International Journal of Environmental Science and Technology
https://doi.org/10.1007/s13762-023-05243-7

ORIGINAL PAPER

Identification of plantation areas for the endangered oriental sweetgum tree (*Liquidambar orientalis* Miller, 1768) in Türkiye

O. Ürker[1,2] · A. Günlü[3]

Received: 20 September 2022 / Revised: 17 July 2023 / Accepted: 21 September 2023

Abstract

Only two places in the world are home to the 2,500 hectares of fragmented forests of the tertiary relict oriental (Anatolian) sweetgum tree species (*Liquidambar orientalis* Miller, 1768): southwestern Türkiye and Rhodes Island (Greece). It is on the brink of extinction due to ongoing anthropogenic pressures. The goal of this study, which used the analytical hierarchy process as the approach, was to identify alternate in situ conservation places where the oriental sweetgum tree may persist owing to suitable living circumstances. The study area was chosen to be on southwestern Türkiye in light of historical records and current data from field studies and forest stands to analyze the potential plantation areas. Soil and climate factors with 0.3597 (36%) weight ratios were the best criteria to determine potential plantation areas. The two most important parameters in identifying the potential plantation area for the Anatolian sweetgum tree were alluvial, alluvial coast, and hydromorphic soils with a weight of 70.3% and average winter temperature of 6–10 °C with a weight of 66.87%. The area under the curve value was determined to be 0.750. According to the results, the most suitable areas for plantations were generally observed as riverine habitats where the species spread naturally during its history. The results are useful for forestry managers in developing successful plantation practices will alleviate the fragmentation and contribute to the species avoiding the genetic bottleneck, considering almost half of the entire study area has potential to develop medium- (488,448 ha, 41.2%) and high (95,400 ha, 8.1%)-level oriental sweetgum tree plantations.

Keywords Analytical hierarchy process (AHP) · In situ conservation · *Liquidambar orientalis* (Miller, 1768) · Plantation · Remote sensing

Introduction

The fragmentation of forest ecosystems is one of the main causes for the quick depletion of natural resources. The quality of the habitat and internal forest regions decreases as a result of forest fragmentation (Batar and Watanabe 2017). Deforestation is considered the primary reason for the reduction in terrestrial biodiversity (Mengist et al. 2022). Typically, forest areas are divided into small areas due to human use for farming or invasion by non-forest plant species (Forman and Collinge 1995; Healey et al. 2018). The idea of fragmentation refers to the breaking up of the original environment into smaller sections that a variety of new habitats isolate from one another (Wilcove et al. 1986; Myroniuk et al. 2020). Numerous studies cited habitat fragmentation as the main cause of the decline of biodiversity (Bascompte et al. 2002; Fahrig 2002; Vogt and Riitters 2017).

There are some options to prevent habitat fragmentation and reduce its impact. The corridor strategy, for instance, is among the best and most practical techniques (Sharma and Roy 2007). Corridors are forest clusters that provide integrity between forest fragments. Biological corridors reinforce the interplay between forest fragments (Forman and Godron 1986; Myroniuk et al. 2020). The genetic diversity is preserved between the forest clusters joined with corridors; thereby, the survival capacities and sustainability of the species are increased. The provision of links between forest

Editorial responsibility: Samareh Mirkia.

✉ O. Ürker
okan.urker@gmail.com

1 Eldivan Vocational School of Health Services, Çankırı Karatekin University, 18200 Çankırı, Turkey

2 NATURA The Society For The Conservation of Nature and Culture, 06690 Ankara, Turkey

3 Department of Forestry Engineering, Faculty of Forestry, Çankırı Karatekin University, 18200 Çankırı, Turkey

Published online: 16 October 2023

clusters or the strengthening of existing links has an important place in ecology and landscape conservation planning.

Conservation biologists are frantically trying to come up with ways and instruments for the protection and preservation of species due to the current rates of habitat loss, landscape transformation, and community, extinction at the species, and even ecosystem level (Areendran et al. 2020). Maintaining current levels of genetic diversity in rare or threatened species is one of the objectives of many conservation initiatives, along with habitat preservation (Williams 1991). In situ conservation, which permits evolution to advance in the zone of natural occurrence, and ex situ conservation, which presents a better level of protection to germplasm than in situ conservation, are the two generally employed methods for conserving plant genetic resources (Frankel and Soule 1981). Ex situ conservation refers to the conservation of a species off-site in botanical gardens or seed banks, whereas in situ conservation refers to the preservation of a species or population on-site where they naturally occur.

Thus, the in situ option ensures a long-term dynamic situation where the populations continue to evolve in nature, as opposed to a static, one-dimensional, or artificial environment afforded by all of the various ex situ conservation options (Thielges 2001).

Planting trees at a suitable point can be shown as one of the most effective in situ conservation measures for tree species. But, it is difficult to define either "afforestation" or "plantation forests" precisely (Mather 1993). Particularly, it is generally challenging to discriminate between afforestation and various forms of tree farming, as well as between plantation forests and enrichment planting or the restoration of damaged forest ecosystems (Kanowski 1997; Srivastava and Tyagi 2016). Afforestation/plantation development must carry out within a holistic approach to land use and ecosystem management (Mengist et al. 2022). For instance, properly considered ecosystem-based plantation forestry has been shown to impact mostly the ecology and biodiversity of tropical regions (Krishnapillay and Razak 2001).

In parallel to this introduction, the oriental (Anatolian) sweetgum forests that were chosen for this research are fragmented and currently on the verge of extinction (Kavak and Wilson 2018). Oriental sweetgum tree species (*Liquidambar orientalis* Miller, 1768) is generally found in riverine habitats along the coasts of Southwestern Türkiye (Özkil et al. 2017). More specifically individual or in groups, trees can grow from 10 to 35 m in flood plains, tiny grooves, marshes, valley sides along streams, or waterlogged alluvial habitats (Kavak and Wilson 2018). The oriental sweetgum tree is extremely sensitive to environmental variables. It adopts wet and humid environments with 1000–1200 mm of rain. It favors alluvial soils on flat land and low elevations (optimum 0 to 500 m) (Kaya and Alan 2003; Ürker and Çobanoğlu 2017). Furthermore, the species requires consistent water supply and a yearly average temperature of 15–20 °C (Kurt 2008; Corbaci et al. 2019).

The local peoples have benefited from this tree in many different ways for about four thousand years from the Carian Civilization, which is the oldest written and archaeological evidence in the region, to the present day (Ürker et al. 2014a, b). On the other hand, the fact that the leaves are cooked, used as a therapy forest at various times due to the healing effect of its pleasant smell, and the bark remaining from the stem parts during the oil is used as incense in funeral ceremonies, important religious days and places of worship, shows that the tree is important not only in material but also in spiritual terms (Huş 1949; İktüeren and Acar 1987; Ürker et al. 2014a, b). On the other hand, the main factor in bringing these forests to the brink of extinction is the process of transforming rural forest areas into agricultural areas in order to meet the food needs of the cities as a result of the urbanization policies that have developed systematically since the 1950s (Ürker et al. 2017).

The tree was identified as vulnerable on the 1997 Red List (IUCN 1997). This species was also noted as critically threatened on the 2017 European Red List (Rivers et al. 2017). Currently, the species has threatened position on the IUCN Red List Category (EN A2c Ver-2021.3) due to its dense fragmentation ratio (Kavak and Wilson 2018). Today, the European Forest Genetic Resources Programme (EUFORGEN) lists this species as a protected tree on the scale of the continent of Europe (Alan and Kaya 2003; EUFORGEN 2009). This endangered species is included in a Resolution 4 habitat type at a higher level (G1.3) in the Bern Convention. It is also related to Annex I habitat types in the EU Habitats Directive.

There have been some local conservation activities; nevertheless, these measures are insufficient to avoid the extinction of the species. There are 75 ex situ collections around the world (Botanic Gardens Conservation International-BGCI 2017). The entire European range of the species (the Butterfly valley-Rhodes) is within a NATURA 2000 site (GR 4210006), and it is also protected by Greek law as a natural monument (Kavak and Wilson 2018).

However, unlike silvicultural studies and studies about non-wood product (sweetgum oil) treatments, the characteristics of Türkiye's remnant oriental sweetgum forests in terms of conservation biology have not been extensively studied by science (Ürker et al. 2014a, b). Most studies related to the conservation of these forests concentrated on wildlife properties (Acatay 1963; Akman et al. 1992; Ürker and Lise 2018; Ürker and İlemin 2019; Ürker and Benzeyen 2020; Ürker and Yorulmaz 2020) or genetic structuring of the remaining populations (Taşkın et al. 2008). There is an active conservation program for this species run by the Turkish Forestry Service to prevent overexploitation (Yaltırık and Efe 2000). There are four gene conservation forests and a seed orchard to support ex situ conservation efforts in Türkiye (EUFORGEN 2009).

Considering the information at hand, the appropriate Turkish institutions have previously devised strategies for ex situ and in situ protection to reduce the possibility of extinction as a result of possible environmental breaks and anthropological pressures. Even though the current in situ and ex situ conservation efforts are worthwhile strategies to guarantee the species' genetic continuation, when considering forest habitats, they are insufficient to boost a species' genetic diversity and preserve the long-term viability of wildlife and ecosystem services (Ürker and İlemin 2019; Ürker and Benzeyen 2020; Ürker and Yorulmaz 2020).

By using selective breeding techniques, it is vital to boost heterozygosity in order to assure the survival of the species, shape connection clusters between habitats that are very distant from one another, and build psychological barriers. These measures are all consistent with the aims and driving forces mentioned above (Taşkın et al. 2008). Considering the current situation, based on historical records and current distribution data of the species, planting even one group of sweetgum trees in any environment where it is known to be ecologically viable and tested will be very valuable in preserving the species' future.

There are several ways to do this. For example, converting plantation sites of invasive species such as *Eucalyptus sp.*, which intersect with the habitat characteristics of the oriental sweetgum trees, re-establishment of forest corridors, and re-unification of fragmented groves have paramount importance for oriental sweetgum forests. New afforestation/plantation sites are inevitably needed in order to establish connectivity between forest fragments that are severely disconnected from each other in a very large geographical area (Ürker and Yalçın 2011).

