to Southeast Central America, Southwest Asia, and Southeast Asia. There are several fossil species of Liquidambar that provide evidence of its relict status today (Hsu and Andews, 2005).

It is named *Liquidambar* due to the resin obtained from these trees (Huş, 1949). They secrete resin from their body when wounded, which has a significant value for people in their respective regions. The resin is economically important due to its natural balsam content, medicinal purposes, cosmetics, and soap making. It also is an important export item that makes the sweetgum tree a key income source for local populations (İktüren and Acar, 1987).

The oriental (Anatolian) sweetgum tree (*Liquidambar orientalis* Miller, 1867) is a medium-sized deciduous tree

* Correspondence: okanurker@karatekin.edu.tr

and a tertiary relict endemic species with a natural range limited solely to the south-western part of Türkiye as well as in the Island of Rhodes and the Island of Cyprus (Akman et al., 1992; Kaya and Alan, 2003; Caudullo et al., 2017). Although there are two varieties defined in this region (*L. orientalis* Mill. var. *orientalis* and L. *orientalis* Mill. var. *integriloba*); previous isozyme and RAPD loci analysis showed that these varieties were not significantly different from each other at the genetic level due to ongoing hybridization (Taşkın et al., 2008). According to the drilling records, the species lived in different points of Anatolia until the last ice age (Peşmen, 1982). Similarly, paleobotanical and palynological studies found some leaf and pollen fossils in 7 different basins of Central Anatolia and Western Anatolia from the Miocene Period (Acar et al., 1992). As a result, the species is defined as relict as its distribution range shifted from Europe and northern Russia to the warmer and sheltered regions such as Southwestern Anatolia where glaciation has not been experienced (Akman et al., 1992).

Oriental sweetgum is distributed in healthy forests around the coastal districts of Southwestern Türkiye (Ozkil et al., 2017). It flowers from March to April and the seed dispersal mainly occurs by winds during November and December. Regeneration strategies are very diverse such as seed germination, root sprouts, root grafts, tissue culture, etc. (Kaya and Aksakal, 2005). Trees can grow from 10 m to 35 m individually or in groups in flood plains, small grooves, marshes, valley sides near streams, or waterlogged alluvial forests. Occasionally, it can be found on slopes and in dry soil (Kavak and Wilson, 2018). Trees are found in almost pure stands (shallow gallery forests), mostly in areas with less inclination and abundant water (Ürker and Çobanoğlu, 2017). Oriental sweetgum is highly sensitive to abiotic factors. It prefers mostly rainy and humid places with approximately 950–1200 mm of rain (Kurt, 2008). It prefers alluvial soils on smooth ground, and low altitudes (optimum 0 to 500 m) (Kaya and Alan, 2003). Moreover, a regular water supply and a 15–20 °C annual average temperature are crucial for the species.

Despite their importance, the oriental sweetgum forests are in great trouble. State-sponsored farming initiatives in Türkiye, mostly in the form of incentives for citrus plantations, led to significant shrinkage of sweetgum forests since the 1950s. From 6312 ha in 1949, the groves shrank to 1337 ha in 1987 and currently, it stands at no more than 2000 ha (Huş, 1949; Kurt, 2008; Ozkil et al., 2017). The sweetgum forests are highly fragmented, and they are now on the brink of extinction due to these local agriculture policies (Ürker and Çobanoğlu, 2017; Ozkil et al., 2017). Oriental sweetgum has been given Endangered (EN - A2c) status on IUCN Red List Categories (Ver. 2022.1) (IUCN, 2023; Kavak and Wilson, 2018). EUFORGEN has listed this species as a protected tree on the scale of the European Continent (Kaya and Alan, 2003; EUFORGEN, 2009). According to the forestry statistics published by Republic of Türkiye Ministry of Agriculture and Forestry, the distribution of sweetgum forests declined sharply during the last decades, also resulting in increased forest fragmentation (General Directorate of Forestry, Republic of Türkiye, 2012).

The result is a scattered, fragmented family of threatened sweetgum groves (Ürker and Yalçın, 2011; Ozkil et al., 2017). Fragmented forests are harder to rescue and rehabilitate in the long run (Fahrig, 2003). As a result, the reestablishment of forest corridors and the reunification of the fragmented groves as restoration are crucial for this species to survive (Ülgen et al., 2020; Sharma and Roy, 2007). Biological corridors constructed from trees using silvicultural methods are forest clusters that maintain the integrity of forest fragments and they have a great potential for the ecological and economic sustainability of forest ecosystems (Myroniuk et al., 2020). Although this conservation approaches results in significant knowledge and effective practical outcomes for restoration efforts, only little work has been done to investigate the bioecological demands and the effects of climate change on the remaining sweetgum forests (Yaltirik and Efe, 2000; Kurt, 2008; Corbaci et al., 2019). Therefore, research on the effects of future climate changes such as the possible distribution shifts for this species is often overlooked (Taşkın et al., 2008).

Species distribution models (SDM) provide a valuable tool for identifying the range and patterns of distribution of species, often revealing patterns that would not be otherwise evident from existing data (Blanco et al., 2020; Pecchi et al., 2019). This information is valuable for guiding inventory, informing conservation strategies, designing preserves, and evaluating the conservation project effects (Helliwell and Chapman, 2013). In SDM, climate change scenarios are also widely used in conservation biology with predictive model principles (Hossell et al., 2003). These change scenarios are becoming more sophisticated, such as that they can be applied at the regional and subregional scale at which most nature conservation takes place. Techniques are being developed that allow the distribution of species under different climate scenarios to be modeled (Kirby, 2003). Those scenarios may help to explore various critical questions relating to the degree to which the current patterns of species occurrence may or may not survive in the future.

In this study, we aimed to explore the ecological and climatic factors that affect the past and future distribution patterns of the oriental sweetgum tree. To do this, we used the ecological niche modeling approach and predicted the species' distribution range from Mid-Holocene to the present, and to the future climatic projections (2070). We suggest that the results from this study will provide significant knowledge to the broader conservation policies of the oriental sweetgum forests, especially for the conservation efforts on the forest connectivity and permeability which allows the species movement in response to climate change.

