http://silvaworld.org
SilvaWorld
e-ISSN: 2822-6127
https://prensip.gen.tr

RESEARCH ARTICLE

Stand Analysis and Distribution Areas of European Aspen (*Populus tremula* L.) Forests in Türkiye

İbrahim Turna ✉ • Fahrettin Atar

Karadeniz Technical University, Faculty of Forestry, Department of Forest Engineering, Trabzon/Türkiye

ARTICLE INFO

Article History
Received: 19.12.2023
Accepted: 23.02.2024
First Published: 31.03.2024

Keywords
Developmental stages
Ecology
Populus tremula
Stand

ABSTRACT

The aim of the study is to analyze the studies that have been done and need to be done on the general characteristics, distribution areas, and silviculture of European aspen stands naturally distributed in Türkiye. In the study, data obtained from the General Directorate of Forestry, Department of Forest Administration, and Planning for the year 2019 was used as the material. With these data, the spatial extent of European aspen stands in Türkiye was determined. Based on the obtained data, pure stands of European aspen, primarily in the regions where they have the most extensive spatial distribution, were examined on-site. Additionally, by evaluating the planning data in comparison with the current situation, European aspen stands were analyzed from a silvicultural perspective. The study determined that the total extent of European aspen forests in Türkiye is 278,013.7 hectares. Of the European aspen stands in Türkiye, 40.4% are in Elazığ, 17.3% in Erzurum, 15.7% in Trabzon, 11.4% in Kayseri, and 7.5% in Giresun Regional Directorates of Forestry. Furthermore, 92.3% of European aspen stands are located within these five regional directorates. Moreover, in Türkiye, 34,916.6 hectares of pure aspen stands and 13,745.6 hectares of stands dominated by aspen exhibit degraded qualities. Depending on the developmental stages, the largest spatial distribution in both pure stands (8,886.3 ha) and stands dominated by aspen (6,071.3 ha) has been identified in the ab developmental stages. When examining the developmental stages of European aspen in Türkiye, it's generally observed that young European aspen stands prevail. The management objective of same-aged pure and mixed aspen forests should be redefined according to both the succession stages and habitat conditions. In stands with ecological functions, protection and moderate interventions must be made, and in stands with production functions, necessary tending interventions must be made on time and sustainability must be ensured.

Please cite this paper as follows:

Turna, İ., & Atar, F. (2024). Stand analysis and distribution areas of European aspen (*Populus tremula* L.) forests in Türkiye. *SilvaWorld*, *3*(1), 15-27. https://doi.org/10.61326/silvaworld.v3i1.148

1. Introduction

In Turkish forestry, the European aspen species is known to be one of the pioneering tree species, and therefore, there is a lack of silvicultural studies both in scientific research and technical applications. Indeed, according to recent data on plans, the increasing distribution areas of aspen species in both pure and mixed stands, along with the functions they undertake, are remarkable. Especially in extreme regions, its ability to form pure or mixed stands is important not only as a pioneering species but also due to its diverse functions (economic, ecological, and socio-cultural). Emerging as a crucial tree species that comes to the rescue of ecosystems in forest gaps, abandoned agricultural lands, and areas of forests disrupted by biotic and abiotic damages. Indeed, the European aspen species, through anthropogenic impacts, reaches areas devoid of vegetation (such as clear-cutting, fire, pests, fungi, etc.), often establishing temporary, sometimes permanent stands and preparing suitable climate and soil conditions for succeeding tree species while contributing to a wide range of ecological

✉ Corresponding author
E-mail address: turna@ktu.edu.tr

functions. Due to the species being considered a pioneer and secondary species in Turkish forestry, there hasn't been much research conducted by both the forestry organization and universities and research institutions on this species until now. However, Saatçioğlu (1976) included the European aspen species under the heading "High Economic Value Mass Tree Species (Primary Species)" in his book "Biological Foundations and Principles of Silviculture" stating that the European aspen is a considerably large tree in Türkiye, regarded as one of the primary tree species.