Land suitability analyses to identify the potential afforestation/plantation areas produced many contradictory and disproportionate alternatives. Land suitability analyses are very suitable for the use of multi-criteria decision-making (MCDM) analysis based on geographic information systems (GIS), since it is carried out by evaluating criteria in a holistic sequence (Malczewski 2006). Consequently, approaches like a weighted linear combination (WLC), ordinal weighted average (OWA), ideal point method (IPM), analytical hierarchy process (AHP), fuzzy logic, and land suitability studies typically use artificial neural networks (ANN) within the scope of MCDM (Çavuş and Koç 2015; Malczewski 2004). Among the many MCDM analyses, AHP provides more practical and powerful possibilities for the creation of multiple alternatives, with the combination of classified qualitative and quantitative data use (Çavuş and Koç 2015). AHP shows up as a highly powerful technique, especially when decision makers cannot produce clear solutions to problems with different alternatives (Özdağoğlu and Özdağoğlu 2007).

AHP is frequently applied to various facets of forestry management in Türkiye and other countries (Sivrikaya and Küçük 2022; Sivrikaya et al. 2022). To assess the efficiency with which AHP integrates stakeholder preferences into regional forest planning, including its scope and viability, the Australian Regional Forest Agreement Program could serve as an illustration. The outcomes demonstrated that AHP can boost the process's transparency and legitimacy while also formally including the public in decision-making (Ananda and Herath 2003). A similar study was out in Türkiye employed the AHP approach to demonstrate the importance of sustainable forest management (SFM) by focusing on the sustainability of wood products rather than other sustainability indices. The study also discovered that Türkiye's SFM indicators had a categorization issue (Bayram 2021). Some researchers combined GIS and AHP to successfully complete afforestation estimations (Ismail 2009; Eslami et al. 2010; Hashemi 2018; Muğla and Türk 2020; Yağcı and İşcan 2021). Studies about determining suitable afforestation areas by using the AHP method in Türkiye have also focused on choosing the best tree types for industrial plantations (Şen and Güngör 2018). In this kind of study using AHP to detect the most suitable afforestation areas in Türkiye, land use capability, large soil groups, rainfall, slope, aspect, and erosion were used as the main criteria (Yağcı and İşcan 2021).

The goal of this research which was carried out between the years 2021 and 2022, was to identify suitable locations for tree planting for the in situ conservation approach where the oriental sweetgum tree could survive in optimum living conditions while considering the species' geographical, biological, ecological, eco-physiological, and climatological demands using the AHP approach southwestern Türkiye as the study area. Compared to previous studies involving the AHP approach, the originality of this study is greatly enhanced as it presents a new approach that can contribute to the long-term conservation of the species by developing specific afforestation techniques that prioritize the creation of biological corridors from trees of an endangered plant species.

Using the AHP method, it was possible to predict how the oriental sweetgum tree will spread under bioecological conditions. In this study, the AHP approach was employed for the first time in Türkiye and the rest of the globe to identify viable/suitable/potential places for afforestation in order to improve the long-term conservation of a tree species that is on the verge of extinction.

The novelty of this study is significantly higher when compared to earlier studies using the AHP approach because it proposes a novel strategy that can aid in the long-term conservation of the species by developing specific afforestation methods that prioritize the building of ecological corridors using trees from a plant species that is in danger of extinction.

Materials and methods

Study area

In order to analyze potential sweetgum plantation areas, the southwestern coast of Türkiye between the Great Meander River (westernmost) and Orontes River (easternmost), based on historical records and current information regarding forest standing, was chosen as the study area. The oriental sweetgum, which flourishes in riverine woodlands where the tertiary remnant oriental sweetgum (*Liquidambar orientalis* Miller) predominates, has a very limited range in the coastal districts of southern Anatolia (max. 2500 hectares in Türkiye) and the island of Rhodes (an isolated population only covering 25 hectares max. natural/protected area called Butterfly Valley in Petaloudes-Rhodes Island, Greece) (Alan and Kaya 2003; Ürker and Çobanoğlu 2017; Caudullo et al. 2017) (Figure 1).

These trees' trunks can be used to make oil, which is well-known in the areas where it is produced (Huş 1949; Torlak 2012). In shallow creek water and basin areas, you can find groups of or single oriental sweetgum trees. Additionally, the trees are situated in little groves in groups and/or by the rivers' shores (Dirik 1986; Kurt 2008; Arsalan and Şahin 2016). Except for individual tree communities on creeks, valley floors, and hilly slopes, nearly all of the natural woodlands/forests of the species are under different kinds of official protection/conservation status in Türkiye (Kurt 2008; Ürker and Çobanoğlu 2017) (Table 1).

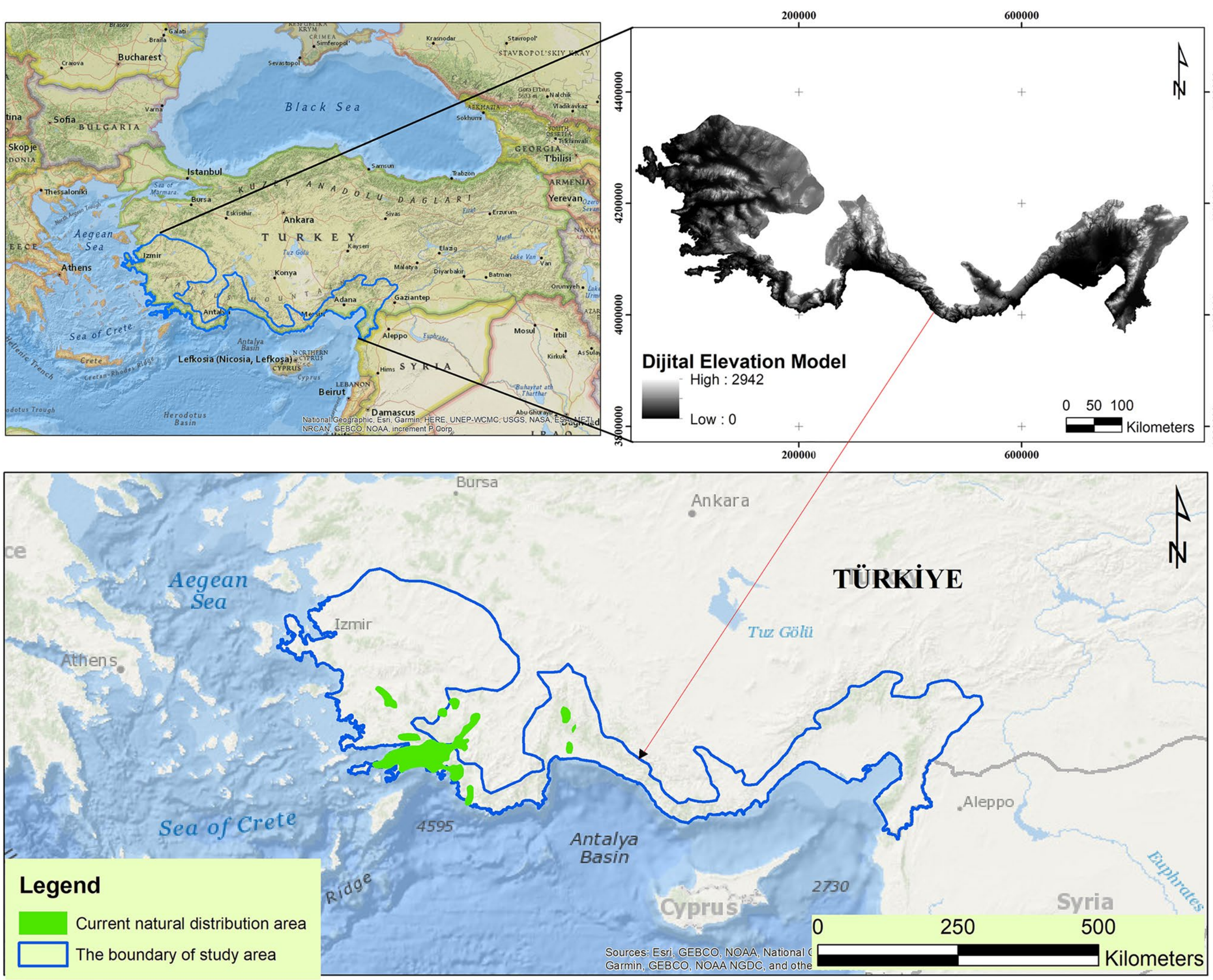

Fig. 1 The maps of the study area. Up-left: The boundary of the study area. Up-right: DEM map of the study area. Down: Current natural distribution areas of *Liquidambar orientalis* around the world (developed from Caudullo et al. 2017)

Table 1 Official protection/conservation status in Türkiye for oriental sweetgum woodlands (Kurt 2008; Ürker and Çobanoğlu 2017)

Name and status of the area	Size (hectares)
Köyceğiz-Dalyan *Specially Protected Area* (In situ)	770 ha
Köyceğiz Yunus Emre *Arboretum* (Ex situ) *P.S. Even though this place is called an arboretum, in reality there is no ex situ protected area established yet. Natural sweetgum woodlands comprise 30 hectares of this area. The rest contains red-pine forests, maquis and stone pine plantations	286 ha
Köyceğiz *Biogenetics Reserve Area* (Ex situ)	30 ha
Sütçüler (Burdur) Sweetgum Tree *Nature Protection Site* (In situ)	88.5 ha
Kızılyaka (Ula-Gökova) *Genetic Reserve & Research Forest* (Ex situ)	245 ha
Bucak (Isparta) *Genetic Reserve Forest* (Ex situ)	32 ha
Göcek *Seed Stand Site* (In situ)	72.8 ha
Çetibeli (Marmaris) *Seed Stand Site* (In situ)	128 ha
Göcek Dikmentepe *Seed Garden* (Ex situ)	2.2 ha
Total Area	1654.5 ha

Although the area of these riverine forests was 6,312 hectares in Türkiye in 1949, the groves shrank to 1,337 hectares in 1987 and now they are very fragmented. Only approximately 2,500 hectares of oriental sweetgum woodlands remains because of anthropogenic influences including agriculture, urbanization, and tourism (Güner et al. 1993; Efe 1987; Ürker and Çobanoğlu 2017). Although significant environmental protection measures were taken in recent decades to end the settlement of these forests, today a highly fragmented forest texture remains (Kurt 2008; Ürker and İlemin 2019).