2. Materials and methods

2.1. Study area

We designated our study area from Rhodes Island (Greece) to the southern coasts of Türkiye between the Great Meander River and Orontes River (Figure 1). We choose this area because it is the only area where regular and reliable data on the natural distribution of the species have been obtained since the last glacial period (Caudullo et al., 2017). The Mediterranean climate is often seen in the study area. The annual precipitation quantities are fairly high in locations where the oriental sweetgum tree grows, often between 950 and 1200 mm. But since it has not rained in the study region for a while, the summer drought has lasted anywhere from 3 to 6 months. Due to its closeness to tiny rivers or groundwater, the oriental sweetgum tree endures this dry summer season (Corbaci et al., 2019). The species grows best in humid, flat areas with alluvial, alluvial shore, and hydromorphic alluvial soil types in the hot Mediterranean environment (Güner et al., 1993; Kurt, 2008). The oriental sweetgum tree grows most effectively in the maritime zone (0–200 m) in coastal areas, although it also grows rather well between 200 and 400 m and less healthily between 400 and 600 m. On hot, south/southeast facing slopes, it may thrive at altitudes of up to 900 m if it discovers a suitable land structure (Güner et al., 1993; Kurt, 2008; Corbaci et al., 2019). The oriental sweetgum tree can only grow in a narrow strip along perennial water lines and streams at the bottom of valleys in locations with high slopes. However, flat and very slightly sloping (0–5%) regions where water may spread are better suited for the development of forests (Huş, 1949; Özkil et al., 2017).

2.2. SDM methodology

We performed SDM to understand the past and the possible future changes in the geographical distribution related to climate change. We used WorldClim version 1.4 (CMIP5) for past (about 6000 years ago), present, and future (2070) potential distributions. The presence data which was collected by field observations between 2015 and 2020 were used to model several global climate change scenarios (see Figure 1 and Appendix 1). We used 2.5 arc/min resolution for past, current, and future climatic variables due to the magnitude of the study area. The modeling area is selected

Figure 1. The study area. The gray dots in Figure 1 represent the distribution areas of oriental sweetgum recorded by different researchers in the past but not present today. The orange dots indicate the current oriental sweetgum records compiled by Caudullo et al. 2017. The red dots are the current occurrence records obtained from The Breakdown Table of Oriental Sweetgum Areas which had been prepared by the Muğla Regional Directorate of Forestry (Muğla RDoF 2012). Green areas on the map are the distribution areas that are updated during the field studies carried out by us within the scope of this study (see Appendix 1). The green crosses are the current occurrence records that were not previously recorded in the literature and were newly added during the field studies carried out by us during this study (see Appendix 1).

at 35° to 39° northern latitudes and 25.5° to 37° eastern longitudes. The modeling extent within the modeling area was constructed by outlining the distribution of Anatolian sweetgum with a 20-km buffer. For future projections, three global climate models (GCMs) were selected (BCC-CSM2-MR, CNRM-CM6-1, and IPSL-CM6A-LR) and the results were averaged to be able to use the variations in the predictions of each global climate model. WorldClim version 1.4. projections for the Mid-Holocene were also produced for the same three GCMs (BCC-CSM5, CNRM-CM5, and IPSL-CM5A) as future projections. A correlation analysis between 19 bioclimatic variables was conducted to remove highly correlated variables to eliminate the effect of collinearity from the models (Elith et al., 2006). The variables that have correlation coefficients greater than 0.95 were removed based on the ecological needs of the species (see Appendix 2). The ecologically less important variables between correlated couples were removed from the data set. As a result, 13 bioclimatic variables were used to build the models (BIO2, BIO3, BIO4, BIO5, BIO7, BIO8, BIO9, BIO11, BIO12, BIO15, BIO16, BIO17, and BIO18). The species distribution models are widely used in ecological practices and there are several R packages available to apply a variety of modeling methods such as GLMs, random forest, etc. In this study, the 'dismo' package in R (Hijmans, 2011) was used to build species distribution models by the MaxENT algorithm (Philips et al., 2009). The model was built with 1000 random background points and with 50 repeats. To construct the current distribution model of Anatolian sweetgum, MaxEnt function in dismo package was used, except for the background point beforementioned, other parameters were used as the default values of the function.

Default parameters of MaxEnt function which were used in this study are shown below (Table 1).

Also, jackknifing was applied to detect the most important variable which shapes the species' distribution. Lastly, for past and future models, we used the predict function by using the current model to construct projections and the evaluate function was used to test the current distribution model's significance with 1000 random points by using AUC values.

3. Results

SDM of *L. orientalis* was built with 0.925 AUC. We consider this a robust prediction as the AUC values closer to 1 indicate more precise and descriptive models (Philips et al., 2006). The AUC values higher than 0.8 demonstrate that the predictive power of the models is higher and more accurate than a random prediction. Both the Mid-Holocene model and future predictions have been averaged to be able to extract information from different GCMs; Figure 2 shows the averaged results of the models; and Appendix 3 shows the results of each global climate model (BCC-CSM5, CNRM-CM5, and IPSL-CM5A), separately. Besides, the variable BIO16 (precipitation of the wettest quarter) was the most explanatory variable which is in line with the ecological properties of the species (Figure 2).

The SDM results show that the available habitats for *L. orientalis* in the Mid-Holocene (See Appendix 4) narrowed down through the following centuries until today. It can also be seen in Figure 2a that the available habitats were in the north of its current distribution. While the species is mostly distributed in coastal riverine forests

Table 1. Default parameters of MaxEnt function.

lq2lqptthreshold		integer	80	Number of samples at which product and threshold features start being used
l2lqthreshold		integer	10	Number of samples at which quadratic features start being used
hingethreshold		integer	15	Number of samples at which hinge features start being used
beta_threshold		double	-1.0	Regularization parameter to be applied to all threshold features; negative value enables automatic setting
linear	l	boolean	true	Allow linear features to be used
quadratic	q	boolean	true	Allow quadratic features to be used
product	p	boolean	true	Allow product features to be used
threshold		boolean	true	Allow threshold features to be used
hinge	h	boolean	true	Allow hinge features to be used
betamultiplier	b	double	1.0	Multiply all automatic regularization parameters by this number. A higher number gives a more spread-out distribution.
maximumbackground	MB	integer	10000	If the number of background points / grid cells is larger than this number, then this number of cells is chosen randomly for background points

