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A NEW MODEL FOR DETERMINING TREE SPECIES COMPATIBLE WITH THE ECOLOGICAL CONDITIONS OF THE AREAS TO BE AFFORESTED

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Abstract

Afforestation is an indispensable practice for the sustainability of forests in the absence of sufficient forest. Planting tree species compatible with local environmental factors will contribute to the strengthening and protection of forests. This study aims to develop a statistical model to determine the optimal growing areas of tree species compatible with local environmental factors using GIS. While creating this model, nine main environmental factors (lithology, landform, elevation, slope, aspect, temperature, precipitation, soil type, soil depth) that affect the distribution of tree species were determined. These factors were analyzed along with their sub-criteria. Analyzes were done using the AHP method. According to the analysis results, the distribution of tree species in the study area is affected by temperature, precipitation, elevation, slope, landform, and soil depth. The optimal growth areas of each tree species are quite different from each other. The results show that this method is easy to apply in forest planning and offers forest decision support systems opportunities to create a wide variety of alternative plans.

Keywords: Afforestation, Tree Species, Ecological Condition, Forest Analysis, Suitability Map

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INTRODUCTION

Forest ecosystem, which includes many organic elements, both provides basic habitats for various species and provides various ecosystem services to human society (Ferreira et al., 2018; Isbell et al., 2015; Ouyang et al., 2021). The most important ecosystem services that forests provide to human society are climate regulation, CO^2 storage, biodiversity reservoirs, protection of soil and water resources (Bonan, 2008; Federici et al., 2015; Morales-Hidalgo et al., 2015; Nüchela et al., 2019; Peng et al., 2014; Vie et al., 2009; Wenhua, 2004). In addition, it contributes to both the local and global economy (FAO, 2011). For all these reasons, today sustainable forest management planning decisions are considered in terms of both economic and other factors such as ecological and social values (Nilsson et al., 2016; UN, 1992). In the absence of sufficient forest cover, afforestation studies are carried out on land suitable for forests. With afforestation studies, the sustainability of natural forests, strengthening of degraded forests and afforestation of lands that lack forest cover are provided. Choosing tree species that are compatible with local environmental factors is necessary for sustainable development. Environmental factors affect forest stability directly or indirectly due to their effects on the species richness of forests, and structural features of the stand (Jucker et al., 2016; Poorter et al., 2017). In areas with different plant species composition, biodiversity is expected to be positively associated with stability, as plant species respond differently to environmental changes (Mazzochini et al., 2019)**.** Understanding the impact of environmental factors on species richness and wood production, especially in forests, will positively affect forest productivity (Jucker et al., 2014; Paquette & Messier, 2011). However, understanding how species are affected by environmental conditions can only be determined by detecting the change in the spatial distribution of plant species along with environmental variables (Jucker et al., 2016). Therefore, it is important to understand how variability in environmental factors affects stability (Ouyang et al., 2021).

Analyzing the ecological conditions of plant cover takes an important place in the forest ecosystem. It is also necessary to ensure sustainability. Analysis of the relationship between plant cover and environment requires a detailed understanding of environmental factors affecting the plant cover (Austin, 2005). Geographical context, ecological elements and biodiversity are the basis of environmental factors (Guo & Ren, 2014). Environmental factors are important in the distribution of plant species in the world (Adams, 2009; Greve et al., 2011). Climate is the most important environmental factor affecting the distribution of plant cover (Frank, 1988). Climate affects the diversity and productivity of plant cover both as an environmental factor and depending on the change it has shown over the years (Forrester & Bauhus, 2016). Plant cover is a dynamic component of global transformation, particularly sensitive to climate change (Mazzochini et al., 2019; Reichstein et al., 2013; Seddon et al., 2016). For all these reasons, it is necessary to analyze the relationship between climate and plant cover in the forest ecosystem in detail and to determine the climate sensitivity of plant species.

The composition and spatial distribution of plant species are generally associated with topographic and edaphic factors (Comita et al., 2007; Guo et al., 2017; Harms et al., 2001; Kalajnxhiu et al., 2012; Kanagaraj et al., 2011; Liu et al., 2016). Topographic and edaphic factors influence species distribution by structuring space (Whittaker, 1956). However, topographical factors are the most important factors controlling the distribution of species in the forest (Barrio et al., 1997; Florinsky & Kuryakova, 1996; Sebastia, 2004; Wang et al., 2015). In order to determine the effect of topography on the distribution of plant cover, landform, elevation, slope and aspect factors are commonly evaluated (Frank, 1988; Laamrani et al., 2014; Ohsawa et al., 2008). Depending on the elevation, especially climatic conditions and soil properties change (Tsui et al., 2013). The slope factor can affect the hydrological conditions of space, the depth of the soil and thus the plant distribution. Aspect affects the direction of flow, evaporation, and evaporation density (Moore et al., 1991). Combinations of these topographic factors determine the development and distribution of plant cover (Wang et al., 2015).

With the dissolution of the bedrock, many minerals and elements are released. As these become soluble in soil water, the plants are fed. Plants have different requests such as temperature, water and light depending on their species, as well as the nutrients they take from the soil. The nutrients contained in bedrock are extremely important in terms of the settlement and development of plants. The inability to get the nutrients it needs from the environment prevents the development of the plant and from time to time stops it completely (Atalay, 2006). In the study area, different plant cover has developed on the lithology consisting of rocks of different time, structure and characteristics.

This study is based on the hypothesis that tree species, which are the main elements of the forest ecosystem, and environmental factors are related. Based on this hypothesis, Göksun Plain and its surroundings have been determined as the study area. There are two reasons why Göksun Plain and its surroundings are determined as the study area. First, two geomorphological units are defined in Göksun Plain and its surroundings, separated by distinct differences from each other. These are the Göksun Plain, which stretches between 1100-1400 meters, and the high mountainous areas surrounding it. The ecological conditions of these two geomorphological units are quite different from each other as well as their plant covers. The second reason is, the study area located in the south of the Anatolian cross is located in the transition zone of the Iran-Turan and Mediterranean phytogeographic regions. Both its morphology and its location in the transition zone between different phytogeographical regions made the study area very rich in terms of biodiversity. Biodiversity improves forest stability, ecosystem functioning, services (Hautier et al., 2014; Jucker et al., 2014) and supports the functions of the basic ecosystem (Cardinale et al., 2011). Therefore, it is aimed to develop natural capital by protecting biodiversity (Jucker et al., 2016; MAF, 2014).