European aspen (*Populus tremula* L.) is a species belonging to the genus *Populus* in the Salicaceae family of the order Salicales within Angiosperms, divided into five main sections. The European aspen is situated within the Trepidae sub-section of the Leuce section (Kayacık, 1981; Jobling, 1990). The European aspen forests, with a wide distribution, especially in the Northern Hemisphere encompassing Europe and Asia, are naturally found throughout Europe as a whole, North Africa, Central and Northern Asia, Siberia, Northern Korea, Northern Japan, Türkiye, and the Caucasus (Yaltırık, 1993). Therefore, this species is naturally distributed across a vast geography, both globally and within Türkiye. The extensive natural range of the species is a consequence of its ability to adapt to extreme environmental conditions.

In Türkiye, it is noted that the species thrives exceptionally well in Western Thrace, Western Anatolia, and the Black Sea region. It's found individually, in clumps, or in groups across all forest regions except for the Southeast and the steppe regions of Central Anatolia. Particularly, it occupies areas along streams, rivers, and within forest clearings (Saatçioğlu, 1976; Yaltırık, 1993). Although literature on the species' distribution areas in Türkiye often states its absence in the Southeast and the steppe regions of Central Anatolia, natural occurrences have been identified through field surveys and incorporated into management plans in regions such as Kayseri, Sivas, Bitlis, Bingöl, Van, Siirt, and Hakkari within the Inner and Eastern Anatolian territories, where it forms extensive stands. This situation has been reported in studies conducted by Atalay (2019), Atalay et al. (2021), Turna et al. (2021), and Turna and Atar (2022). Özel et al. (2018), in a study conducted in the Erzurum-Pasinler region, found that aspen trees in this region are the second closest tree species to the tree line after Scots pine, which are found in the subalpine and war zones. In addition, as a result of this study, it has been found out that this species, notwithstanding its natural area of occupancy across Türkiye, could thrive up to 2,460 m in altitude and extent of occurrence.

Although the forest management plans provide the extent of areas where European aspen forests naturally occur, there's an inadequacy in terms of information regarding the management methods, stand characteristics and silvicultural treatments. It's evident from current forest management plans that European aspen forests are increasingly spreading over considerably vast areas compared to previous plans. Nevertheless, field personnel from the General Directorate of Forestry have indicated the existence of European aspen stands that are yet to be reflected in the plans. Technical field surveys and observations conducted by us have revealed the presence of European aspen forests that are not recorded in the forest management plans. Indeed, in a study conducted by Turna et al. (2021), it was found that despite the absence of European aspen areas in the forest management plans of the Horasan Forestry Directorate, the renewed plan in 2021 identified 9,541.4 hectares of forest area designated for aspen management. The aim of this study is to analyze the general characteristics, extent of distribution, and silviculture of naturally occurring European aspen stands in Türkiye, as well as to assess the studies conducted and the necessary research that needs to be undertaken in this field.

2. Materials and Methods

In the study, the data obtained from the General Directorate of Forestry, Department of Forest Administration, and Planning for the year 2019 was used as the material. These data were utilized to determine the spatial extent of pure and mixed European aspen stands in Türkiye. The forest stands types, developmental stages (Table 1), and status of pure and mixed stands related to silvicultural interventions were evaluated concerning the Regional Forest Directorates (RFDs). Consequently, based on the data acquired, on-site examinations of European aspen stands, particularly the pure stands in the Regional Directorates with the highest spatial distribution of European aspen stands, were conducted. Additionally, plan data was assessed in comparison with the current status to analyze aspen stands from a silvicultural perspective. Throughout this process, the growing conditions of aspen forests were considered, and recommendations were provided regarding silvicultural intervention methods based on stand establishment characteristics.

Table 1. Classification of developmental stages.