Data description

There are many different multi-criteria decision-making techniques used in such studies (Rashidi and Sharifian 2022). Some of these are machine learning techniques (MLT), logistic regression (LR) (Ahmad and Rizvi 2023), analytical hierarchy process (AHP) (Dindaroglu 2021; Sivrikaya and Küçük 2022), analytical network process (ANP), VIKOR, TOPSIS, and fuzzy logic (Saaty and Varga 1991; Vang et al. 2016; Seyed and Alireza 2017; Sari 2021). Of course, these methods have advantages and disadvantages over each other. AHP is the most preferred and widely used method in such studies. The main advantages of the method are its flexibility and simplicity in finding solutions; it allows objective and objective consideration of both qualitative and quantitative information; it allows the decomposition of problems into hierarchical levels, which enables the analysis of problems with varying degrees of detail; and it measures the consistency of the evaluation made by the decision makers. In this context, a map for determining the potential distribution area of the oriental sweetgum tree species was produced using the AHP method.

During the production of this map, the following steps were followed. First of all, the main criteria and subcriteria affecting the distribution area of sweetgum were determined. The determined subcriteria were weighted within themselves using the AHP method. Then, weights were made for the main criteria and the weight of each main criterion was determined. Subsequently, each layer was combined by overlaying and the sweetgum distribution area index was calculated using the GIS raster calculator command. The index value was divided into four main groups (not suitable, less suitable, suitable, very suitable) with the natural break command.

When determining the potential status of sweetgum plantation areas closest to nature based on data from the books and literature, and current fieldwork in the area of study, climate, large soil groups, slope, aspect, and elevation were evaluated as the main factors. Between Figures 4 and 8 show the parameters affecting the potential distribution area of oriental sweetgum tree. These elements account for the development and spread of sweetgum forests in the most effective and sufficient way (Efe 1987; Kurt 2008; Ürker et al. 2015; Corbaci et al. 2019). Although climate and large soil group are the biggest factors in the formation of sweetgum forests (Yaltırık and Efe 2000; Ürker and Yalçın 2011; Corbaci et al. 2019), there are significant, modest, and negligible influences on the occurrence of these woods depending on the values of the five important factors.

To build a database for geographic information systems (GIS), the digital land cover data from the CORINE project prepared by the European Environment Agency (EEA) for 2018 were downloaded for the region of research from https://land.copernicus.eu, and the analysis of data was completed with spatial analysis tools in GIS. The ALOS PALSAR satellite picture served as the source for the digital elevation model (DEM). Maps of aspect, slope and elevation were created using DEM info. The map of large soil groups developed by Karabulut et al. (2011) was produced using GIS in the study. Climate data were downloaded from http://worldclim.org/ as a digital raster file (Worldclim 2021). Monthly averages for minimum winter temperature data were generated from the climate data, and a climate map was produced with GIS. Figure 2 shows the methodology for mapping the potential distribution area for oriental sweetgum using the AHP.

Criteria selection

Climate

The oriental sweetgum tree typically prefers hot and warm Mediterranean climates. In Türkiye, there is no natural distribution of sweetgum trees in any place where the average minimum temperature of the coldest month in winter (min. winter) is lower than 3 ℃ (Kurt 2008). Therefore, the oriental sweetgum tree is very sensitive to frost events. The oriental sweetgum tree has maximum distribution in coastal areas of southwestern Türkiye with a minimum winter temperature of 6–10 ℃ (Efe 1987; Yaltırık and Efe 2000; Kurt 2008).

In areas where the oriental sweetgum tree spreads, the annual precipitation amounts are quite high, generally between 950 and 1200 mm. However, rain has not fallen for a time that the summer drought in the study area is between 3 and 6 months. The oriental sweetgum tree survives this dry period in summer due to its proximity to small rivers or groundwater. Even though the primary climate factors are air temperature and total precipitation-mediating plant development and adaptation (Corbaci et al. 2019), the life quality and expectancy of the oriental sweetgum tree are largely dependent on groundwater or the

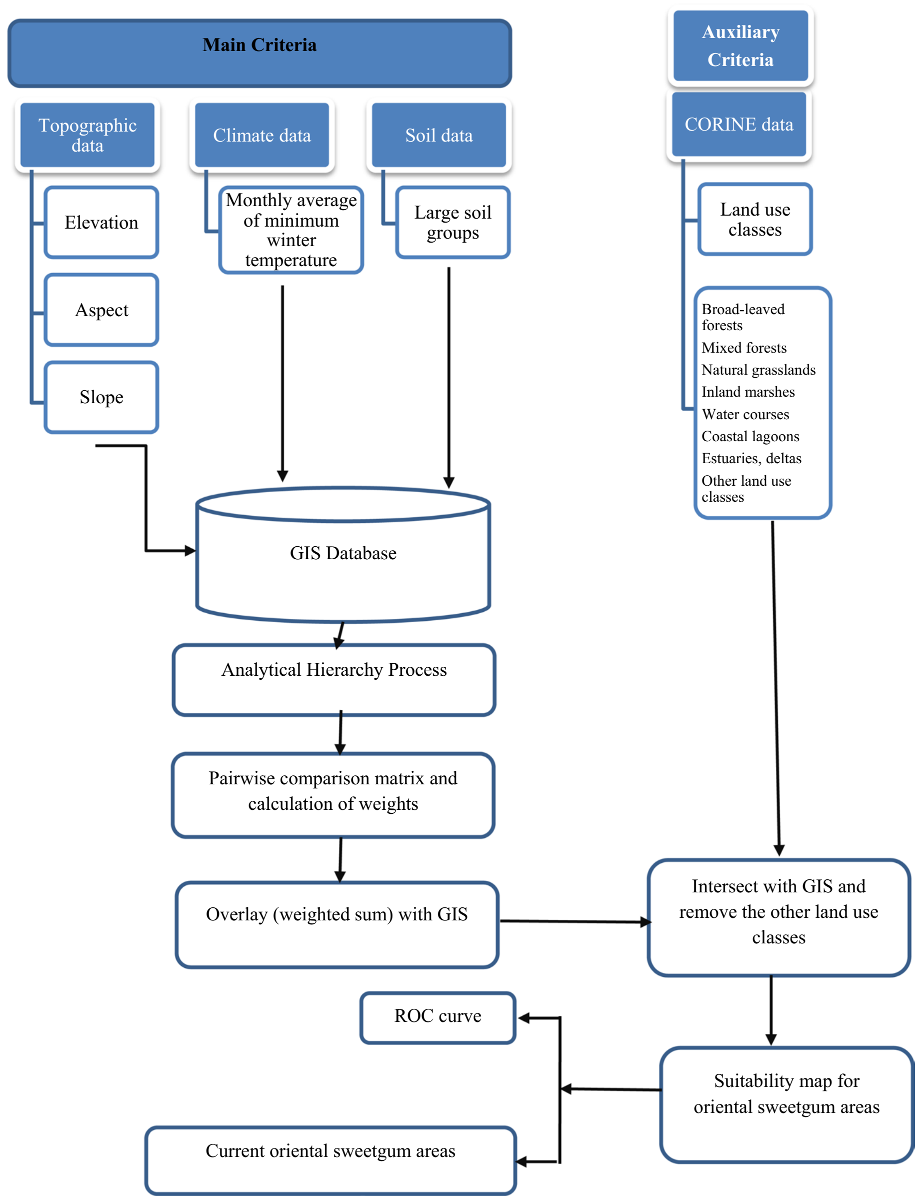

Fig. 2 Methodology for mapping the potential distribution area for oriental sweetgum using AHP

presence of constantly flowing streams (Ürker and Yalçın, 2011; Özkil et al. 2017).

Considering the findings of the Maxent Species Distribution Model prepared within the structure of an examination into the species' current bioecological circumstances, the most important climatic layers (as bioclimate variables) affecting the distribution of the species are *'Precipitation of Wettest Quarter* (48.7%),' *'Maximum Temperature of Warmest Month'* (16.7%),' and *'Annual Precipitation* (11.2%)' (Ürker et al. 2015). Therefore, locations with an average lowest winter temperature of less than 5 °C were given a poor score, places equivalent to 5 ℃ were given a moderate score, and, if any, high scores were given for locations with temperatures between 6 and 10 °C and over 10 °C. Figure 3 shows the climate criterion map.

Large soil groups (LSGs)

In the hot Mediterranean climate, lands with wet and flat ground and generally alluvial (A), alluvial coast (S), and hydromorphic alluvial (H) soils are the places where oriental sweetgum plants thrive best (Güner et al. 1993; Kurt 2008). Following this, some afforestation works were carried out locally in the research region in years past on red Mediterranean soils (T) and red-brown soils of the Mediterranean (E). Although these plantation works were partially successful, there was a requirement for hard work (such as the constant availability of food and water) in the plantations carried out on these soil groups and all other LSGs (Ürker 2021, personal observation comment). The map of large soil groups that was developed by Karabulut et al. (2011) was utilized in the research. Three classes were created by classifying these soil groups using GIS. As a result, the soil groups (A, S, and H) were assigned high values; moderate values for the T and E soil groups; and low values for all the remaining soil groups. Figure 4 shows the large soil groups criterion map.

Elevation and aspect

Although the oriental sweetgum tree displays best growth in the marine zone (0–200 m) in coastal regions, it has relatively healthy growth 200 to 400 m and more fragmented growth between 400 and 600 m in height. However, if it finds suitable land structure, it may flourish at altitudes of up to 900 m on hot and south/southeast facing slopes (Güner et al. 1993; Kurt 2008; Ürker and Yalçın 2011). In the most recent ground investigations, we carried out The Aksu River's (Antalya, Türkiye) upper altitudes contained trees that looked like oriental sweetgum trees at an altitude of approximately 1300 m; however, because the terrain slopes heavily at these higher altitudes, the oriental sweetgum trees developed in a thin strip on the southern aspects. There was nowhere to put it to allow the trees to transform into a forest ecosystem, and the floristic structures of sweetgum communities were also very poor (Ürker 2021, personal comment). As a result, within the parameters of the research field, high values were chosen for places according to the height (elevation) range of 0–400 m, moderate values for places corresponding to the elevation range of 400–600 m, and low values for all places above 600 m. Similarly, flat areas and places with south and southeast aspects were given high scores, places with east and southwest aspects were given moderate scores, and all other aspects were given low scores. Figure 5 and 6 show elevation and aspect criterion maps, respectively.