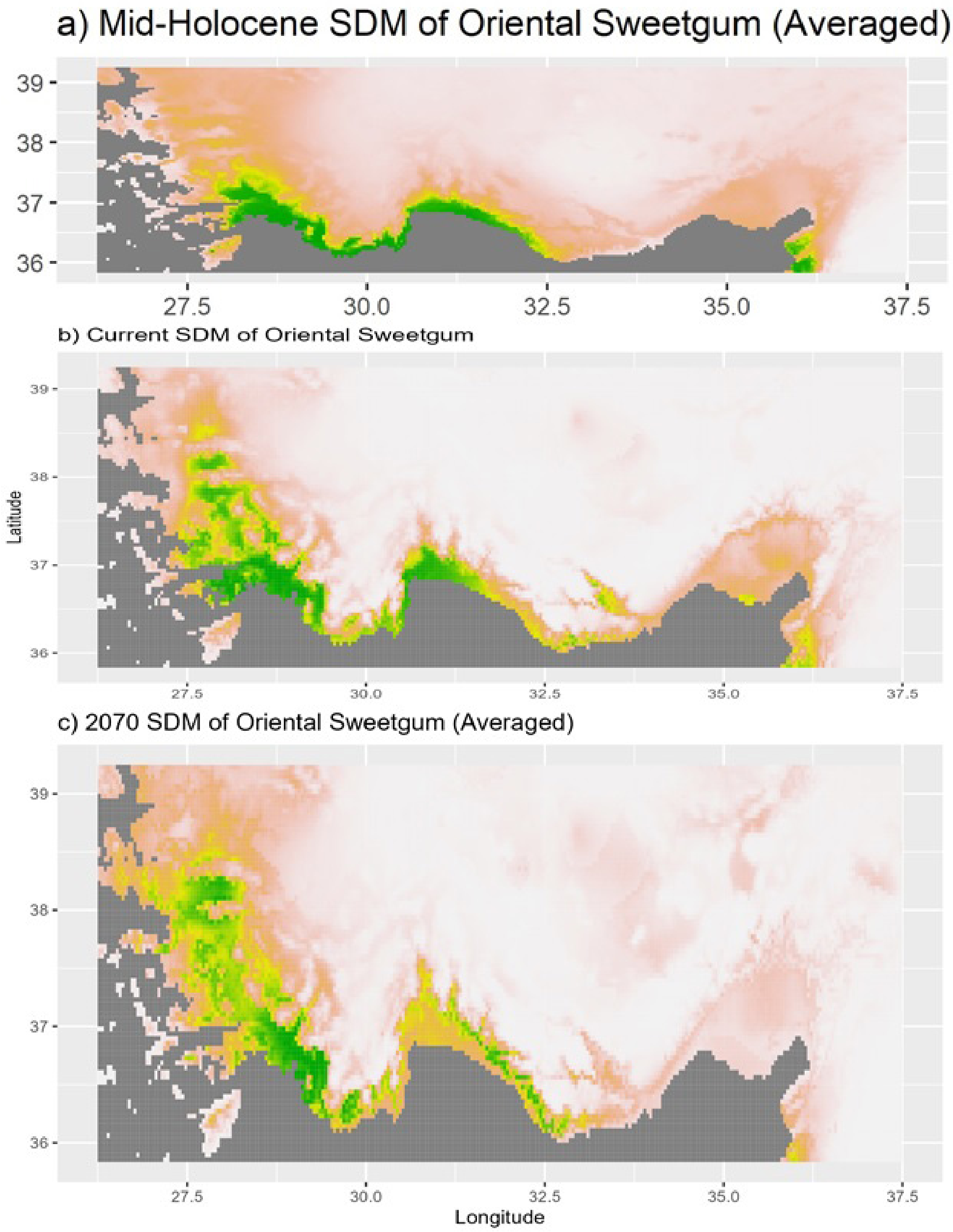


Figure 2. SDM results of *L. orientalis*. **a**) Mid-Holocene (approximately 6000 years B.C.) distribution predictions based on the current distribution of *L. orientalis*, an average of 3 different GCMs' modeling results (BCC-CSM5, CNRM-CM5, and IPSL-CM5A). **b**) Current (1970–2000) distribution predictions of *L. orientalis*. **c**) Future (2070) distribution predictions of *L. orientalis*, an average of 3 different GCMs' modeling results (BCC-CSM5, CNRM-CM5, and IPSL-CM5A). The occurrence probabilities of each model are increasing from pink to green.

of southwestern Anatolia currently, Mid-Holocene results show the same occurrence probability for inner riverine forests as in coastal sides of southwestern Anatolia. The high occurrence probability predicted in Mid-Holocene models is also in line with the historical pollen record of the species (Dirik, 1986).

The results also demonstrate a good representation of its current distribution which forms a compact and high-probability distribution area in southwestern Anatolia, especially around the coastal sides of those regions (Figure 2b). It is seen that the dark green areas in the occurrence probability map almost completely overlap with the current distribution points in the location map presented in Figure 1.

However, the future predictions show a potential habitat expansion for *L. orientalis* in contrast to the habitat reduction from Mid-Holocene to the present day (Figure 2c). This result contradicts the expected range contraction with most of the Anatolian tree species (Usta Baykal, 2019; Dağtekin et al., 2022; Tekin et al., 2022). The results also suggest latitudinal expansion from the coastal sides of southwestern Anatolia to the Great Meander River. Orontes River and its surroundings follow the Mid-Holocene probabilities in the future, suggesting the availability of suitable habitats for *L. orientalis.*

4. Discussion

In this study, we aimed to explore the effects of past and future climate changes on *L. orientalis* distribution across the southern coasts of Türkiye by utilizing a species distribution modeling approach. Our results showed that the species' distribution range in the Mid-Holocene was slightly larger than today. The distribution range is contracted as the temperatures cooled down from Mid-Holocene to today, and modeling results indicate that "the precipitation of the wettest quarter" (BIO16) was the most explanatory climatic variable affecting the range shifts. This is a plausible explanation considering that the sweetgum is highly sensitive to warm and humid conditions. In fact, annual precipitation is relatively high in locations where the oriental sweetgum tree grows, ranging between 950 mm and 1200 mm (Kurt, 2008). Corbaci et al. (2019) indicated that the primary climate factors are air temperature and total precipitation mediating plant development of the tree. Ürker and Yalçın (2011) pointed out that the life quality and expectancy of the tree are largely dependent on groundwater or the presence of constantly flowing streams. Given these results, we suggest that modeling outcomes are consistent with the previous literature.

On the other side, our results showed that the distribution range of the sweetgum is to potentially expand by 2070 with globally rising temperatures (see Appendix 5). This presents significant implications with respect to the conservation aspects of the species. We believe that the sweetgum tree can expand its natural distribution along the southwestern coast of Türkiye, between the Orontes River (easternmost) and the Great Meander River (westernmost) in the next decades; however, it is crucial to take appropriate measures to improve the connectedness and permeability of landscapes surrounding protected areas, allowing for species migration in response to rising temperatures. While the shrinkage or displacement of endemic or endangered species with the increase in temperatures is a problem (de Queiroz et al., 2012; Deb et al., 2017; Cotado and Munne-Bosch, 2020; Rovzar et al., 2016; Thomas et al., 2016), the fact that the habitat of this species can expand further emerges as an opportunity for the future of the species.

Planting trees at strategic locations have been demonstrated to be one of the most successful in situ conservation techniques for tree species (Mather, 1993). However, afforestation/plantation development must be done in conjunction with a comprehensive strategy for land use and ecosystem management. From the perspective of conservation biology, approaches such as species distribution models (SDM), land suitability analysis (LSA), and forest management plans (FMP) are used to improve the long-term in situ conservation capacity of a tree species (Malczewski, 2006; Moukrim et al., 2019).