Developmental stages	Criteria (average diameter at breast height)
a (regenerated)	<8.0 cm
b (young)	8.0 – 19.9 cm
c (mature)	20.0 – 35.9 cm
d (over-mature)	>36.0 cm

3. Results and Discussion

3.1. The Distribution Area of European Aspen Stands

The spatial distribution of European aspen stands in Türkiye based on 2019 data concerning pure aspen stands, stands dominated by aspen, and mixed stands involving aspen with other species is presented in Table 2.

Table 2. The distribution area of European aspen stands (2019).

Sequence No	Regional Forest Directorates	Pure Aspen (ha)	Aspen + Other (ha)	Other + Aspen (ha)	Total (ha)
1	**Amasya**	1205.8	443.7	1176.0	2825.5
2	**Ankara**	2593.4	617.4	5220.9	8431.7
3	**Artvin**	436.0	0.0	13.8	449.8
4	**Balıkesir**	0.0	0.0	4.1	4.1
5	**Bursa**	94.2	0.0	223.0	317.2
6	**Çanakkale**	236.0	0.0	45.2	281.2
7	**Denizli**	25.3	0.0	152.9	178.2
8	**Elazığ**	13010.2	5983.0	93149.8	112243.0
9	**Erzurum**	21360.8	10147.8	16475.8	47984.5
10	**Eskişehir**	3.0	0.0	882.2	885.2
11	**Giresun**	5227.1	2752.7	12911.7	20891.5
12	**Isparta**	12.7	0.0	0.0	12.7
13	**İstanbul**	693.2	443.8	406.2	1541.2
14	**İzmir**	3.6	0.0	0.0	3.6
15	**Kahramanmaraş**	103.2	0.0	0.0	103.2
16	**Kastamonu**	372.9	390.8	3191.6	3953.3
17	**Kayseri**	5945.1	5991.6	19826.3	31763.0
18	**Konya**	9.9	83.9	44.4	138.2
19	**Kütahya**	92.6	183.2	1737.7	2013.5
20	**Muğla**	0.0	12.3	172.6	184.9
21	**Sakarya**	62.3	51.2	140.4	253.9
22	**Trabzon**	6975.1	5106.4	31657.7	43739.2
23	**Zonguldak**	0.0	5.4	90.9	96.3
Total					278013.7

European aspen forests in Türkiye cover a total area of 278,013.7 hectares (Table 2). According to the 'National Poplar Commission Country Development Report 2016-2019' prepared by Velioğlu et al. (2020), they are found across approximately 287,005.5 hectares, with 152,408.8 hectares classified as productive stands, while the remaining 134,596.7 hectares are reported to be degraded stands. Additionally, the wood production volume in European aspen forests for the year 2019 is stated to be 132,134 m^3. In Türkiye, European aspen forests, either in pure or mixed stands, are present within 23 out of 30 Regional Directorates of Forestry. In this study, the five Regional Directorates with the highest distribution of European aspen stands within these 23 Regional Directorates were evaluated from a silvicultural perspective. The ranking of spatial distribution by Regional Directorates is as follows: Elazığ (112,243.0 ha), Erzurum (47,984.5 ha), Trabzon (43,739.0 ha), Kayseri (31,763.0 ha), and Giresun (20,891.5 ha) RFDs. Accordingly, in Türkiye, 40.4% of European aspen forests are located in Elazığ, 17.3% in Erzurum, 15.7% in Trabzon, 11.4% in Kayseri, and 7.5% in Giresun RFDs. Furthermore, 92.3% of European aspen stands are found within these five Regional Directorates (Figure 1).