Slope

One of the key components influencing the length and breadth of the oriental sweetgum forest is the terrain's slope. In areas with high slope, the oriental sweetgum tree can only grow in a thin strip along permanent water lines and streams at the foot of valleys (Kurt 2008; Özkil et al. 2017). However, the forest can develop more easily in flat lands and very

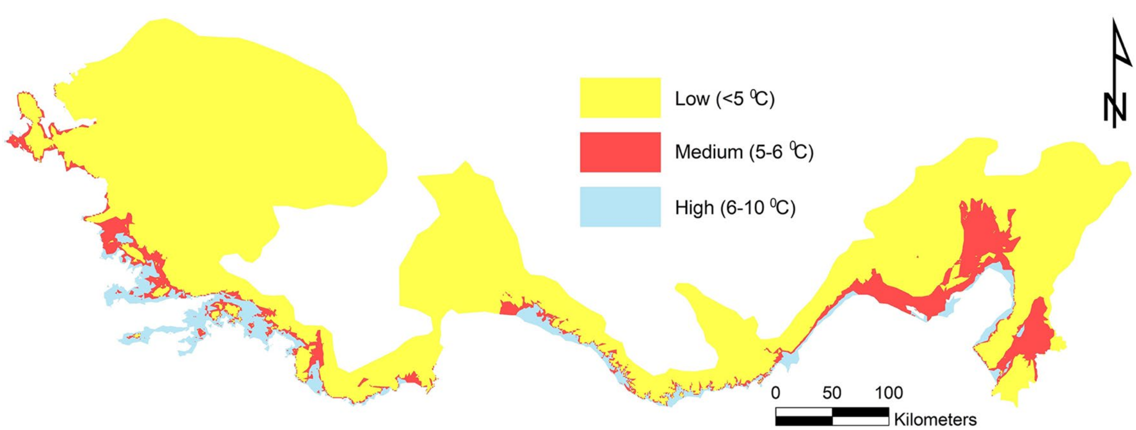

Fig. 3 Climatic criterion (monthly average of minimum winter temperature) (℃) map

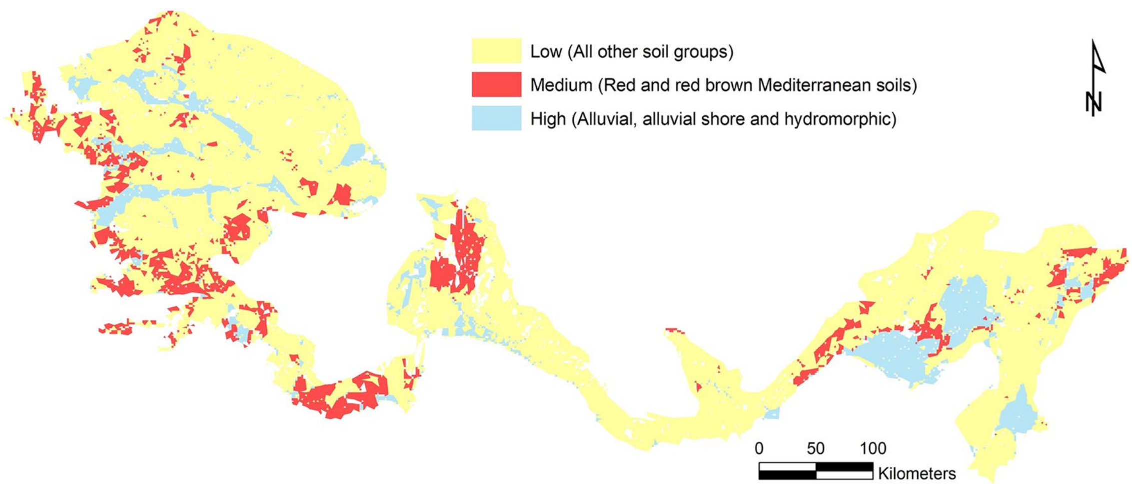

Fig. 4 Map of large soil groups

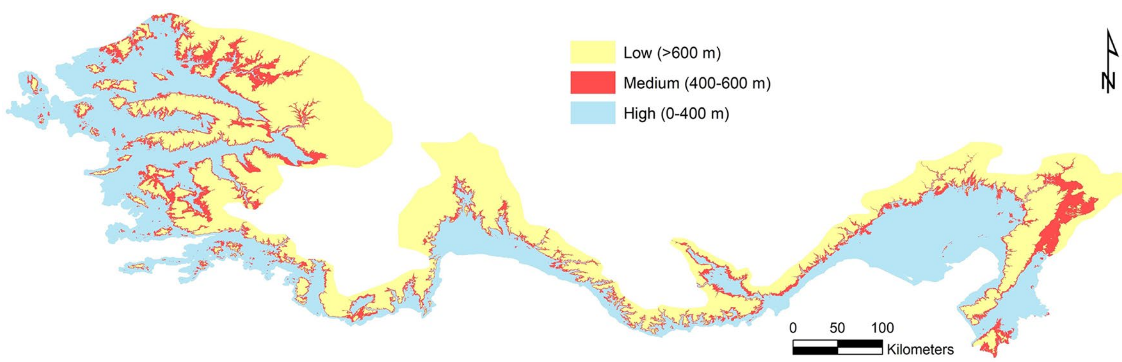

Fig. 5 Elevation criterion map

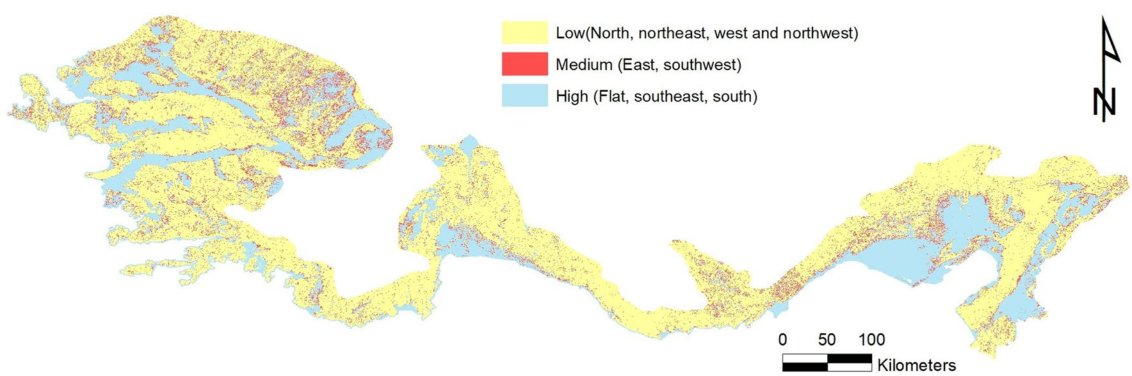

Fig. 6 Aspect criterion map

slightly sloping lands (0–5%) where water can disperse (Huş 1949; Güner et al. 1993; Kurt 2008). Therefore, in addition to high ratings for flat areas within the study area, high ratings were also given for places with 0–5% slope, moderate ratings for places with 5–10% slope, and all locations with

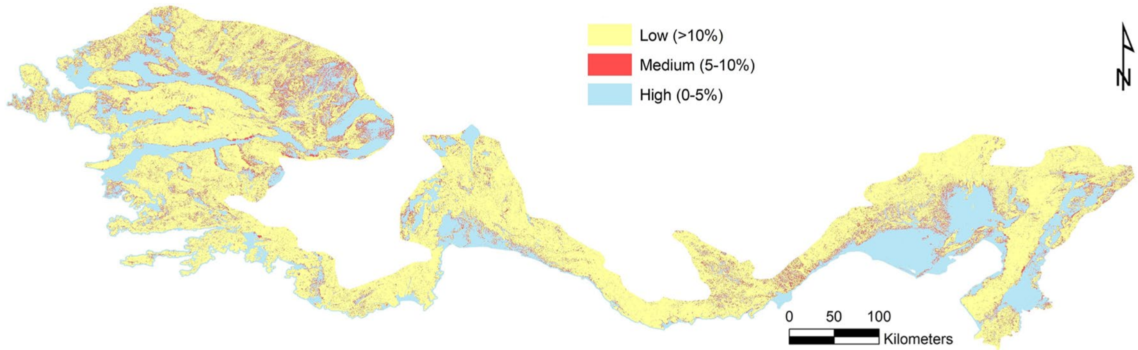

Fig. 7 Slope criterion map

slopes more than 10% receive bad ratings. Figure 7 shows the slope criterion map.

Analytical hierarchy process (AHP) method

The AHP technique is a mathematical approach that examines mixed decisions using various parameters (Saaty 1980). It was successfully implemented in different areas of forestry (Saaty and Vargas 1991; Sivrikaya and Küçük 2022). In the AHP technique, weighting of several parameters is used to govern pairwise comparisons of two properties at the same time (Akıncı et al. 2013). Users can choose the parameters' weights while resolving a multi-factor problem using the AHP technique, one of the most widely used multiple-factor analysis techniques. Using the AHP technique, targets, criteria, subcriteria, and options are developed in a hierarchical model for each issue (Saaty 2012). Depending on a literature review, the four criteria were chosen for the AHP technique. After the hierarchical structure of the problem was established, the weights for the criteria affecting the purpose were calculated (Akıncı et al. 2013). To compare the criteria in one level with the other criteria in the next hierarchy level, scoring is done by using *fundamental scale for pairwise comparison* developed by Saaty (1980), and a pairwise comparison matrix is produced.