As a result of the analysis, tree species compatible with the ecological conditions of the study area were determined. In addition, the boundaries of the optimal growing area of each tree species are clearly drawn. With the data obtained, a model based on the determination of tree species compatible with ecological conditions has been developed. This model is an important reference that can be used in planning the areas to be afforested.

MATERIALS AND METHODS

Study Area

Göksun Plain and its surroundings determined as the study area is located in the northwest of Turkey’s Kahramanmaraş Province. The plain is surrounded by the Binboğa Mountains from the north and northeast, the Kandil, Gücük and Kaman mountains from the south and southeast, and the Dibek Mountains from the west (Figure 1). It is located between latitudes 37^{0} 52 ‘30’ ‘ – 38^{0} 22’ 39 ‘’ N and longitudes 36^{0} 27 ‘31’ ‘ – 36^{0} 37’ 55 ‘’ E. Within these limits, the study area is 119410 ha.

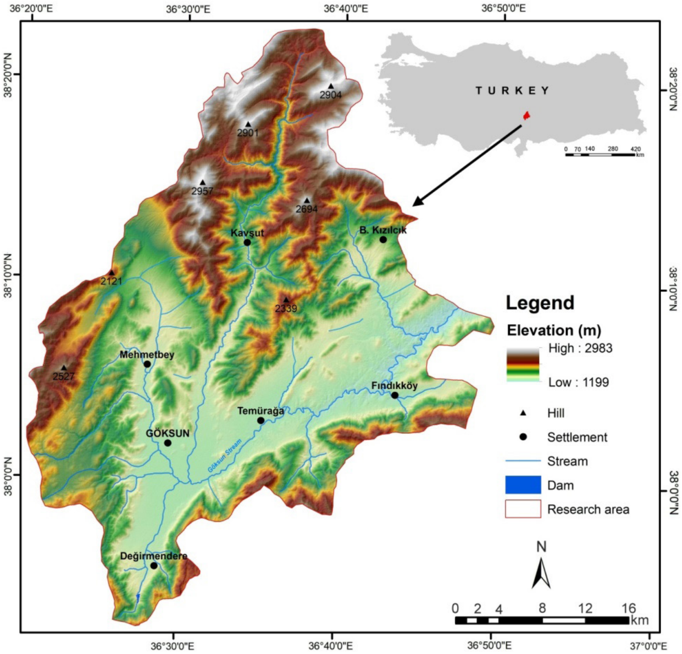

Figure 1: Location Map of the Study Area

The study area consists of lithological units of different ages and characteristics from Paleozoic to Quaternary (MRE, 2010). The morphological appearance has developed under the control of the lithological and tectonic structures. Göksun Plain is the center of the study area. It is surrounded the plateau areas with elevations varying between 1400-2000 m. There are high mountainous areas with elevations exceeding 2000 m at the outermost. The maximum elevation in the research area is 2983 m and the minimum elevation is 1199 m. The average elevation is 1785.22 meters. The elevation difference is 1784 meters.

In the study area located in the transition area between the Mediterranean and the interior regions, there are examples of flora and fauna belonging to both ecological regions with the effect of its location. The influence of the continental climate is felt in the northern parts of the study area and the Mediterranean climate in the southern parts. Species such as *Cedrus libani*, *Abies cilicica*, maquis representing the Mediterranean floristic region and species such as *Quercus* spp., *Juniperus* spp. compatible with the harsh terrain of the continental climate coexist in the study area. Although the effect of other geographical factors, the main factor affecting the existence and distribution of plant cover is climate. The plant cover in the study area constitutes 8.31% *Pinus nigra*, 3.94% *Abies cilicica*, 6.33% *Cedrus libani*, 2.56% *Quercus* spp., 13.76% *Juniperus* spp., 0.09% *Walnut* spp.,% 0.02 other leafy trees (Olt), 12.85% mixed forest, 0.81% maquis, 51.33% steppe and Alpine meadow (MAF, 2014). The average temperature is 8.8 C^0, the highest temperature is in July (20.7 C^0), the lowest temperature is in January (-3.9 C^0). Annual total precipitation is 618.9 mm, the highest precipitation is 95.4 mm in December, and the lowest total precipitation falls in July with 7.3 mm.

Generation of Base Maps

Geographical factors (lithology, landform, elavation, slope, aspect, soil type and soil depth) that shape the ecological conditions of tree species were determined first while generating the basic maps (Figure 2). Sub-criteria for these factors were also defined in detail. Each of the sub-criteria was scored according to the effect severity for the plant species. Thus, it was included in the suitability analysis with the main criteria. Base maps were created for each factor subjected to analysis. In the following, the data constituting the basic maps and the sources from which the data are obtained are specified (Table 1).

Table 1: The Base Maps and Their Sources Used in This Study

Data	Data Type	Source	Base Maps
Forest Inventory Map (1/25 000)	Vektör	Ministry of Agriculture and Forestry	Tree Species
Geology Map (1/100 000)	Raster	General Directorate of Mineral Research and Exploration	Lithology
Topography Map (1/25 000) Satellite image	Raster	Ministry of National Defence General Directorate of Mapping TUBITAK Space Technologies Research Institute	Landform
Topography Map (1/25 000)	Raster	Ministry of National Defence General Directorate of Mapping	Elevation Slope Aspect
Temperature and Precipitation Maps (Spatial resolution ~1 km^2 – 30 seconds)	Raster	WorldClim Website	Temperature (C^0) Precipitation (mm)
Soil Map (1/100 000)	Raster	Ministry of Agriculture and Forestry	Soil type Soil depth (cm)

The temperature and precipitation map was created using the WorldClim version 2.1 climate data for 1970-2000 released in January 2020 (Worldclim, 2020). Global cross-validation correlations are ≥0.99 for temperature and 0.86 for precipitation in climate surface maps created with a high-quality climate network (Fick & Hicmans, 2017). Monthly average temperature and monthly precipitation data were obtained from the WorldClim Website. The obtained data were used after converting to annual average temperature and precipitation data in this study.