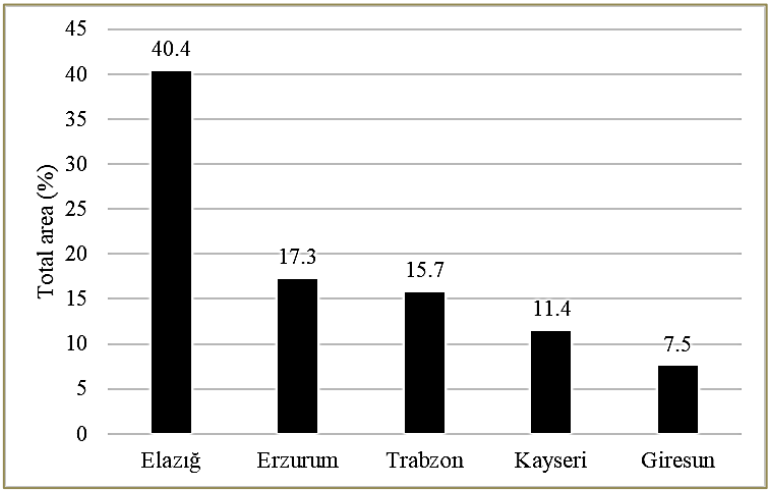


Figure 1. The area of European aspen stands in the top five regional directorates with the largest spread area.

The distribution of pure European aspen stands is as follows: Erzurum (21,360.8 ha), Elazığ (13,010 ha), Trabzon (6,975.1 ha), Kayseri (5,945.1 ha), and Giresun (5,227.1 ha). Stands where European aspen is mixed should be considered separately, categorizing them as either European aspen-dominated or dominated by other species (such as oak, Scots pine, black pine, etc.). Silvicultural interventions in mixed stands dominated by other species and those in stands dominated by European aspen may vary, indicating the need for distinct approaches. Especially considering the mixture ratio and form of stands, it is necessary to determine whether European aspen exhibits a pioneer species characteristic. For instance, in mixed stands where oak or Scots pine dominates, aspen may gradually retreat from the area. However, in mixed stands dominated by aspen (especially aspen+oak mixtures), aspen can entirely take over the dominant position over time. Accordingly, the spread area of mixed stands dominated by aspen is listed as Erzurum (10,147.8 ha), Kayseri (5,991.6 ha), Elazığ (5,983.0 ha), Trabzon (5,106.4 ha), and Giresun (2,752.7 ha). When considering the spread area of both pure and aspen-dominated stands, the importance of the species becomes evident (Figure 2).

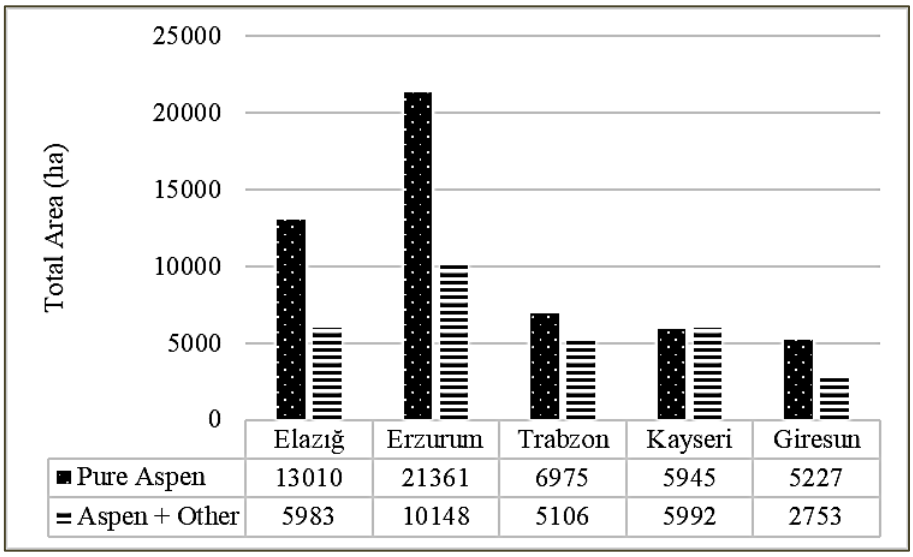


Figure 2. The top five regional directorates with the highest spread area of pure aspen and aspen-dominated stands.