Saaty (1980)'s pairwise comparisons enable the independent analysis of each factor's contribution, allowing easier decision-making (Rezaei-Moghaddam et al. 2006; Sivrikaya and Küçük 2022; Sivrikaya et al. 2023). The assessment of the consistency ratio (CR) is another crucial stage in AHP processing. In the literature, the standard CR threshold value of 0.10 was frequently utilized as a measure of consistency in a set of AHP application decisions. If CR is less than 0.10, the pairwise comparison matrix is considered consistent, and the weight values computed are valid and can be used. Whenever the CR value exceeds 0.10, the pairwise comparison matrix is not be considered consistent and the calculated weight values are not valid and usable (Saaty 2001). The calculated index and consistency ratio equations are given below.

$$\text{Consistency Index (CI)} = \lambda_{max} - n / n - 1 \tag{1}$$

$$CR = CI/RI \tag{2}$$

In Eq. 1, the number of criteria is n, and λ max is the highest eigen value. In Eq. 2, RI is the random index which changes based on the number of criteria being compared. Saaty's RI values (1980) were utilized in this study.

Depending on the potential suitability of areas for sweetgum, each parameter was assigned a specific value. A number from 1 to 10 were allocated to each parameter. While 1 is low suitability sweetgum area, 10 refers high suitability sweetgum area. The raster calculator function in GIS was used to use climate, soil, slope, aspect, and elevation along with the weight values assigned to each parameter for each pixel to construct a prospective suitability map for sweetgum trees. Then, a potential suitability map for the sweetgum tree was produced by applying the equation to execute a weighted overlay of the main criteria (3).

$$PSAI = (0.3597 \times S) + (0.3597 \times C) + (0.1617 \times S) + (0.0788 \times A) + (0.0400 \times E) \tag{3}$$

where PSAI is potential sweetgum area index, S: soil criterion, C: climate criterion, S: slope criterion, A: aspect criterion and E: elevation criterion.

Land use classes

Considering the information obtained from the AHP computations, an additional filtering requirement emerged regarding which plantation decisions can be applied in practice in these areas. Coordination of Information on the Environment (CORINE) data for the year 2018 were used for filtering in this study. CORINE is frequently utilized in Türkiye and encompasses the production of maps showing land cover/use at a scale of 1/100,000 produced by computer-aided visual interpretation methods of satellite images according to the Land Cover/Use Classification data determined by the European Environmental Agency (EEA 2006). ArcGIS 10.5 software and the polygon class merge tool were used to consolidate classes. Fieldwork was used to support the image interpretation among the various forms of land cover accounted for by the classification. CORINE contains a total of 44 classes; however, only land cover categories that can be found in the study area were considered. The third level and a total of 7 classes (which were state-owned natural areas) were filtered in this study (Fig. 8). These third-level land use classes can be ranked as broad-leaved forests (3.1.1), mixed forests (3.1.3), natural grasslands (3.2.1), inland marshes (4.1.1), water courses (5.1.1), coastal lagoons (5.2.1), and estuaries, deltas (5.2.2).

Validation of potential sweetgum area map

The receiver operating characteristic (ROC) analysis was utilized in this study to validate the association between the sweetgum tree's existing distribution area and its potential distribution area. A frequent technique for evaluating the reliability of a developed model in future forest mapping investigations is the ROC curve (Wakie et al. 2016; Khwarahm 2020). The ROC curve indicates that the false-positive rate on the X-axis and the genuine-positive rate on the Y-axis, are a visual way to assess the balance between specificity and sensitivity (Gheshlaghi et al. 2020). The area under the receiver (AUC) operating curve is calculated using the ROC curve that was utilized to evaluate model performance. The best result is shown by the highest AUC value (Yesilnacar 2005). AUC values ranging from 0.5 to 0.6, 0.6 to 0.7, 0.7 to 0.8, 0.8 to 0.9, and 0.9 to 1.0 indicate poor, medium, good, very good, and perfect estimations, respectively (Gheshlaghi et al. 2020; Sivrikaya and Küçük 2022).

Because the data in multiple hits files can be processed in series or parallel, allowing the results of multiple predictions to be viewed side-by-side or combined, ROCPLOT which is a generic and flexible software tool for ROC analysis and the validation of predictive methods (Ison and Blades 2005), had been used for this study. ROCPLOT is freely available for download as part of the European Molecular Biology Open Software Suite, EMBOSS (http://emboss.sourceforge.net/apps/rocplot.html).

Results and discussion

General findings

To determine the weights, every criterion's importance should be explained while creating the map of probable distribution zones for the sweetgum tree with AHP method. The AHP pairwise comparison matrix was utilized to produce the weights for the criteria and parameter in this study. The CR values for climate, soil, aspect, slope, and elevation were determined for the four pairwise comparison matrices (Table 2). All of the criteria and parameter have a different CR value that is less than 0.1 when Table 2 is checked. Climate, soil, aspect, slope, and elevation were calculated to have CR values of 0.03 each. Soil and climate criteria, with 0.3597 (36%) weight ratio, were the best criteria to determine potential sweetgum forest areas. When the parameters are considered, the two most important parameters in determining the potential area for sweetgum trees were alluvial, alluvial shore, and hydromorphic soils with a weight of 70.3%, and temperature of 6–10 ℃ with a weight of 66.87%.

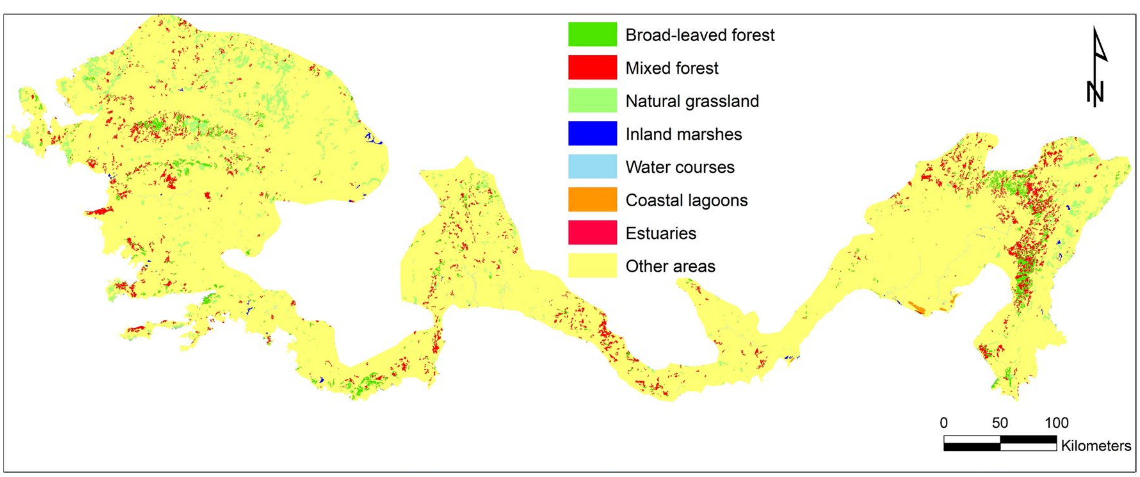

Fig. 8 Land use classes for AHP calculation

Table 2 All factors, weights, parameters and consistency ratios

Criteria (factors)	CR	Weights	Parameters	CR	Weights
Soil	0.03	0.3597	Alluvial, alluvial shore and hydromorphic Red and red brown Mediterranean soils All other soil groups	0.016	0.7030 0.2066 0.0905
Climate		0.3597	6–10 ℃ 5–6 ℃ < 5 ℃	0.006	0.6687 0.2431 0.0882
Slope		0.1617	0–5% 5–10% > 10%	0.070	0.5105 0.3893 0.1001
Aspect		0.0788	Flat, southeast, south East, southwest North, northeast, west and northwest	0.003	0.6479 0.2299 0.1222
Elevation		0.0400	0–400 m 400–600 m > 600 m	0.056	0.6434 0.2828 0.0738

The most crucial factors in identifying the possibly eligible sites in this investigation for the sweetgum tree were soil and climate, and the weight of both was approximately 72%. These parameters were followed by slope with 16%, aspect with 8%, and elevation with 4% weights. Despite the fact that a variability of climatic conditions and soil types was the most crucial elements in the growth of oriental sweetgum trees and the spread of the forest, it was discovered that no specific parameter is useful on its own when the pertinent criteria are considered (Güner et al. 1993; Kurt 2008; Özkil et al. 2017; Kavak and Wilson 2018). The three factors of "water, temperature, and flat alluvial soils" have the greatest impact on how a tree develops. However, while the temperature and water dominate in the first degree (Corbaci et al. 2019), for the growth of the oriental sweetgum tree, the soil is in the second degree, while the slope of the ground hinders further expansion and, consequently, forest formation (Örtel 1988; Kurt 2008; Ürker et al. 2015).

Other areas in the land use classes map (Fig. 8) determined using the CORINE map, which are unsuitable for sweetgum trees, were extracted from the potential sweetgum area index map using GIS. Finally, locations where the sweetgum tree could grow were made. Based upon the determined potential sweetgum area index, three categories—low, medium, and high—were assigned to the potential sweetgum area map (Fig. 9). The areas with potential suitability for sweetgum in each suitability category are demonstrated in Table 3. The results indicated that 50.7% (600,384 ha), 41.2% (488,448 ha), and 8.1% (95,400 ha) it had low, medium, and high-level appropriateness for oriental sweetgum trees in the research area, respectively.