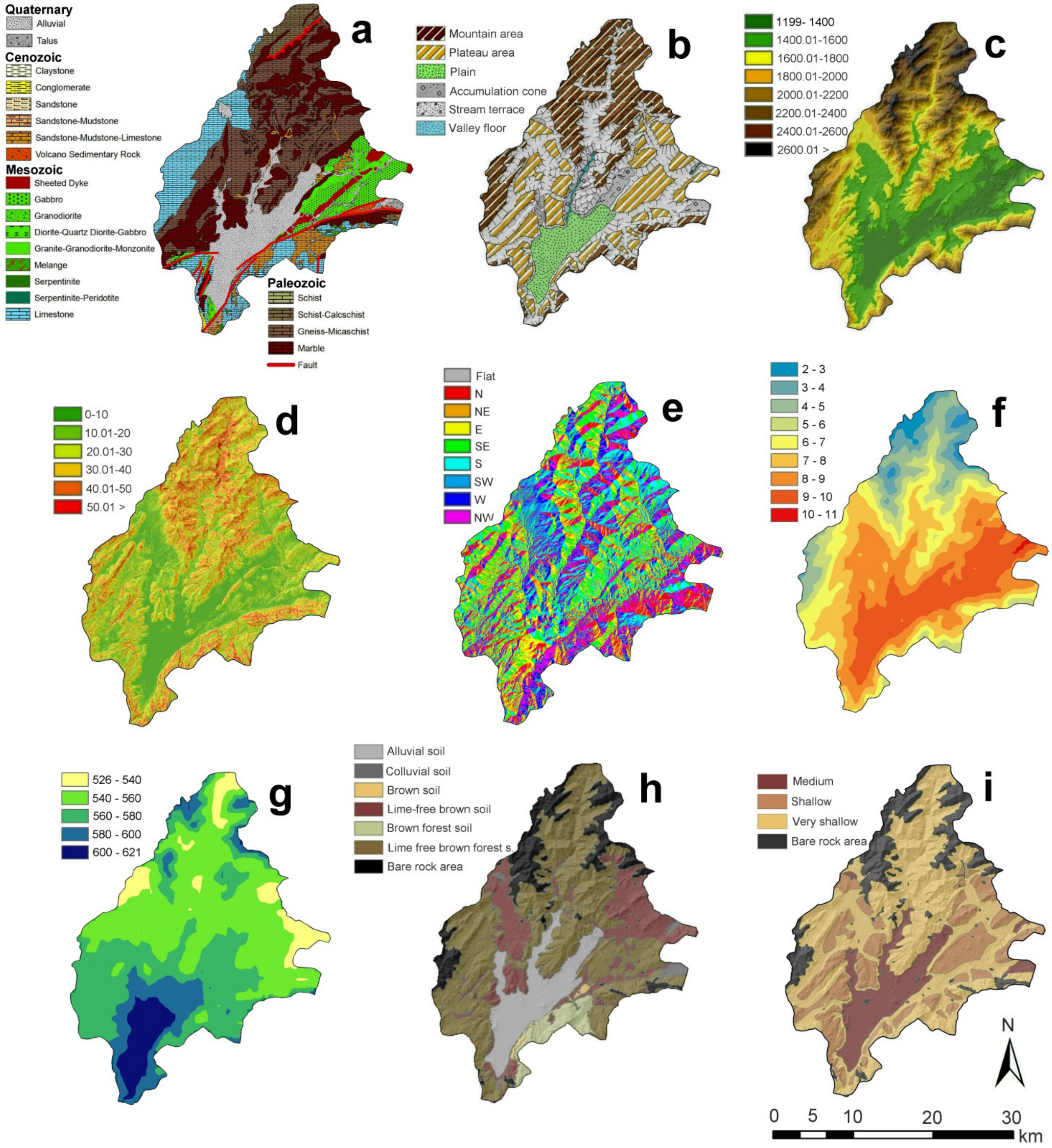

Figure 2: Base Maps Used in the Study: a) Lithology, b) Landform, c) Elevation (meter), d) Slope (degree), e) Aspect (degree), f) Temperature (C^0), g) Precipitation (mm), h) Soil Type, i) Soil Depth (cm) Maps

Generation of Statistical Weights for Model Maps

Multiple criteria decision analysis (MCDA) is a set of decision analysis methods that can be used to address problems characterized by multiple and conflicting goals (Belton & Stewart, 2002). One of the most frequently used MCDA methods in participatory forest planning is the Analytical Hierarchy Process (AHP) developed in the 1970s (Saaty, 1980b). In this study, the AHP method was used in the process of creating optimal growing conditions and suitability maps for each tree species. As stated in Saaty (Saaty, 1980a), in the AHP method, defining variables are compared with the level of importance determined among themselves for each level. The results obtained are processed into a matrix form. In this study, the importance level of variables was determined by considering the selectivity of tree species as a result of overlapping tree species and factor maps. Paired comparisons were made with the determined importance level and related matrices have been created. Thus, the weighted linear combination values were determined for each tree type used in the analysis. According to the weighted linear combination values obtained as a result of the suitability analysis, it has been observed that the most effective factors in the distribution of all tree species are temperature, precipitation, elevation, slope, landform and soil depth. The least effective factors are aspect and lithology (Table 2).

Table 2: Weighted Linear Combinations (WLC) of Criteria Used in the Suitability Analysis

WLC	*Quercus* spp.	*Juniperus* spp.	*P. nigra*	*C. libani*	*A. cilicica*	*Walnut* spp.	Olt
Lithology	5,5	9	4,2	7	7	6,6	4,8
Landform	6,9	11,6	8,5	8,4	6,3	13,3	8,7
Elevation	12,7	9,4	15,4	10,9	13,9	10,8	13
Slope	12,6	14	15,9	10,9	9,6	17,1	11,2
Aspect	4,4	4,4	4,9	4,3	4,2	4	4
Temperature	14,4	16,3	12,1	20,8	22	12,7	19,6
Precipitation	22,1	20,1	17,7	18,3	18,9	16,3	16,6
Soil type	8	6,4	6,8	6,1	8,7	7,2	7,1
Soil depth	13,4	8,8	14,5	13,3	9,4	12	15

The consistency control of the obtained weighted linear combination values. The consistency check measures the logical inconsistency of judgments and allows the identification of possible errors in judgments. The consistency rate (CR) must be 0.10 (10%) or less for the method to be valid. If this ratio is greater than 0.10, paired comparison matrices need to be reconstructed (Saaty, 1980a). In this study, the weighted linear combination values of the paired comparison matrices applied for each tree species show high consistency (Table 3).