Our results also confirm that using the SDM approach has high potential in decision-making processes in regard to conservation efforts of endemic species. SDMs have been used increasingly in recent years as a conservation tool to analyze especially endemic species' extinction risks due to various factors (e.g., climate change, land use change, land cover change). For instance, Usta Baykal (2019) used SDMs to compare possible future distributions of Anatolian black pine (*Pinus nigra* J.F. Arnold) and Trojan fir (*Abies nordmanniana* subsp. *equi-trojani* (Asc. & Sint. ex Boiss.) Coode & Cullen) to assess conservation priority areas in possibly overlapping habitats for the endemic and endangered Trojan fir. Also, Aksoy (2022) used the SDM approach to predict the future distribution of *Platanus orientalis* L. which is one of the most prevalent monumental trees in Türkiye. Their results show habitat gain at higher altitudes and habitat loss at lower altitudes which emphasizes the importance of efficient conservation actions (Aksoy, 2022). Likewise, this study provides important insights to analyze the potential future status of an important endemic tree species in Türkiye.

Studies show that using species distribution modeling is highly valuable in conservation efforts such as in identifying areas of high conservation value (Sahana et al., 2023) or survey efforts to identify potential translocation areas (Eyre et al., 2022). However, it is also shown that complementing species distribution modeling with other approaches such as field survey data including current land use properties, legal status, and conservation status will improve the applicability of the model results in the field. We also note that our modeling results do not have the highest resolution to differentiate between riparian and non-riparian areas which are to be found as most suitable areas for the oriental sweetgum. Besides, improving data quality and applying complementary methodological approaches would increase the statistical robustness of modeling outcomes (Cayuela et al., 2009).

4.1. Conclusion and future directions
We used the SDM approach to understand the past, current, and future distribution patterns of endangered *L. orientalis* in order to contribute to its short- and future-term conservation efforts. The future potential distribution range of the oriental sweetgum tree is mostly government-owned marshlands, wetlands, riverbanks, and other areas where the tree has been known to distribute naturally throughout its history. It is noteworthy that most of these areas fall within the mega/catastrophic forest fires, which started to increase throughout the Mediterranean Basin (Kalem et al., 2022). We see a high potential to use sweetgum forests as an important tool in buffering ecological crises. For instance, the sweetgum forests can be utilized in order to reduce the severity and movement of fires, especially in the form of riparian habitats and riverine forest ecosystems in these areas. Overall, we suggest that appropriate conservation measures should be established and maintained; the oriental sweetgum tree can survive many more decades by taking advantage of the rising temperatures.

Acknowledgments
We are most grateful to Burak Akbaba, Yasin Ilemin, and Alp Giray for their help during the fieldwork. We thank the Republic of Türkiye, the General Directorate of Nature Conservation and National Parks, and G.D. of Forestry (Regional Directorate of Muğla, Operational Directorate of Köyceğiz) for their scientific work permits and logistic support.

Funding
This work was financially supported by the Rufford Foundation (project no. 16444-2).

Conflict of interest
The authors declare that they do not have any conflict of interest regarding this paper. The authors have no relevant financial or nonfinancial interests to disclose.

Contribution of authors
All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Okan Urker, Nurbahar Usta Baykal, and Eren Ada. The first draft of the manuscript was written by Okan Urker and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript. Research and publication ethics were complied with in the study. We declare that the figures or figures obtained from external sources within the study are materials that do not require copyright permission, by citing the relevant source.

References

Acar İ, Gemici Y, Genç A, Özel N (1992). Past and Present Situation of Anatolian Sweetgum Forests. Second Edition of International Symposium of Ecology and Environmental Problems, Pages. 127-133, 5-7 November 1992, Ankara. (in Turkish)

Acatay A (1963). Distribution of Sweetgum Tree (*Liquidambar orientalis* Mill.) in Turkey, Newly Detected *Liquidambar orientalis* var. *suber* variety and Insects Infested on Sweetgum Tree. From Forest Entomology and Forest Conservation Chair Studies, Istanbul University, Faculty of Forestry, Pages.10-56, Istanbul. (in Turkish)

Akman Y (1995). Forest Vegetation of Turkey. Ankara University, Faculty of Science, 450 Pages, Ankara. (in Turkish)

Akman Y, Ketenoğlu O, Kurt L (1992). Floristic structure of communities of *Liquidambar orientalis* Mill. Growing around Fethiye-Marmaris and Bucak. Doğa-Turkish Journal of Botany, 16: 273-86. (in Turkish)

Anonymous (2018). Gateway to the Paleobiology Database. http://fossilworks.org/?a=taxonInfo&taxon_no=54637 (The web page has been visitied in 11th February of 2018)

Atay İ (1985). Importance and Silvicultural Characteristics of Sweetgum Tree (*Liquidambar orientalis* Mill.). Journal of Forestry Faculty of Istanbul University, 12.11.1985, Pp.15-21, Istanbul. (in Turkish)

Behrensmeyer AK, Turner A (2013). Taxonomic occurrences of Hamamelidaceae recorded in the Paleobiology Database. Fossilworks. http://www.fossilworks.org/cgi-bin/bridge.pl?a=taxonInfo&taxon_no=54637 (The web page has been visitied in 19th July 2023)

Berkel A (1955). Studies on macroscopic properties and anatomical structure of sweetgum (*Liquidambar orientalis* Mill.) Wood. Journal of Forestry Faculty of Istanbul University, Serial A, Volume V, No 1 and 2, Page.1, Istanbul. (in Turkish)

Blanco JA, Ameztegui A, Rodríguez F (2020). Modelling forest ecosystems: a crossroad between scales, techniques, and applications. Ecological Modelling 425:109030

Caudullo G, Welk E, San-Miguel-Ayanz J (2017). Chorological maps for the main European woody species. Data in Brief 12: 662-666. https://doi.org/10.1016/j.dib.2017.05.007

Cayuela DJG, Newton AC, Kolb M, de Alburquerque FS, Arets EJMM et al. (2009). Species distribution modeling in the tropics: Problems, potentialities, and the role of biological data for effective species conservation. Tropical Conservation Science 2 (3):319-352 https://doi.org/10.1177/194008290900200304

Corbaci OL, Bilgili BC, Oner N, Ersahin S, Kasko-Arici Y (2019). Potential use of natural turkish sweetgum species in landscape design in Turkey. Fresenius Environmental Bulletin, 28: 2A/2019, Pp.1621-1626

Cotado A, Munne-Bosch S (2020). Distribution, trade-offs and drought vulnerability of a high-mountain Pyrenean endemic plant species, *Saxifraga longifolia*. Global Ecol Conserv 22:e00916

Dağtekin D, Şahan EA, Denk T, Köse N, Dalfes HN (2020). Past, present and future distributions of Oriental beech (*Fagus orientalis*) under climate change projections. PloS one, 15(11)