Eskandaria et al. (2022) researched the best locations for eucalyptus wood farming in southern Iran using 22 criteria and the fuzzy analytical hierarchy approach, according to the investigations in the literature on the issue (FAHP). They claimed that the most crucial elements for the ideal

Table 3 Area with potential suitability for sweetgum in each category

Potential suitability for sweetgum category	Area (ha)	Percent (%)
Low	600,384	50.7
Medium	488,448	41.2
High	95,400	8.1
Total	1,184,232.00	100

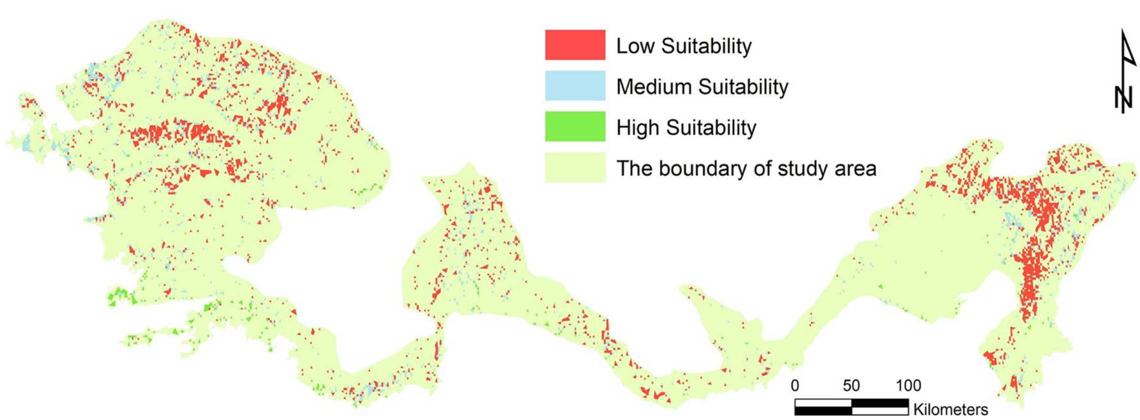

Fig. 9 Potentially suitable sweetgum area map prepared by the AHP method

sites for eucalyptus growth were water (weight: 0.34) and land cover (weight: 0.32). Akıncı et al. (2013) produced a map of suitable agricultural lands in the Yusufeli district of Artvin (Türkiye) using the AHP method. The suitable lands for agriculture map were created depending on the weight of nine variables, and the results demonstrated that 118,478.51 ha (51.2%) was marginally suitable, 5250.89 ha (2.3%) was moderately suitable, and 989.25 ha (0.4%) was highly suitable. Slope, aspect, and elevation criteria from topographic elements were applied by Akıncı et al. (2013), and the weight rankings derived from AHP produced results that were identical to this study findings. In a study conducted by Yağcı and İşcan (2021), the aim was to determine suitable afforestation areas by AHP method. Large soil groups, rainfall, slope, aspect, and erosion were the six variables that were utilized in that research, and the weight of each criterion was estimated using the AHP technique. When the results are assessed, the weight (0.36) of the large soil groups in this investigation, the weight (0.3597) was quite close to that was obtained for the large soil groups in this study. Bagherzadeh (2018) investigated the land suitability assessment for Norway maple and black locust using AHP in the northeast of Iran. A total of 14 criteria were taken into consideration as elements influencing the land suitability. There were employed the same four criteria (climate, aspect, slope, and elevation) in this study. When the results are evaluated, three criteria (aspect, slope, and elevation), except the climate criterion, had different results from this study. Alternatively, put the criteria in this current study were weighted in this order: slope (16.2%), aspect (7.9%), and elevation (4.0%), but in Bagherzadeh's (2018) study, the criteria were weighted in this order: elevation (17.3%), slope (12.1%), and aspect (6.2%). In the study by Bagherzadeh (2018), the highest weight ratios were obtained for soil and climate criteria. Similar outcomes were obtained in this investigation. As a result, the climate conditions and soil play crucial roles in supporting the plant growth process (Lavalle et al. 2016).

In a study by Bagaram et al. (2016), the AHP method was attempted to be utilized to identify possible *Quercus suber* distribution locations. The study's most important elements determining the range of *Quercus suber* were found to be climate, slope, thickness of sand in the soil, slope of the clay layer in the ground and soil types. In the study, the potential areas for *Quercus suber* were classified in 4 categories as good, medium, low, and very low. It was discovered that 17.40, 40.18, 34.84, and 4.28% of the area were classified in these suitability levels according to the potential distribution area of the oak, respectively. In another study by Gholizadeh et al. (2019) using the AHP method, attempts were made to identify potential distribution areas of *Quercus robur* and *Pinus silvestris*. When the study's findings were analyzed, it was discovered that aspect, soil depth, soil texture, and altitude were the most crucial factors in the potential spread of both tree species. The AHP method was applied in a study by Bravo-Bello et al. (2020) in Mexico to identify the likely distribution zones of 15 distinct species. When the results were contrasted with the potential distribution zones of five different species (*Pinus leiophylla, Buddleja cordata, Quercus glaucoides, Ceanothus caeruleus*, and *Litsea glaucescens*), they scored highly. To sum up, if the current ecological situation and highly fragmented nature of sweetgum forests are considered, new plantation sites are inevitably needed in order to establish connectivity between forest fragments that are severely disconnected in large geographical area.

Validation of maps for potentially suitable areas for sweetgum

The accuracy of the map showing areas that would be good for sweetgum was evaluated using the ROC curve (Gheshlaghi et al. 2020). Because of the ROC curve is a visual technique, the false-positive and real-positive values at each point on the curve can be assessed using this approach. The accuracy of the potential appropriateness for the AHP-produced sweetgum area map was predicted using the ROC curve (Fig. 10). The AUC value in this study was found to be 0.750. When the study by Gheshlaghi et al. (2020) was examined, the ROC value obtained was at a good level. The prospective, potential, and suitable areas were determined using the AHP model for sweetgum trees produced acceptable results. El Jazouli et al. (2019) assessed landslide susceptibility mapping in Morocco using the AHP method. Landslide vulnerability, land cover, distance to a road, distance to a drainage network, slope gradient, aspect, lithology, and distance to a fault were all mapped using elevation. The ROC curve was used in this study to assess the precision

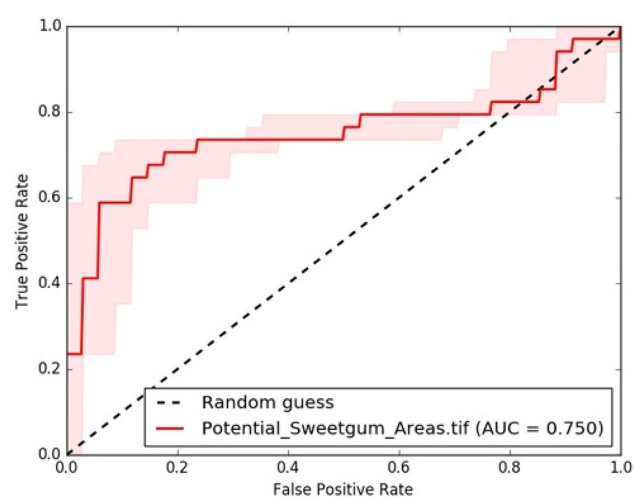

Fig. 10 ROC curve of the potential suitability for sweetgum area map

of the landslide susceptibility map, which was calculated to be 76.7 percent. In a subsequent study, Das et al. (2022) used the AHP approach to evaluate the zonation of landslide susceptibility in the Darjeeling Himalaya. The ROC curve's accuracy for the landslide susceptibility map was 90%, according to the study's findings.

The riparian habitats with sweetgum tree dominance in the fire-proned red-pine forest ecosystems (*Pinus brutia* Ten.) where the fires' location contributed to minimizing damage and providing wildlife with cover as they burned, according to a different investigation into the socio-economic and ecological impacts of the Mega Fires that occurred in Türkiye in 2021 (Kalem et al., 2022). Moreover, different material and moral values will come to the fore with sweetgum afforestation, far beyond the standard and conventional benefits provided by forests in addition to strengthening the production of sweetgum oil and frankincense, which have been produced in these forests for thousands of years, such as health tourism based on forest therapy, the development of the beekeeping sector based on sweetgum pollen and propolis. Because planting sweetgums has so many advantages, the results of that study improve the likelihood that the forestry management units in charge of the study area will use the findings of this study.

Conclusion

The purpose of this study was to discuss about the ecological and climatic elements that influence the prospective distribution patterns of the oriental sweetgum tree (*Liquidambar orientalis* Miller). The AHP technique was used to anticipate the probable dispersion of the oriental sweetgum tree under bioecologic circumstances. In order to promote the long-term conservation of a tree species that is on the edge of extinction, for the first time in Türkiye and the rest of the world, the AHP technique was used in this study to locate viable/suitable/potential areas for afforestation.

Using remote sensing, historical records and current distribution areas, land ownership and land use status, GIS analysis, AHP calculations, ROC curves, and CORINE filtering while taking the species' ecological requirements into account, approximately 94,500 hectares of land (8% of the total area) in different areas with a width of 800 km along southern coastal zone of Türkiye was detected to be plantation sites with high potential. On the other hand, the fact that 41% of the total area (as a large part of it) has medium potential (488,448 hectares) also indicates that the success rate in practice across the study area may be high. In other words, in the light of the data obtained from this study, it has been revealed that almost half of the study area can yield successful results for sweetgum plantation applications.

After the final corrections of the remote sensing/GIS analyses were completed, terrestrial field checks were carried out at potential plantation sites to update the data about ownership status of the areas, land use status and official protection status, etc. According to first impressions, the candidate areas for plantation were generally state-owned swamp lands, wetlands, riverbanks, etc., where the sweetgum tree is known to spread naturally during its history.

Since the results obtained with the AHP approach in this study are testable as a result of using different models and approaches, the consistency of the study can be tested with these different methods if desired. Although the potential afforestation areas of the species have been determined within the scope of this research, it is unclear to what extent the forest management units will consider the strategic plantation works that will minimize habitat fragmentation and the corridor methodology that can be used in this context, and this uncertainty constitutes the biggest limitation of the study. This uncertainty will be overcome by new researches that will encourage forest managers to start piloting the results of the study in the ongoing process. These pilot applications can be made on randomly selected points in the study area, considering the findings obtained from this study. The following can also be suggested for future research studies measuring the main research findings; the success rate (survival rates) of experimental afforestation studies to be carried out in randomly selected pilot areas with low–medium–high potentials offered by the model can be tested.

Although the habitat fragmentation may not end with afforestation activities, the genetic flow will be triggered again and the heterozygosity rate will increase in population genetics due to the newly established plantation areas. This will cause the species to avoid a genetic bottleneck to some extent. If the oriental sweetgum afforestation is carried out in areas with high potential identified using the AHP method, both economic and ecological gains will be provided.

Acknowledgements We thank Ali Kaya (NATURA) for his assistance in the field and Giovanni Caudullo (Senior GIS analyst at the European Commission's Joint Research Centre) for his technical advice during the study.

Author's contribution AG performed GIS analyses and AHP modeling. OÜ weighted the parameters to be analyzed in the light of the bioecological characteristics of the species and provided local control of the results obtained and was a major contributor in writing the manuscript. All authors read and approved the final manuscript.

Funding The study was partly supported by the Rufford Foundation (Project ID 33742-D).

Data availability The data used to support the findings of this study are included within the manuscript.

Declarations

Conflict of interest The authors declare that they have no competing interests.