Table 3: AHP Indicators of Criteria for Each Tree Species in the Suitability Analysis

	Quercus spp.	*Juniperus* spp.	*P. nigra*	*C. libani*	*A. cilicica*	*Walnut* spp	Olt
λmax	9.576	9.543	9.816	9.509	9.668	9.779	9.603
CI	0.072	0.068	0.102	0.064	0.083	0.097	0.075
CR	0.05	0.047	0.07	0.044	0.057	0.067	0.052

Generation of Model Maps

All layers obtained from the criteria were converted to the same pixel size raster (grid) format. Model equations were created for each tree species. In GIS, layers were overlapped according to the model equation created in line with their statistical weights. By evaluating the results, suitability maps were created for each tree species. The suitability maps are classified as follows: 1 – not suitable, 2 – less suitable, 3 – medium suitable, 4 – very suitable, 5 – high suitable.

Quercus spp.= (Lithology *5,5) + (Landform* 6,9) + (Elevation*12,7) + (Slope*12,6) + (Aspect*4,4) + (Temperature*14,4) + (Precipitation*22,1) + (Soil type*8) + (Soil depth*13,4)

While creating the result map, priority order was determined among tree species. Priority order was determined using the AHP method, considering the geographical factors that shape the ecological conditions of tree species. Accordingly, the priority order of the tree species in the study area is as follows: 1. *Juniperus* spp., 2. *P. nigra*, 3. *C. libani*, 4. *A. cilicica*, 5. *Quercus* spp., 6. *Walnut* spp., 7. Olt (Table 4).

During the preparation and registration of the maps, Arc-GIS 10.7 GIS software was used. While applying the AHP method, QGIS 2's AHP tool was used.

Table 4: WLC Values of Tree Species

Tree Type	*Quercus* spp.	*Juniperus* spp.	*P. nigra*	*C. libani*	*A. cilicica*	*Walnut* spp	Olt	WLC
Quercus spp.	1	1/5	1/3	1/3	1/2	3	3	**0.08**
Juniperus spp.	5	1	2	2	4	7	7	**0.345**
P. nigra	3	1/2	1	2	2	5	5	**0.218**
C. libani	3	1/2	1/2	1	2	4	4	**0.168**
A. cilicica	2	1/4	1/2	1/2	1	3	3	**0.108**
Walnut spp	1/3	1/7	1/5	1/4	1/3	1	2	**0.045**
Olt	1/3	1/7	1/5	1/4	1/3	1/2	1	**0.036**
λmax= 7.215 CI=0,036 CR= 0,027								

RESULTS

As a result of the analysis, the boundaries of the optimal growing areas of each tree species in the study area were determined. Accordingly, a suitability map was created for each tree species (Figure 3). Looking at Figure 3 and Table 5, it is seen that 0.69% of the total area is not suitable, 45.06% is very suitable and 0.08% is high suitable for *Quercus* spp. For *Juniperus* spp., 4.38% of the total area is less suitable, 51.03% is very suitable and 38.66% is high suitable. For *P. nigra*, 0.61% of the total area is less suitable, 27.65% is very suitable and 58.51% is high suitable. For *C. libani*, 8.33% is less suitable, 28.61% is very suitable and 41.75% is high suitable. For *A. cilicica*, 5.84% of the total area is not suitable, 26.97% is very suitable and 29.04% is high suitable. For *Walnut* spp., 2.75% of the total area is not suitable, 9.97% is very suitable, 0.09% is high suitable. For Olt, 2.66% of the total area is not suitable, 39.35% is medium suitable, 36.25% is very suitable (Figure 3, Table 5).

In the research area, 0.09% of the total area for *Walnut* spp, 29.04% for *A. cilicica*, 41.75% for *C. libani*, 58.51% for *P. nigra*, 38.66% for *Juniperus* spp. and 0.08% for *Quercus* spp. have optimal growing conditions. In general, the most suitable tree species with the study area are *P. nigra, C. libani* and *A. cilicica*. The plain and surrounding plateau areas are particularly suitable for tree species such as *P. nigra C.libani, A. cilicica, Quercus* spp. and *Juniperus* spp. Mountainous areas are the most suitable areas for *Juniperus* spp. Northern and western parts of the study area show high suitability for *C. libani, A cilicica* and *Juniperus* spp. The eastern parts show high suitability for *P. nigra, Juniperus* spp. and *Quercus* spp. Southern parts show high suitability for *Walnut* spp. and Olt. Areas higher than 2400 meters in the study area correspond to high sloping, bare rocky areas without soil cover. Since these areas are above the tree growth limit, only high mountain meadows are found (Figure 3, 4).