Davis PH (1972). Flora Of Turkey and East Aegean Islands. Vol-4: Page.246

De Queiroz TF, Baughman C, Baughman O, Gara M, Williams N (2012). Species distribution modeling for conservation of rare, edaphic endemic plants in White River Valley, Nevada. Natural Arens Journal 32 (2):149–158

Deb CR, Jamir N, Kikon ZP (2017). Distribution prediction model of a rare orchid species (Vanda bicolor Griff.) using small sample size. American Journal of Plant Science 8 (6):1388–1398

Dirik H (1986). Studies on Rejuvenation of Anatolian Sweetgum *(Liquidambar orientalis* Mill.). M.Sc. Thesis, Istanbul University, Institute of Science, Istanbul. (in Turkish)

Efe A (1987). Studies on the morphological and palynological characteristics of *Liquidambar orientalis* Mill. in Turkey. Journal of Forestry Faculty of Istanbul University, Serial A, Volume 37 (2):273-286, İstanbul. (in Turkish)

Elith J, Graham CH, Anderson RP, Ferrier S, Guisan A et al. (2006). Novel methods improve prediction of species' distributions from occurrence data. Ecography. 29: 129–151

EUFORGEN (2009). Distribution map of Oriental sweetgum (*Liquidambar orientalis*). The webpage link (http://www.euforgen.org) was visited on 03.03.2022

Eyre AC, Briscoe NJ, Harley DKP, Lumsden LF, McComb LB et al. (2022). Using species distribution models and decision tools to direct surveys and identify potential translocation sites for a critically endangered species. Diversity and Distributions. 28:700–711. https://doi.org/10.1111/ddi.13469

Fahrig L (2003). Effects of habitat fragmentation on biodiversity. Annual Review of Ecology, Evolution, and Systematics. 2003, 34, 487–515

Fick SE, Hijmans RJ (2017). WorldClim 2: new 1km spatial resolution climate surfaces for global land areas. International Journal of Climatology 37 (12): 4302-4315

General Directorate of Forestry, Republic of Türkiye (2012). The Report of Forestry Statistics of Turkey, Year 2012. Orman Genel Müdürlüğü, Ankara. (in Turkish)

Güner A, Vural M, Duman H, Dönmez AA, Şağban H (1993). Günlük ağacı (*Liquidambar orientalis* Miller) Köyceğiz'deki Durum. The Karaca Arboretum Magazine, II: 33-42. (in Turkish)

Gür H (2013). The effects of the late Quaternary glacial–interglacial cycles on Anatolian ground squirrels: range expansion during the glacial periods. Biological Journal of the Linnean Society 109: 19–32

Habel JC, Junker M, Schmitt T (2010). High dispersal ability and low genetic differentiation in the widespread butterfly species *Melanargia galathea*. Journal of Insect Conservation 14: 467–478

Helliwell R, Chapman J (2013). Use of Species Distribution Models in Conservation Biology. Report on file with: Interagency Special Status/Sensitive Species Program. U.S. Department of Interior, Bureau of Land Management, Oregon/Washington and U.S. Department of Agriculture, Forest Service, Region 6. Portland, Oregon. 22p

Hijmans RJ, Phillips S, Leathwick J, Elith J (2011). Package 'dismo'. Available online at: http://cran.r-project.org/web/packages/dismo/index.html

Hossell JE, Ellis NE, Harley MJ, Hepburn R (2003). Climate change and nature conservation: Implications for policy and practice in Britain and Ireland. Journal for Nature Conservation. Volume 11, Issue 1, 2003, Pages 67-73. https://doi.org/10.1078/1617-1381-00034

Hsu E, Andews S (2005). Tree of the year: *Liquidambar* (PDF Link: http://dendrology.org/site/images/web4events/pdf/Tree%20info%20IDS_04_pp11_45_TreeoftheYear.pdf). International Dendrology Society Yearbook. 2004: 11–45

Huş S (1949). Importance of Sweetgum Tree (*Liquidambar orientalis* Mill.) in Forestry and Chemical Investigation of Sweetgum O*il*. General Directorate of Forestry Publication No: 83, Pages: 7-27. (in Turkish)

Işik K (2011). Rare and endemic species: why are they prone to extinction? Turkish Journal of Botany 35 (4): 411–417

Iktüeren Ş, Acar İ (1987). Natural distribution of sweetgum tree (*Liquidambar orientalis* Mill.), production and marketing of sweetgum oil. Journal Series of Forestry Research Institute Publications, Vol. 33, Number 2, No:66, Pp.7-15. (in Turkish)

IUCN (2023). The IUCN Red List of Threatened Species. Version 2022.1. Available at: www.iucnredlist.org. (Accessed: 1 January 2023)

Kalem S, Ürker O, İlemin Y (Eds.) (2022). Ecological and Socio-economic Effects of Major Forest Fires in The Mediterranean Region of Turkey. Technic Reports of WWF-Turkey & NATURA. 63 Pages, PrintWorld Publishing, Istanbul-Turkey. Available at: www.wwf.org.tr, Accessed: 4 June 2023. (in Turkish)

Kamer Aksoy Ö (2022). Predicting the potential distribution area of the *Platanus orientalis* L. in Turkey today and in the future. Sustainability 14 (18): 11706

Kavak S, Wilson B (2018). *Liquidambar orientalis*. The IUCN Red List of Threatened Species 2018: e.T62556A42326468. https://dx.doi.org/10.2305/IUCN.UK.2018-1.RLTS.T62556A42326468.en. Downloaded on 11 April 2021.

Kaya Z, Alan M (2003). EUFORGEN Technical Guidelines for genetic conservation and use for oriental sweetgum (*Liquidambar orientalis*), International Plant Genetic Resources Institute, Rome- Italy

Kaya Y, Aksakal Ö (2005). Distribution of Endemic Plants in the World and Turkey. Journal of Faculty of Education of Erzincan University, Vol.7, Pages.85-99. (in Turkish)

Kirby K (2003). Climate change – implications for practical nature conservation in the 21st century. Journal for Nature Conservation. Volume 11, Issue 1, 2003, Page 1

Kurt L (2008). Biodiversity Report of Anatolian Sweetgum Tree (Frankincense Tree). Special Environmental Protection Agency of Turkish Republic, Ankara. (in Turkish)

Küçükala A, Durmuşkahya C, Koray Z (2010). Final Report of Educational Studies Project for Conservation of Sweetgum Tree.70 Pages, Special Environmental Protection Agency of Turkish Republic, Ankara. (in Turkish)

Malczewski J (2006). Integrating multi-criteria analysis and geographic information systems: The ordered weighted averaging (OWA) approach. International Journal of environmental Technology and Management, 6(2), 7–19

Mather AS (Ed) (1993). Afforestation: policies, planning and progress. Belhaven Press. 223 p