Human and animal rights This article does not contain any studies with human participants or animals performed by any of the authors.

References

Acatay A (1963) Sığla Ağacı'nın (*Liquidambar orientalis* Mill.) Türkiye'de Yayılışı, Yeni Tespit Edilen *Liquidambar orientalis* var. *suber* varyetesi ve Sığla Ağacı'na Musallat Olan Böcekler. Orman Entomolojisi ve Orman Koruma Kürsüsü Çalışmalarından, Faculty of Forestry, Istanbul University, pp10–56, Istanbul. (In Turkish)

Ahmad F, Rizvi J (2023) GIS modeling of environmental parameters for identification of landscape for expansion of biodiversity conservation, and greenery projects (a case study for Neom region, Saudi Arabia). Model Earth Syst Environ 9(2):2987–2992

Akıncı H, Yavuz Özalp A, Turgut B (2013) Agricultural land use suitability analysis using GIS and AHP technique. Comput Electron Agric 97:71–82

Akman Y, Ketenoğlu O, Kurt L (1992) Fethiye-Marmaris ve Bucak Çevrelerinde Yetişen *Liquidambar orientalis* Mill. Topluluklarının Floristik Yapısı. Doğa-Turkish Journal of Botany 16:273–286 ((**In Turkish**))

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

Ananda J, Herath G (2003) The use of Analytic Hierarchy Process to incorporate stakeholderpreferences into regional forest planning. Forest Policy Econ 5(2003):13–26

Areendran G, Raj K, Sharma A, Bora PJ, Sarmah A, Sahana M, Ranjan K (2020) Documenting the land use pattern in the corridor complexes of Kaziranga National Park using high resolution satellite imagery. Trees, Forests and People, Volume 2, December 2020, https://doi.org/10.1016/j.tfp.2020.100039

Arsalan MB, Şahin HT (2016) Unutulan Bir Orman Ürünü Kaynağı: Anadolu Sığla Ağacı (*Liquidambar orientalis* Miller). Journal of Bartın Faculty of Forestry 18(1):103–117 ((**In Turkish**))

Bagaram BM, Mounir F, Lahssini S, Ponette Q (2016) Site Suitability Analysis for Cork Oak Regeneration Using GIS Based Multicriteria Evaluation Techniques in Maamora Forest-Morocco. Open Access Library J 3(3)

Bagherzadeh A (2018) Assessment of land suitability for Norway maple and black locust plantations in the northeast of Iran. J For Sci 64(3):129–138

Bascompte J, Possingham H, Roughgarden J (2002) Patchy populations in stochastic environments: critical number of patches for persistence. Am Nat 159:128–137

Batar AK, Watanabe T (2017) Kumar A (2017) Assessment of land-use/land-cover change and forest fragmentation in the Garhwal Himalayan Region of India. Environments 4:34. https://doi.org/10.3390/environments4020034

Bayram BÇ (2021) A sustainable forest management criteria and indicators assessment using fuzzy analytic hierarchy process. Environ Monitor Assess 193. Article number: 425

BGCI (2017) Plant Search. Botanic Gardens Conservation International, London. Available at: https://www.bgci.org/plant_search.php

Bravo-Bello JC, Martinez-Trinidad T, Romero-Sanchez ME, Valdez-Lazalde JR, Benavides-Meza H (2020) The analytic hierarchy process for selection of suitable trees for Mexico City. iForest 13: 541–547. DOI: https://doi.org/10.3832/ifor3481-013

Caudullo G, Welk E, San-Miguel-Ayanz J (2017) Chorological maps for the main European woody species. Data in Brief 12, 662-666. DOI: doi.org/10.1016/j.dib.2017.05.007 https://figshare.com/articles/Liquidambar_orientalis_chorology/11347805

Corbaci OL, Bilgili BC, Oner N, Ersahin S, Kasko-Arici Y (2019) Potential Use of Natural Turkish Sweetgum Species in Landscape Design in Türkiye. Fresenius Environmental Bulletin, 28, 2A/2019, pp1621–1626

Çavuş CZ, Koç T (2015) Çanakkale Boğazı Doğusunda Arazi Kullanım Uygunluğunun Yerleşme Açısından Analizi. Coğrafi Bilimler Dergisi 13(1):41–60 ((**In Turkish**))

Das S, Sarkar S, Kanungo DP (2022) GIS-based landslide susceptibility zonation mapping using the analytic hierarchy process (AHP) method in parts of Kalimpong Region of Darjeeling Himalaya. Environ Monit Assess 194:234. https://doi.org/10.1007/s10661-022-09851-7

Dindaroglu T (2021) Determination of ecological networks for vegetation connectivity using GIS & AHP technique in the Mediterranean degraded karst ecosystems. J Arid Environ 188:104385

Dirik H (1986) Anadolu Sığlası (*Liquidambar orientalis* Mill.)'nın Gençleştirilmesi Üzerine Çalışmalar. MSc Thesis, The Institute of Science, Istanbul University, pp 18–36, Istanbul. (In Turkish)

EEA (2006) CORINE Land Cover (CLC) 2006 technical guidelines. Technical report of European Environment Agency, No 17/2007. 66 pp, ISBN: 978–92–9167–968–3

Efe A (1987) Studies on the morphological and palynological characteristics of *Liquidambar orientalis* Mill. J Faculty for Istanbul Univ 37(2):84–104 ((**In Turkish**))

El Jazouli A, Barakat A, Khellouk R (2019) GIS-multicriteria evaluation using AHP for landslide susceptibility mapping in Oum Er Rbia high basin (Morocco). Geoenvironmental Disasters, vol. 6, no. 1, 24 Apr. 2019, p. NA. Gale Academic OneFile, link.gale.com/apps/doc/A583423244/AONE?u=anon~a435a41&sid=googleScholar&xid=1df84d14. Accessed on 9 April 2022

Eskandaria S, Behnamfar K, Pourghasemi HR (2022) Tiefenbacher JP (2022) Provision of eucalyptus wood farming potential map in Iran: an application of land cover, ecological, climatic, hydrologic, and edaphic analysis in a GIS-based fuzzy AHP framework. Ecol Ind 136:108621

Eslami A, Roshani M, Hassani M (2010) The application of GIS in selection of suitable species for afforestation in southern forest of Caspian Sea. J Environ Sci 4(3):223–226

EUFORGEN (2009) Distribution map of Oriental/Anatolian sweetgum (*Liquidambar orientalis*). The webpage link (http://www.euforgen.org) was visited on 11.04.2021

Fahrig L (2002) Effect of habitat fragmentation on the extinction threshold: a synthesis. Ecol Appl 12:346–353

Forman RTT, Godron M (1986) Landscape ecology. John Wiley, New York

Forman RTT, Collinge SK (1995) The spatial solution to conserving biodiversity in landscapes and regions. In: DeGraaf RM, Miller RI (eds) Conservation of faunal diversity in forested landscapes. Chapman and Hall, London, pp 537–568

Frankel OH (1981) Soule ME (1981) In Conservation and Evaluation. Cambridge University Press, Cambridge

Gheshlaghi HA, Feizizadeh B, Blaschke B (2020) GIS-based forest fire risk mapping using the analytical network process and fuzzy logic. J Environ Plann Manage 63(3):481–499. https://doi.org/10.1080/09640568.2019.1594726

Gholizadeh A, Bagherzadeh A, Keshavarzib A (2019) Model application in evaluating land suitability for Oak and Pine forest