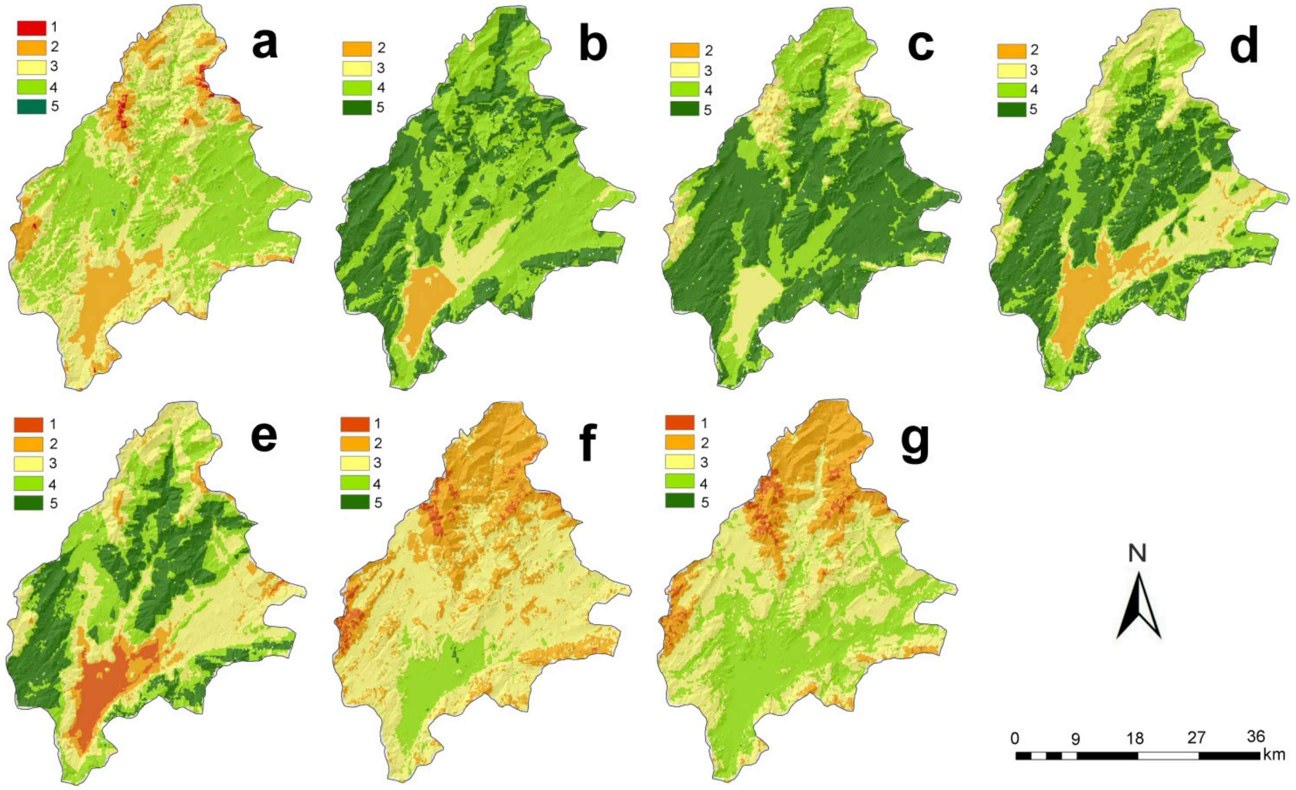

Figure 3: Suitability Model Maps: a) Quercus spp. b) Juniperus spp. c) P. nigra d) C. libani e) A. cilicica f) Walnut spp g) Olt (1 – Not Suitable , 2 – Less Suitable, 3 – Medium Suitable, 4 – Very Suitable, 5 – High Suitable)

Table 5: The Proportion of Each Tree Species According to Suitability Class

Suitability	*Quercus* spp.	*Juniperus* spp.	*P. nigra*	*C. libani*	*A. cilicica*	*Walnut* spp.	Olt
	%	%	%	%	%	%	%
Not suitable	0.69	-	-	-	5.84	2.75	2.66
Less suitable	15.82	4.38	0.61	8.33	6.53	32.42	21.74
Medium suitable	38.35	5.93	13.23	21.31	31.62	54.77	39.35
Very suitable	45.06	51.03	27.65	28.61	26.97	9.97	36.25
High suitable	0.08	38.66	58.51	41.75	29.04	0.09	-

The study area is most suitable for *P. nigra* in terms of geographical conditions (58.51%). However, today there is only 8.25% of the total area. The second most suitable tree type for the study area is *C. libani* (41.75%). It shows distribution in only 6.33% of the total area. While J*uniperus* spp. has optimal growing conditions in 38.66% of the total area, today it is found in 13.77% of the total area. *A. cilicica* has distribution in only 3.94% of the total area. However, 29.04% of the total area has optimal growing conditions.

Quercus spp., *Walnut* spp. and Olt show low compatibility with the geographical conditions of the research area. On the other hand, all three tree species have distribution above the suitability rate. While high suitable areas for *Quercus* spp. were 0.08%, today it is distributed in 2.56% of the total area. The suitability rate and distribution rate of *Walnut* spp. are almost the same.

While high suitable areas for *Walnut* spp. were 107 ha, today it has 110 ha distribution in the study area. There are no areas with high suitability for Olt. On the other hand, it has 23 ha (0.02%) areal distribution today (Figure 4, Table 6).

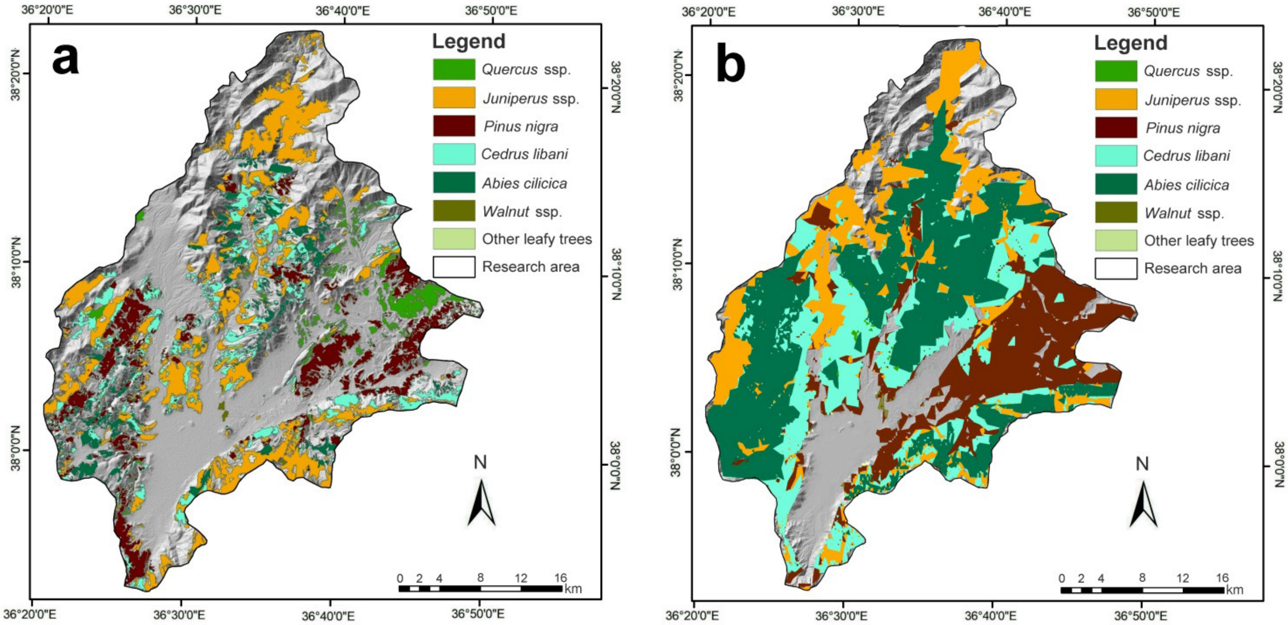

Figure 4: a) Distribution Map of Existing Tree Species, b) Distribution Map of Optimal Growing Areas of Tree Species