Moukrim S, Lahssini S, Rhazi M, Alaoui HM, Benabou A et al. (2019). Climate change impacts on potential distribution of multipurpose agro-forestry species: *Argania spinosa* (L.) Skeels as case study. Agroforestry Systems 93(4):1209–1219

Muğla RDoF (2012). Muğla Regional Directorate of Forestry, The Breakdown Table of Oriental Sweetgum Areas – 2012. Muğla-Türkiye. (in Turkish)

Myroniuk V, Kutia M, Sarkissian AJ, Bilous A, Liu S (2020). Regional-Scale forest mapping over fragmented landscapes using global forest products and landsat time series classification. Remote Sensing. 12 (1):187. Doi:10.3390/rs12010187

Orsenigo S, Montagnani C, Fenu G, Gargano D, Peruzzi L et al. (2018). Red Listing plants under full national responsibility: extinction risk and threats in the vascular flora endemic to Italy. Biological Conservation 224:213–222

Ozkil A, Ürker O, Zeydanli U (2017). Art in sweetgum forests. Nature Conservation Centre (DKM), Ankara. Dumat Ofset Publishing, First Edition, 161 Pages, ISBN: 978-605-82749-0-7

Pecchi M, Marchi M, Burton V, Giannetti F, Moriondo M et al. (2019). Species distribution modelling to support forest management. A literature review. Ecological Modelling 411:108817

Perktaş U, Gür H, Ada E (2015). Historical demography of the Eurasian green woodpecker: integrating phylogeography and ecological niche modelling to test glacial refugia hypothesis. Folia Zoologica 64: 284–295

Peşmen H (1982). Plant Cover of Anatolia from Past to Now. in Insan ve Çevre (Pages.68-75), Publication of the Foundation of Environmental Problems of Turkey, Ankara. (in Turkish)

Petit RJ, Csaikl UM, Bordács S, Burg K, Coart E et al. (2002). Chloroplast DNA variation in European white oaks phylogeography and patterns of diversity based on data from over 2600 populations. Forest Ecology Management 156: 5–26

Phillips SJ, Anderson RP, Schapire RE (2006). Maximum entropy modeling of species geographic distributions. Ecological Modelling 190:231-259

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Rovzar C, Gillespie TW, Kawelo K (2016). Landscape to site variations in species distribution models for endangered plants. Forest Ecology Management 369:20–28

Sahana M, Areendran G, Sivadas A, Raj K, Sharma D et al. (2023). Assessing high conservation value areas for rare, endemic and threatened (RET) species: A study in high altitude Changthang landscape of India. Journal for Nature Conservation. Vol.73, https://doi.org/10.1016/j.jnc.2023.126406

Sharma S, Roy PS (2007). Forest fragmentation in the Himalaya: A Central Himalayan case study. International Journal of Sustainable Development and World Ecology 2007, 14, 201–210

Svenning JC, Skov F (2004). Limited filling of the potential range in European tree species. Ecology Letters 7: 565–573

Taşkın BG, Taşkın V, Küçükakyüz K, Varol Ö, Çöl B et al. (2008). Esterase polymorphisms in relict endemic *Liquidambar orientalis* Mill. var. *orientalis* and *L. orientalis* Mill. var. *integriloba* fiori populations in Turkey. Journal of Cell and Molecular Biology 6 (2):137-146

Tekin O, Cetin M, Varol T, Ozel HB, Sevik H et al. (2022). Altitudinal migration of species of Fir (*Abies* spp.) in adaptation to climate change. Water, Air, & Soil Pollution, 233 (9): 385

Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ et al. (2004). Extinction risk from climate change. Nature 427(6970):145–148

Usta Baykal N (2019). Determining potential niche competition regions between Kazdagi fir (*Abies nordmanniana* subsp. *equi-trojani)* & Anatolian black pine (*Pinus nigra* subsp. *pallasiana*) and conservation priority areas under climate change by using maxent algorithm (Master's thesis, Middle East Technical University)

Ülgen H, Zeydanlı U, Lise Y (eds.) (2020). Orman ve Biyolojik Çeşitlilik (Forest and Biodiversity). Doğa Koruma Merkezi, Ankara, 219 Pages. (in Turkish)

Ürker O, Çobanoğlu N (2017). Anatolian Sweetgum Forests in the Context of Environmental Ethics. 204 Pages. ISBN: 978-3-659-94199-3. LAP-Lambert Academic Publishing, Germany (in Turkish)

Ürker O, Yalçın S (2011). If It Extincts in Köyceğiz, It Extincts All Over the World Too: Sweetgum Forests. TÜBİTAK Science and Technic Magazine, Number 521, Page. 58-63. April 2011, Ankara-Türkiye. (in Turkish)

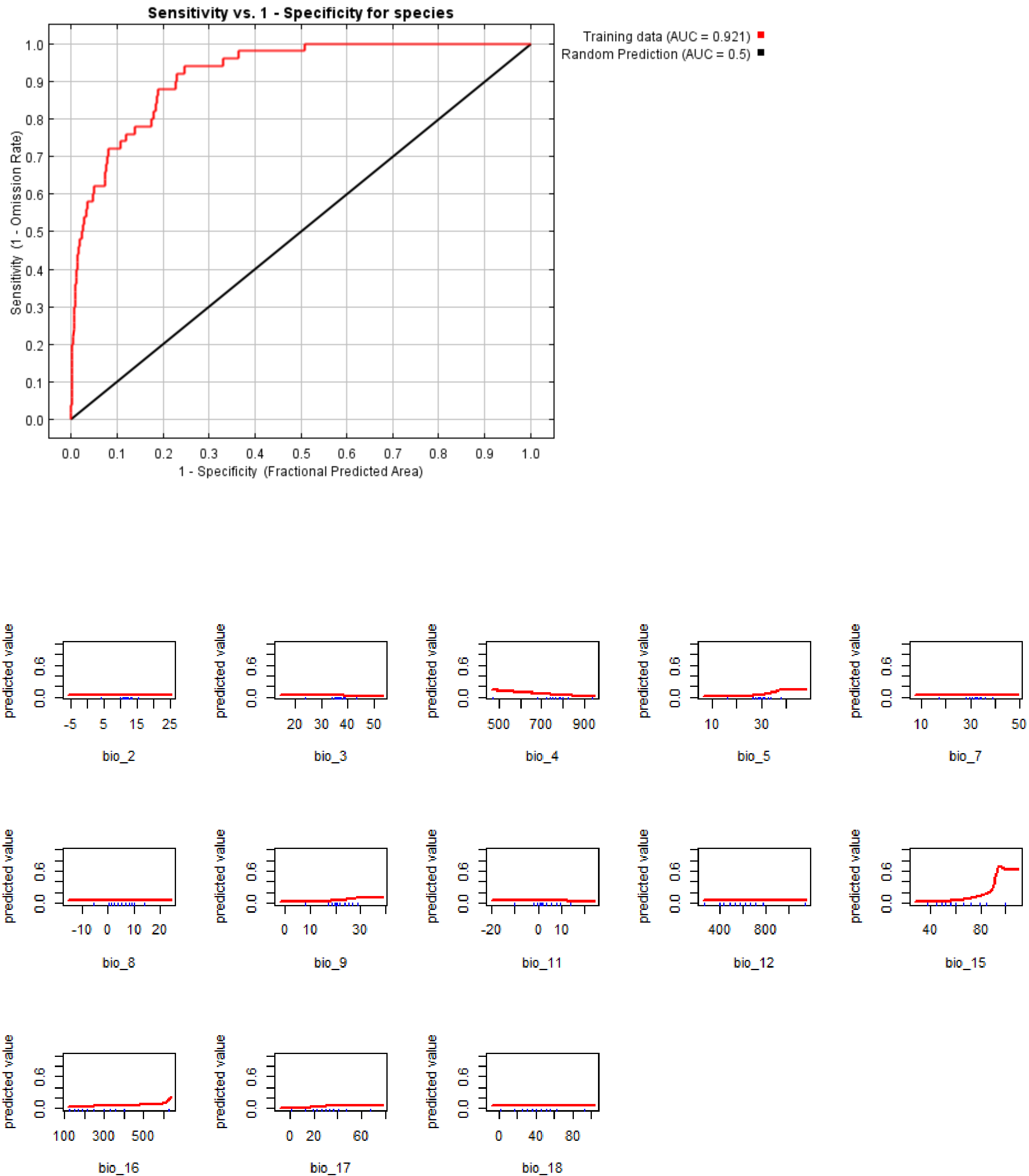
Yaltırık F, Efe A (2000). Plate 386. *Liquidambar orientalis*. Curtis's Botanical Magazine 17(2)