plantations in Northeast of Iran. Gol Ecol Landscapes. https://doi.org/10.1080/24749508.2019.1633217
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**))
Hashemi SA (2018) Ecological capability evaluation for afforestation and forest expansion using Geographic Information System (GIS) in management area of Caspian Sea. An Acad Bras Ciênc 90(4):3761–3768
Healey SP, Cohen WB, Yang Z, Kenneth Brewer C, Brooks EB, Gorelick N, Hernandez AJ, Huang C, Joseph Hughes M, Kennedy RE et al (2018) Mapping forest change using stacked generalization: an ensemble approach. Remote Sens Environ 204:717–728. https://doi.org/10.1016/j.rse.2017.09.029
Huş S (1949) Reçine ve Sığla Yağı Elde Etme Metotları. Ministry of Agriculture, Publications of General Directorate of Forestry, Special Edition-No: 36, 54 Pages, Ankara, Türkiye. (In Turkish)
IUCN (1997) 1997 IUCN Red List of Threatened Plants. IUCN – The World Conservation Union, Gland, Switzerland
Ismail MH (2009) Developing policy for suitable harvest zone using multi criteria evaluation and GIS-based decision support system. Int J Econ Financ 1:105–117
Ison JC, Blade MJ (2005) ROCPLOT: a generic software tool for ROC analysis and the validation of predictive methods. Appl Bioinf 4(2):131–135. https://doi.org/10.2165/00822942-200504020-00006
İktüeren A (1987) Sığla Ağacı'nın (*Liquidambar orientalis* Mill.) Doğal Yayılışı, Sığla Yağı Üretimi ve Pazarlaması. Publications of Forestry Research Institute of Turkish Republic. 33(2), No:66 (In Turkish)
Kalem S, Ürker O, İlemin Y (Eds.) (2022) Ecological and Socioeconomic Effects of Major Forest Fires in The Mediterranean Region of Türkiye. Technic Reports of WWF-Türkiye & NATURA. 63 Pages, PrintWorld Publishing, Istanbul-Türkiye. (In Turkish). Web link: https://wwftr.awsassets.panda.org/downloads/ormanyangnlarweb.pdf?11960/Akdeniz-Bolgesindeki-Buyuk-Orman-Yarginlarinin-Ekolojik-ve-Sosyo-Ekonomik-Etkileri
Kanowski PJ (1997) Plantation forestry at the millennium. Discussion Paper for World Commission on Forests and Sustainable Development. 8 p
Karabulut A, Elbaşı F, Ustaoğlu S, Yatman D (2011) Türkiye büyük toprak grubu haritası, Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğü Toprak Gübre ve Su Kaynakları Merkez Araştırma Enstitüsü Müdürlüğü, Mekanizasyon ve Bilişim Teknolojileri Bölümü, Ankara. (In Turkish)
Kavak S, Wilson B (2018) *Liquidambar orientalis*. The IUCN Red List of Threatened Species 2018: e.T62556A42326468. https://doi.org/10.2305/IUCN.UK.2018-1.RLTS.T62556A42326468.en. Downloaded on 24 March 2021
Khwarahm NR (2020) Mapping current and potential future distributions of the oak tree (*Quercus aegilops*) in the Kurdistan Region. Iraq Ecological Processes 9(1):56. https://doi.org/10.1186/s13717-020-00259-0
Krishnapillay B, Razak MAA (2001) commercial plantation strategy to reduce pressure on tropical forest resources. In: Proceedings of the international conference on ex situ and in situ conservation of commercial tropical trees, held on 11–13 June 2001, pp 387–404, Yogyakarta, Indonesia
Kurt L (2008) Anadolu Sığla Ağacı (Günlük Ağacı) Biyolojik Çeşitlilik Raporu. Özel Çevre Koruma Kurumu Başkanlığı, Ankara. (In Turkish)
Lavalle P, Spain AV, Blouin M, Brown GG (2016) Ecosystem engineers in a self-organized soil: a review of concepts and future research questions. Soil Sci 181(3/4). https://doi.org/10.1097/SS.0000000000000155
Malczewski J (2004) GIS based land use suitability analysis: a critical overview. Prog Plan 62:3–65
Malczewski J (2006) Integrating multi-criteria analysis and geographic information systems: the ordered weighted averaging (OWA) approach. Int J Environ Technol Manage 6(2):7–19
Mather AS (Ed) (1993). Afforestation: policies, planning and progress. Bellhaven Press. 223 p
Mengist W, Soromessa T, Feyisa GL (2022) Forest fragmentation in a forest Biosphere Reserve: Implications for the sustainability of natural habitats and forest management policy in Ethiopia. Resour Environ Sustain 8(1):1–13. https://doi.org/10.1016/j.resenv.2022.100058
Muğla MK, Türk T (2020) Detection of potential afforestation fields by analytical hierarchy process and geographical information systems. J Geodesy Geoinf 2:103–120
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 Sens 12(1):187. https://doi.org/10.3390/rs12010187
Örtel E (1988) Sığla ormanlarımızın durumu. Ormancılık Araştırma Enstitüsü Dergisi, Cilt 34, Sayı 2, No: 68, 93–96. (In Turkish)
Özdağoğlu A, Özdağoğlu G (2007) Comparison of AHP and fuzzy AHP for the multicriteria decision making processes with linguistic evaluations. İstanbul Ticaret Üniversitesi Fen Bilimleri Dergisi 6(11):65–85
Özkil A, Ürker O, Zeydanlı U (2017) Art in Sweetgum Forests (Sığla Ormanlarında Sanat). Nature Conservation Center (Doğa Koruma Merkezi), 161 Syf., Dumat Ofset, ISBN: 978–605–82749–0–7. Ankara. (Turkish&English)
Rashidi F, Sharifian S (2022) A comparative analysis of three multi-criteria decision-making methods for land suitability assessment. Environ Monit Assess 194(9):657
Rezaei-Moghaddam Karami E, Gibson J (2008) Conceptualizing sustainable agriculture: Iran as an illustrative case, January 2006. J Sustain Agric 27(3):25–56. https://doi.org/10.1300/J064v27n03_04unst
Rivers M, Beech E, Barstow M (2017) *Liquidambar orientalis*. The IUCN Red List of Threatened Species 2017
Sari F (2021) Forest fire susceptibility mapping via multi-criteria decision analysis techniques for Mugla, Turkey: a comparative analysis of VIKOR and TOPSIS. For Ecol Manage 480:118644
Saaty TL (1980) The analytic hierarchy process: planning, priority setting and resource allocation. McGraw-Hill, New York
Saaty TL (2001) Decision making with dependence and feedback: the analytic network process, 2nd edn. PRWS Publications, Pittsburgh PA
Saaty TL (2012) Decision making for leaders: the analytic hierarchy process for decisions in a complex world, Third Revised. RWS Publications, Pittsburgh
Saaty TL, Vargas LG (1991) Prediction. Kluwer Academic Publishers, Dordrecht, Projection and Forecasting, p 25
Seyed HM, Alireza SA (2017) A comprehensive MCDM-based approach using TOPSIS, COPRAS and DEA as an auxiliary tool for material selection problems. Mater Des 121:237–253
Sharma S (2007) Roy PS (2007) Forest fragmentation in the Himalaya: A Central Himalayan case study. Int J Sustain Dev World Ecol 14:201–210
Sivrikaya F (2022) Küçük Ö (2022) Modeling forest fire risk based on GIS-based analytical hierarchy process and statistical analysis in Mediterranean region. Eco Inform 68:101537
Sivrikaya F, Özcan GE, Enez K, Sakici OE (2022) Comparative study of the analytical hierarchy process, frequency ratio, and logistic regression models for predicting the susceptibility to Ips sexdentatus in Crimean pine forests. Eco Inform 71:101811
Sivrikaya F, Özcan GE, Enez K (2023) Predicting the susceptibility to Pityokteines curvidens using GIS with AHP and MaxEnt models

in fir forests, Editors: De Felice, F., Petrillo, A. In: Analytic Hierarchy Process - Models, Methods, Concepts, and Applications, IntechOpen.

Srivastava R (2016) Tyagi R (2016) Wildlife corridors in India: viable legal tools for species conservation. Environ Law Rev 18(3):205–223

Şen G, Güngör E (2018) The use of analytic hierarchy process method in choosing the best tree type for industrial plantations: the case of Kastamonu Province. Turkish Journal of Forestry 19(1):63–75

Taşkın BG, Taşkın V, Küçükakyüz K, Varol Ö, Çöl B, Arslan T (2008) Esterase Polymorphisms in Relict Endemic *Liquidambar orientalis* Mill. var. *orientalis* and *L. orientalis* Mill. var. *integriloba* Fiori Populations in Türkiye. Journal of Cell and Molecular Biology, 6(2):137–146. – 2008

Thielges BA (2001) Foreword. Proceedings of the International Conference on ex situ and in situ Conservation of Commercial Tropical Trees, held on 11–13 June 2001, Pages.2–3, Yogyakarta, Indonesia.

Torlak H (2012) Öte Dünyadaki Ruhlarla Özdeşleşmiş Sığla Ağacı (Sweetgum Tree Identified with Spirits of the Other World). Bilim ve Gelecek Dergisi, No 90. Web link: http://www.bilimvegelecek.com.tr/?goster=1476 (In Turkish)

Ürker O, Benzeyen ST (2020) The Importance of Endangered Anatolian (Oriental) Sweetgum Forests for the Bird Species. Research Article. International Journal of Nature and Life Science (IJNLS). 4(1), 14–25pp., Web link: https://dergipark.org.tr/tr/pub/ijnls/issue/54485/677936

Ürker O, Yılmaz T, Öztük Ş, Çobanoğlu N (2014a) Investigation of anatolian sweetgum forests in the scope of environmental sociology. J Sociol Res 17(2):153–187 ((**In Turkish**))

Ürker O, Yorulmaz T (2020) Determination of the bat (Chiroptera) activity in the Anatolian sweetgum forests inside Köyceğiz-Dalyan Specially Protected Area. (General Directorate of Forestry of Turkish Republic) Turkish J For Res 7(1): 88–103, Ankara-TÜRKİYE. https://doi.org/10.17568/ogmoad.651223 (In Turkish)

Ürker O, İlemin Y (2019) A pioneer study on the wildlife properties of anatolian sweetgum forests, a case assesment on mammalian diversity in terms of ecosystem integrity. Research Article. Fresenius Environmental Bulletin, vol 28–No. 7/2019 pp 5474–5480

Ürker O, Lise Y (2018) Examination of sensitive forests concept over oriental (anatolian) sweetgum forests in nature conservation. Anatolian J For Res 4(1):1–10, Çankırı-TÜRKİYE. (In Turkish)

Ürker O, Çobanoğlu N (2017) Çevre Etiği Bağlamında Anadolu Sığla Ormanları (Anatolian Sweetgum Forests in Terms of Environmental Ethics). 204 Pages. ISBN: 978–3–659–94199–3. LAP -Lambert Academic Publishing, Germany, 2017. (In Turkish)

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

Ürker O, İlemin Y, Bulut Ş, Ada E (2015) Anadolu Sığla Ormanları (*Liquidambar orientalis*)'nın Biyo-Ekolojisi ve Bu Ormanlardaki Yaban Hayatı Özellikleri Hakkında Güncel Bir Değerlendirme. 12th National Congress of Ecology and Environment, Mugla Sitki Kocman University, Abstract Book, pp 87–89. September 14–17, 2015, Mugla-TÜRKİYE. (In Turkish)

Ürker O, Yılmaz T, Öztürk Ş, Çobanoğlu N (2014) Anatolian Sweetgum Forests in Terms of Environmental Sociology. Journal of Sociological Research (ISSN:1302–4426), vol 17, No. 2, pp 152–187, Ankara-TÜRKİYE. (In Turkish)

Vogt P, Riitters K (2017) GuidosToolbox: universal digital image object analysis. Eur J Remote Sens 50(1):352–361

Wakie T, Hoag D, Evangelista PH, Luizza M (2016) Is control through utilization a cost effective Prosopis juliflora management strategy? J Environ Manage 168:74–86. https://doi.org/10.1016/j.jenvman.2015.11.054

Wang P, Zhu Z, Wang Y (2016) A novel hybrid MCDM model combining the SAW, TOPSIS and GRA methods based on experimental design. Inf Sci 345:27–45

Wilcove DS, McClellan CH, Dobson AP (1986) Habitat fragmentation in the temperate zone. In: Soule ME (ed) Conservation biology: the science of scarcity and diversity. Sinauer Associates, Sunderland, MA, pp 237–256

Williams JT (1991) For Chron 1991:68

Worldclim (2021) http://worldclim.org/ The webpage had been visited on 12 December 2021

Yağcı C, İşcan F (2021) GIS-based site suitability analysis of afforestation in Konya province, Türkiye. Turkish J Geogr Inf Syst 3(2):89–95

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

Yesilnacar EK (2005) The application of computational intelligence to landslide susceptibility mapping in Türkiye. Dissertation. Melbourne: Department of Geomatics, The University of Melbourne; p 423