Table 6. The Areas and Proportions of Existing Tree Species and Optimal Growing Areas of Tree Species in Göksun Plain and its Surroundings

Tree species	Existing tree species		Optimal growing areas of tree species	
	ha	%	ha	%
Quercus spp.	3063	2.56	96	0.08
Juniperus spp.	16437	13.77	46164	38.66
P. nigra	9852	8.25	69867	58.51
C. libani	7556	6.33	49854	41.75
A. cilicica	4710	3.94	34677	29.04
Walnut spp.	110	0.09	107	0.09
Olt	23	0.02	0	0.00

DISCUSSION

Forests cover only 27.6% of Turkey's surface area. Existing forests are important in terms of both providing ecosystem services and being an economic element that provides raw materials for the wood industry. Afforestation works are carried out to protect and strengthen forests in the country. However, the expected efficiency cannot be obtained from afforestation works carried out by ignoring local ecological conditions. Planting tree species compatible with local ecological conditions in afforestation works is necessary for the sustainability of the forest ecosystem.

In this study, the ecological conditions of tree species, which are an important element of the forest ecosystem in Göksun Plain and its surroundings, were questioned, and then the boundaries of the optimal growing areas of each tree species were drawn. The AHP method, which is frequently used in forest planning studies, was used in the inquiry (Naeem et al., 2012). By using this method proposed by Saaty (Saaty, 1980b), the relationship between many factors and sub-criteria and different tree species was questioned, and the results were adapted to the decision-making process. *Quercus* spp., *Juniperus* spp., *P. nigra*, *C. libani*, *A. cilicica*, *Walnut* spp. and Olt tree species were used for the investigation. Lithology, landform, elevation, slope, aspect, temperature, precipitation, soil type and soil depth were evaluated as factors controlling the distribution of tree species. The degree of influence of these factors was calculated for each tree species.

The method specifies the ideal tree species for each location and prioritizes more than one species when necessary. For example, the results of the analysis indicate close locations as the most suitable growing areas for *P. nigra*, *C. libani*, *A. cilicica*, *Walnut* spp. and Olt. In this case, a ranking should be made by considering the priority order. In the priority ranking, the WLC score of *P. nigra* was 0.218, *C. libani* was 0.168, *A. cilicica* was 0.108, *Walnut* spp. was 0.045 and Olt was 0.036. In this case, the tree type that should be preferred first is *P. nigra*, which has the highest WLC score, and the tree type to be preferred in the last row is Olt. In addition, it contributes to the determination of targets in forest management plans by offering a chance to compare the existing area of each tree species and their optimal growing areas. These results provide the opportunity to make evaluations without limiting the number of options that can be created under local conditions in sustainable forest planning.

Spatial analysis results revealed the necessity of long-term forest management planning for the study area. Spatial analysis results for each tree species showed that the tree species in the study area are not at a sufficient level in the optimal growing area. This result revealed that long-term afforestation plans and projects should be made for the study area. Choosing tree species that are compatible with the ecological conditions of the locality while making afforestation plans and projects will strengthen the structure of the forest and affect its sustainability positively.

In addition to the effective and efficient use of existing resources, it is necessary to determine the geographical potential of the land and to make appropriate afforestation plans in this direction in order to ensure its long-term continuity. In order to prevent the depletion of valuable resources, especially in ecologically sensitive areas such as the study area, due to the intensive use, the results of the study and the proposed solutions should be taken into consideration by the authorized institutions and included in the implementation plans.

CONCLUSIONS

In this study, using a new method, the boundaries of the optimal growing areas of tree species that are compatible with the local ecological conditions of the Göksun Plain and its surroundings have been tried to be determined. Based on the analyzes applied and the methods used, the following conclusions were drawn:

- The methodology used was effective. The degree of impact of the environmental factor that is effective in the distribution of each tree species was determined. Thus, the sensitivity of tree species was determined.
- The boundaries of the optimal growing areas for each tree species in the study area could be clearly and effectively drawn.
- The data obtained as a result of the analysis made in the research area corresponding to an ecologically sensitive area, showed that the tree species are found in a very low ratio in the optimal growing areas.
- This precious area is exposed to a great deformation with ongoing and wrong planning and projects aimed at increasing the afforestation works in the study area, which has high biodiversity potential in terms of the availability of natural conditions. In line with the potential of the land, tree species that are compatible with environmental factors should be planted.

As a result, analyzes have been made in this study by taking into account the local spatial relations. The results of the research will serve as an example for the work to be done for different tree species in different geographical areas.

REFERENCES

Adams, J. (2009). *Vegetation-climate interaction: How plants make the global environment*. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-00881-8.

Atalay, I. (2006). *Soil formation, its classification and geography*. Meta Edition. Printing, Izmir.

Austin, M. P. (2005). *Vegetation and environment: Discontinuities and continuities*. In Vegetation Ecology (eds E. van der Maarel and J. Franklin). https://doi.org/10.1002/978.111.8452592.ch3

Belton, V., & Stewart, T. (2002). *Multiple criteria decision analysis: An integrated approach*. Kluwer Academic Publishers, Springer, Boston, MA. https://doi.org/10.1007/978-1-4615-1495-4

Bonan, G. B. (2008). Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. *Science*, *320*(5882), 1444–1449.

Cardinale, B. J., Matulich, K. L., Hooper, D. U., Byrnes, J. E., Duffy, E., Gamfeldt, L., Balvanera, P., O'connor, M. I., & Gonzalez, A. (2011). The functional role of producer diversity in ecosystems. *American Journal of Botany*, *98*(3), 572–592. https://doi.org/10.3732/ajb.1000364

Comita, L. S., Condit, R., & Hubbell, S. P. (2007). Developmental changes in habitat associations of tropical trees. *Journal of Ecology*, *95*(3), 482–492. https://doi.org/10.1111/j.1365-2745.2007.01229.x

Barrio, G., Alvera, B., Puigdefabregas, J., & Diez, C. (1997). Response of high mountain landscape to topographic variables: Central Pyrenees. *Landscape Ecology*, *12*(2), 95-115. https://doi.org/10.1007/BF02698210

FAO, (2011). Food and agriculture organization of United Nations; state of World's forest [FAO Report]. Rome: FAO 978-92-5-106750-5

Federici, S., Tubiello, F. N., Salvatore, M., Jacobs, H., & Schmidhuber, J. (2015). New estimates of CO2 forest emissions and removals: 1990-2015. *Forest Ecology and Management*, 89-98. https://doi.org/10.1016/j.foreco.2015.04.022.