Appendix 1. The Occurrence points of oriental sweetgum tree.

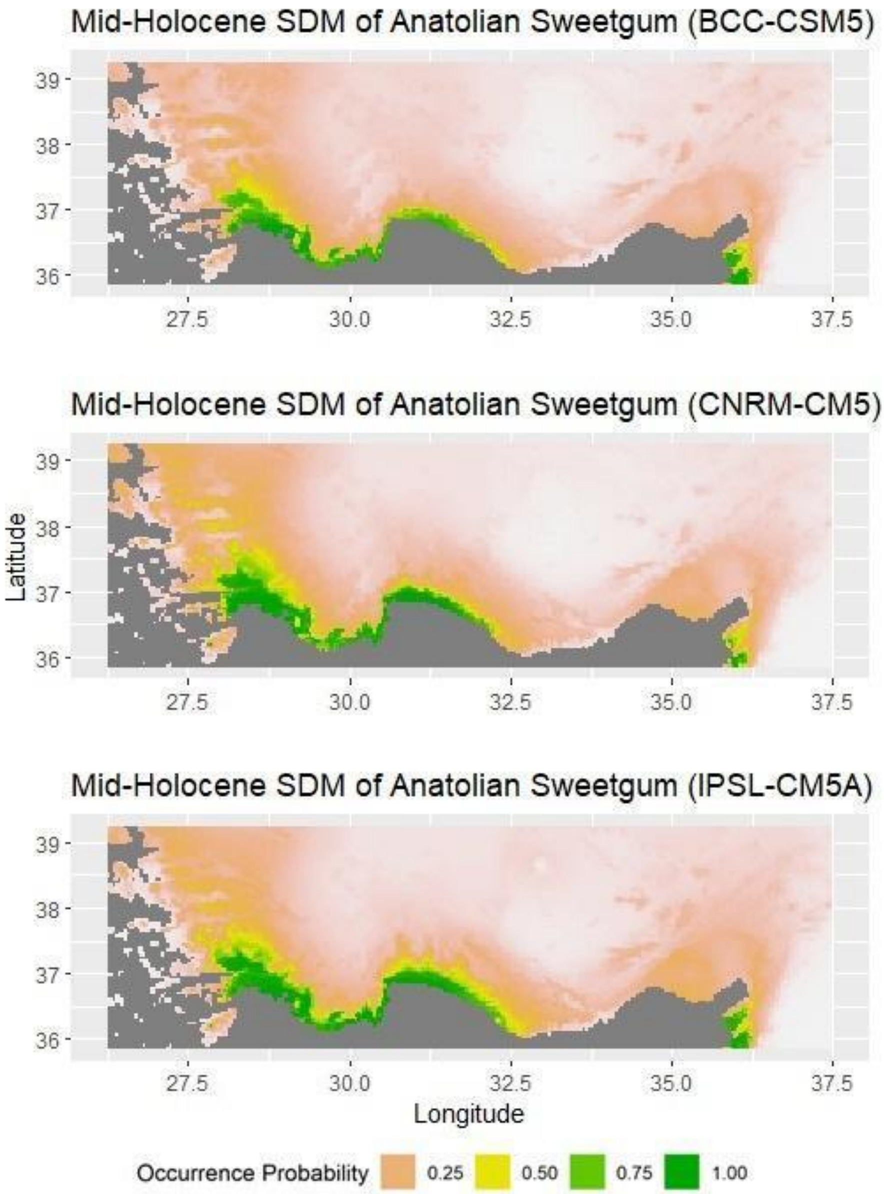
Longitude	Latitude	Longitude	Latitude
29.20531833	37.15496518	28.69261306	37.16245976
27.94153263	37.86704277	28.70118094	37.0975055
28.15363619	37.41430223	28.73418881	37.03553026
33.93704365	36.37499649	28.14719206	36.83853681
31.21258628	37.72492269	28.05800779	36.83737186
31.0029506	37.28365233	28.05099745	36.78644024
30.97716102	37.24550589	27.9100205	36.75696229
30.96174385	37.19508656	27.81927652	36.76861946
30.82107335	37.30487496	27.94626233	36.77885507
30.90417803	37.45493447	28.16512776	36.90302952
29.33715886	36.43721228	28.99369181	36.95644694
29.06513057	36.68580781	27.65805468	37.43528545
28.97320913	36.73534513	27.92389161	38.70794705
28.88261911	36.76581831	28.1059798	38.50333524
28.81272475	36.78966315	29.31583909	36.36037532
28.79530871	36.83713083	36.21856421	37.06044419
28.66914014	36.83592305	34.59498513	36.7840938
28.70930887	36.89893339	36.35100412	36.49785682
28.70795038	36.95525975	28.61636901	37.2595324
28.65310415	36.98359018	28.599183	36.906374
28.61067184	36.95230193	27.288121	37.714635
28.5850252	36.88798366	27.908695	37.863921
28.46780008	36.87300361	27.657517	37.434558
28.3823726	36.85352155	28.161973	37.563972
28.31316202	36.83098719	29.424917	36.806056
28.28264065	36.97120781	28.48305776	37.00274632

	bio_1	bio_2	bio_3	bio4	bio_5	bio_6	bio_7	bio_8	bio_9	bio_10	bio_11	bio_12	bio_13	bio_14	bio_15	bio_16	bio_17	bio_18	bio_19
bio_1	1																		
bio_2	-0.44	1																	
bio_3	0.004	0.704	1																
bio4	-0.52	0.764	0.13	1															
bio_5	0.831	0.091	0.3	-0.02	1														
bio_6	0.959	-0.64	-0.1	-0.72	0.659	1													
bio_7	-0.58	0.921	0.38	0.94	-0.05	-0.78	1												
bio_8	0.512	-0.18	0.05	-0.33	0.451	0.485	-0.27	1											
bio_9	0.984	-0.32	0.04	-0.36	0.904	0.901	-0.45	0.478	1										
bio_10	0.984	-0.32	0.04	-0.37	0.904	0.901	-0.45	0.479	0.9994	1									
bio_11	0.982	-0.55	-0	-0.67	0.731	0.992	-0.71	0.499	0.9367	0.9372	1								
bio_12	0.53	-0.67	-0.3	-0.66	0.176	0.649	-0.72	0.02	0.4504	0.451	0.614	1							
bio_13	0.644	-0.68	-0.2	-0.71	0.296	0.754	-0.76	0.155	0.5627	0.5637	0.723	0.9476	1						
bio_14	-0.37	0.021	0.1	-0.05	-0.45	-0.27	-0.01	-0.37	-0.4	-0.405	-0.302	0.1359	-0.094	1					
bio_15	0.73	-0.52	-0.2	-0.49	0.522	0.754	-0.57	0.243	0.6985	0.6994	0.75	0.6077	0.7878	-0.615	1				
bio_16	0.642	-0.69	-0.2	-0.7	0.296	0.753	-0.76	0.163	0.5621	0.5625	0.721	0.9442	0.9952	-0.116	0.8032	1			
bio_17	-0.28	-0.02	0.1	-0.12	-0.38	-0.19	-0.07	-0.25	-0.324	-0.328	-0.215	0.2211	-0.005	0.961	-0.574	-0.034	1		
bio_18	-0.43	0.074	0.12	-0	-0.49	-0.34	0.044	-0.26	-0.466	-0.463	-0.371	-0.023	-0.22	0.8338	-0.69	-0.25	0.828	1	
bio_19	0.672	-0.66	-0.2	-0.67	0.343	0.77	-0.74	0.091	0.6038	0.6047	0.743	0.9473	0.9835	-0.091	0.7961	0.9836	-0.021	-0.229	1

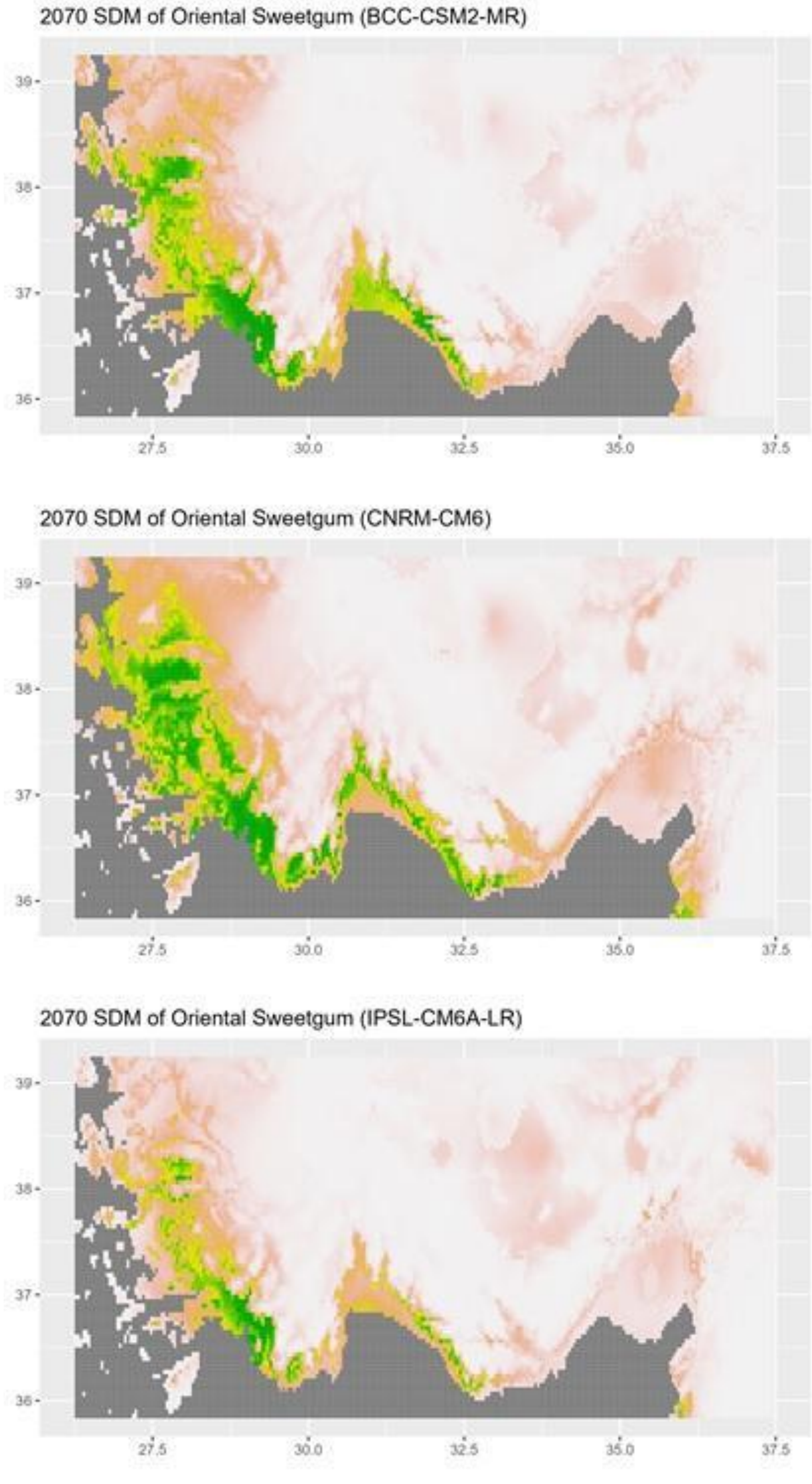
Appendix 2. Correlation matrix of bioclimatic variables within the study extent.



Appendix 3. AUC and response curves of the SDM of oriental sweetgum.



Appendix 4. Mid-Holocene projection results of 3 GCMs.



Appendix 5. 2070 future projection results of 3 GCMs.