Ferreira, J., Lennox, G. D., Gardner, T. A., Thomson, J. R., Berenguer, E., Lees, A. C., Mac Nally, R., Aragão, L. E., Ferraz, S. F., & Louzada, J. (2018). Carbon-focused conservation may fail to protect the most biodiverse tropical forests. *Nature Climate Change*, *8*(8), 744–749. https://doi.org/10.1038/s4155 8-018-0225-7

Fick, S. E., & Hicmans, R. J. (2017). WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, *37*(2), 4302-4315. https://doi.org/10.1002/joc.5086

Florinsky, I. V., & Kuryakova, G. A. (1996). Influence of topography on some vegetation cover properties. *Catena*, *27*(2), 123-141. https://doi.org/10.1016/0341-8162(96)00005-7

Forrester, D. I., Bauhus, J. (2016). A review of processes behind diversity—productivity relationships in forests. Current Forestry Reports, 2(1), 45-61. https://doi.org/10.1007/s40725.016.0031-2

Frank, T. D. (1988). Mapping dominant vegetation communities in the Colorado Rocky Mountain Front Range with Landsat Thematic Mapper and digital terrain data. *Photogrammetric Engineering and Remote Sensing*, *50(12)*, 1727–1734.

Greve, M., Lykke, A. M., Blach-Overgaard, A., & Svenning, J.-C. (2011). Environmental and anthropogenic determinants of vegetation distribution across Africa. *Global Ecology and Biogeography*, *20*(5), 661-674. https://doi.org/. https://doi.org/10.1111/j.1466-8238.2011.00666.x.

Guo, Q., & Ren, H. (2014). Productivity as related to diversity and age in planted versus natural forests. *Global Ecology and Biogeography*, *23*(12), 1461-1471. https://doi.org/10.1111/geb.12238

Guo, Y., Wang, B., Mallik, A. U., Huang, F., Xiang, W., Ding, T., Wen, S., Lu, S., Li, D., & He, Y. (2017). Topographic species-habitat associations of tree species in a heterogeneous tropical karst seasonal rain forest, China. *Journal of Plant Ecology*, *10*(3), 450-460. https://doi.org/10.1093/jpe/rtw057

Harms, K. E., Condit, R., Hubbell, S. P., & Foster, R. B. (2001). Habitat associations of trees and shrubs in a 50-ha neotropical forest plot. *Journal of Ecology*, *89*(6), 947–959. https://doi.org/10.1111/j.1365-2745.2001.00615.x

Hautier, Y., Seabloom, E. W., Borer, E. T., Adler, P. B., Harpole, W. S., Hillebrand, H., Lind, E. M., MacDougall, A. S., Stevens, C. J., & Bakker, J. D. (2014). Eutrophication weakens stabilizing effects of diversity in natural grasslands. *Nature*, *508*(7497), 521-525. https://doi.org/10.1038/nature13014

Isbell, F., Craven, D., Connolly, J., Loreau, M., Schmid, B., Beierkuhnlein, C., Bezemer, T. M., Bonin, C., Bruelheide, H., & De Luca, E. (2015). Biodiversity increases the resistance of ecosystem productivity to climate extremes. *Nature*, *526*(7574), 574-577. https://doi.org/10.1038/natur e15374

Jucker, T., Avăcăriței, D., Bărnoaiea, I., Duduman, G., Bouriaud, O., & Coomes, D. A. (2016). Climate modulates the effects of tree diversity on forest productivity. *Journal of Ecology*, *104*(2), 388-398. https://doi.org/10.1111/1365-2745.12522

Jucker, T., Bouriaud, O., Avacaritei, D., & Coomes, D. A. (2014). Stabilizing effects of diversity on aboveground wood production in forest ecosystems: Linking patterns and processes. *Ecology Letters*, *17*(12), 1560-1569. https://doi.org/10.1111/ele.12382

Jucker, T., Bouriaud, O., Avacaritei, D., Dănilă, I., Duduman, G., Valladares, F., & Coomes, D. A. (2014). Competition for light and water play contrasting roles in driving diversity–productivity relationships in Iberian forests. *Journal of Ecology*, *102*(5), 1202-1213. https://doi.org/10.1111/1365-2745.12276

Kalajnxhiu, A., Tsiripidis, I., & Bergmeier, E. (2012). The diversity of woodland vegetation in Central Albania along an altitudinal gradient of 1300 m. *Plant Biosystems-An International Journal Dealing with All Aspects of Plant Biology*, *146*(4), 954–969. https://doi.org/10.1080/11263.504.2011.634446

Kanagaraj, R., Wiegand, T., Comita, L. S., & Huth, A. (2011). Tropical tree species assemblages in topographical habitats change in time and with life stage. *Journal of Ecology*, *99*(6), 1441-1452. https://doi.org/10.1111/j.1365-2745.2011.01878.x

Laamrani, A., Valeria, O., Bergeron, Y., Fenton, N., Cheng, L. Z., & Anyomi, K. (2014). Effects of topography and thickness of organic layer on productivity of black spruce boreal forests of the Canadian Clay Belt region. *Forest Ecology and Management*, *330*, 144-157. https://doi.org/10.1016/j.foreco.2014.07.013

Liu, X., Zhang, W., Zhang, B., Yang, Q., Chang, J., & Hou, K. (2016). Diurnal variation in soil respiration under different land uses on Taihang Mountain, North China. *Atmospheric Environment*, *125*, 283-292. https://doi.org/10.1016/j.atmosenv.2015.11.034

MAF, (2014). Ministry of Agriculture and Forestry of Turkey; Kahramanmaras tree inventory maps [Map]. Republic of Turkey Ministry of Agriculture and Forestry, retrieved from https://www.tarimorman.gov.tr/Sayfalar/EN/AnaSayfa.aspx

Mazzochini, G. G., Fonseca, C. R., Costa, G. C., Santos, R. M., Oliveira-Filho, A. T., & Ganade, G. (2019). Plant phylogenetic diversity stabilizes large-scale ecosystem productivity. *Global Ecology and Biogeography*, *28*(10), 1430-1439. https://doi.org/10.1111/geb.12963

Moore, I. D., Grayson, R. B., & Ladson, A. R. (1991). Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. *Hydrological Processes*, *5*(1), 3-30. https://doi.org/10.1002/hyp.336.005.0103

Morales-Hidalgo, D., Oswalt, S. N., & Somanathan, E. (2015). Status and trends in global primary forest, protected areas, and areas designated for conservation of biodiversity from the Global Forest Resources Assessment 2015. *Forest Ecology and Management*, *352*(352), 68-77. https://doi.org/10.1016/j.foreco.2015.06.011

MRE, (2010). General Directorate of Mineral Research and Exploration of Turkey; 1 / 100 000 scaled geology maps. Ankara.

Naeem, S., Duffy, J. E., & Zavaleta, E. (2012). The functions of biological diversity in an age of extinction. *Science*,*336*(6087), 1401-1406. https://doi.org/10.1126/science.1215855

Nilsson, H., Nordström, E.-M., & Öhman, K. (2016). Decision support for participatory forest planning using AHP and TOPSIS. *Forests*, *7*(5), 100. https://doi.org/10.3390/f7050100

Nüchela, J., Bøchera.; P. K., & Svenninga, J. C. (2019). Topographic slope steepness and anthropogenic pressure interact to shape the distribution of tree cover in China. *Applied Geography*, *103*(3), 40-55. https://doi.org/doi.org/10.1016/ j.apgeog.2018.12.008

Ohsawa, T., Saito, Y., Sawada, H., & Ide, Y. (2008). Impact of altitude and topography on the genetic diversity of Quercus serrata populations in the Chichibu Mountains, central Japan. *Flora-Morphology, Distribution, Functional Ecology of Plants*, *203*(3), 187-196. https://doi.org/10.1016/j.flora.2007.02.007

Ouyang, S., Xiang, W., Gou, M., Chen, L., Lei, P., Xiao, W., Deng, X., Zeng, L., Li, J., Zhang, T., Peng, C., & Forrester, D. I. (2021). Stability in subtropical forests: The role of tree species diversity, stand structure, environmental and socio-economic conditions. *Global Ecology and Biogeography*, *30*(2), 500-513. https://doi.org/10.1111/geb.13235

Paquette, A., & Messier, C. (2011). The effect of biodiversity on tree productivity: From temperate to boreal forests. *Global Ecology and Biogeography*, *20*(1), 170-180. https://doi.org/10.1111/j.1466-8238.2010.00592.x

Peng, S.-S., Piao, S., Zeng, Z., Ciais, P., Zhou, L., Li, L. Z. X., Myneni, R. B., Yin, Y., & Zeng, H. (2014). Afforestation in China cools local land surface temperature. *Proceedings of the National Academy of Sciences*, *111*(8), 2915-2919. https://doi.org/10.1073/pnas.131.512.6111

Poorter, L., Sande, M. T. van der, Arets, E. J. M. M., Ascarrunz, N., Enquist, B. J., Finegan, B., Licona, J. C., Martínez-Ramos, M., Mazzei, L., Meave, J. A., Muñoz, R., Nytch, C. J., Oliveira, A. A. de, Pérez-García, E. A., Prado-Junior, J., Rodríguez-Velázques, J., Ruschel, A. R., Salgado-Negret, B., Schiavini, I., Swenson, N. G., Tenorio, E. A., Thompson, J., Toledo, M., Uriarte, M.,Hout, P. van der, Zimmerman, J. K., Pena-Claros, M. (2017). Biodiversity and climate determine the functioning of Neotropical forests. *Global Ecology and Biogeography*, *26*(12), 1423–1434. https://doi.org/10.1111/geb.12668

Reichstein, M., Bahn, M., Ciais, P., Frank, D., Mahecha, M. D., Seneviratne, S. I., Zscheischler, J., Beer, C., Buchmann, N., Frank, D. C., Papale, D., Rammig, A., Smith, P., Thonicke, K., van der Velde, M., Vicca, S., Walz, A., & Wattenbach, M. (2013). Climate extremes and the carbon cycle. *Nature*, *500*(7462), 287-295. https://doi.org/10.1038/nature12350

Saaty, T. L. (1980a). *The analytic hierarchy process*. McGraw-Hill International Book Co., New York; London.

Saaty, T. L. (1980b). *The analytic hierarchy process: Planning, priority setting, resource allocation*. McGraw-Hill International Book Co., New York; London. http://www.worldcat.org/search?qt=worldcat_org_all&q=007.054.3712

Sebastia, M.-T. (2004). Role of topography and soils in grassland structuring at the landscape and community scales. *Basic and Applied Ecology*, *5*(4), 331-346. https://doi.org/10.1016/j.baae.2003.10.001

Seddon, A. W. R., Macias-Fauria, M., Long, P. R., Benz, D., & Willis, K. J. (2016). Sensitivity of global terrestrial ecosystems to climate variability. *Nature*, *531*(7593), 229-232. https://doi.org/10.1038/nature16986

Tsui, C.-C., Tsai, C.-C., & Chen, Z.-S. (2013). Soil organic carbon stocks in relation to elevation gradients in volcanic ash soils of Taiwan. *Geoderma*, *209-210(4)*, 119-127. https://doi.org/10.1016/j.geoderma.2013.06.013

UN, (1992). Non-legally binding authoritative statement of principles for a global consensus on the management, conservation and sustainable development of all types of forests, United Nations: New York, retrieved from http://www.undocuments.net/for-prin.htm

Worldclim (2020). Climate data retrieved from: https://www.worldclim.org/data/index.html

Vie, J.-C., Hilton Taylor, C., & Stuart, S. N. (2009). *Wildlife in a changing world: An analysis of the 2008 IUCN Red List of Threatened Species.* Gland, Switzerland. https://doi.org/10.2305/IUCN.CH.2009.17.en.

Wang, B., Zhang, G., & Duan, J. (2015). Relationship between topography and the distribution of understory vegetation in a Pinus massoniana forest in Southern China. *International Soil and Water Conservation Research*, *3*(4), 291-304. https://doi.org/10.1016/j.iswcr.2015.10.002

Wenhua, L. (2004). Degradation and restoration of forest ecosystems in China. *Forest Ecology and Management*, *201*(1), 33–41. https://doi.org/10.1016/j.foreco.2004.06.010

Whittaker, R. H. (1956). Vegetation of the Great Smoky Mountains. *Ecological Monographs*, *26*(1), 1–80. https://doi.org/10.2307/1943577