Elazığ RFDs, ranking first in total area, naturally comprises extensive areas of European aspen, both in pure stands and mixed stands, due to its vast geographic expanse. Similarly, a significant portion of the aspen areas in the region (88.4%) are mixed with oak, while the remaining 11.6% consist of pure stands. The area covered by oak+aspen mixed stands is 92,969.2 hectares, while the area covered by aspen+oak mixed stands is 5,500.1 hectares. Both pure and mixed stands predominantly belong to the young and mature developmental stages in terms of developmental stages. Overall, 54.4% of aspen stands in the region are degraded, while 45.6% have a normal structure. Additionally, it has been noted that both pure and mixed stands are distributed not as contiguous units (e.g., 5-10-20 hectares) but rather as smaller areas (1-2 hectares). Furthermore, due to the region's topographic and other characteristics, it seems less conducive for comprehensive studies.

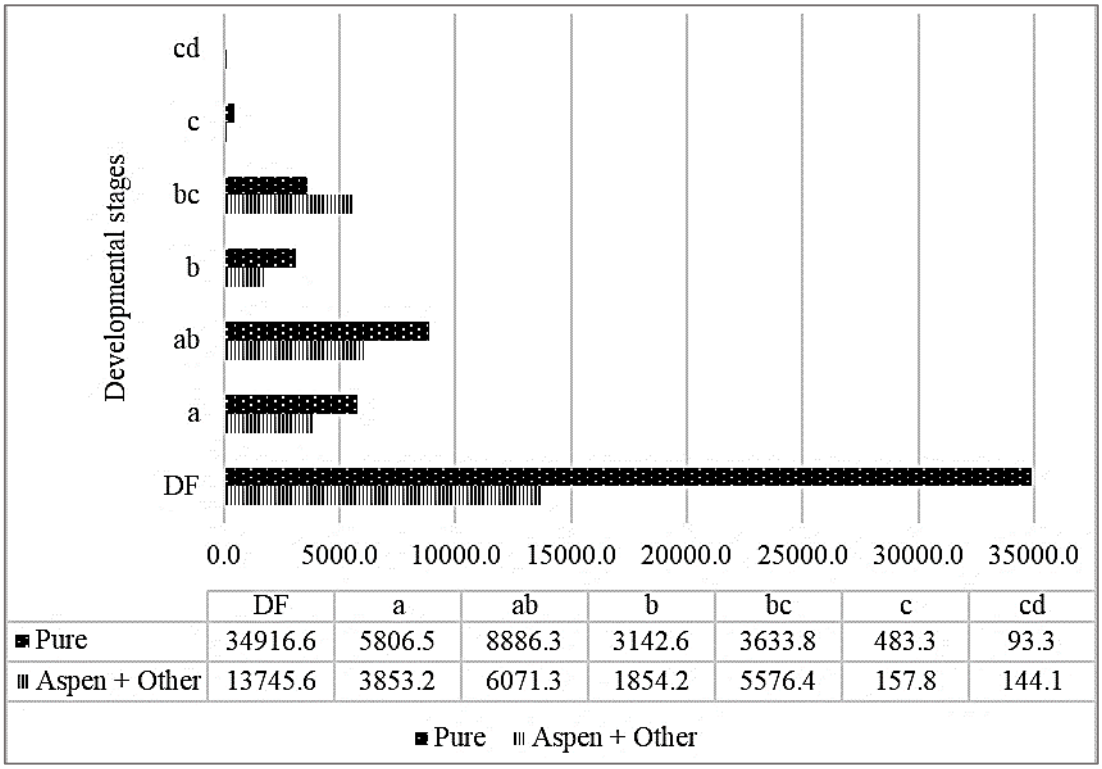
The Erzurum RFDs, ranking second in terms of spread area, comprise 45% (20,798.3 ha) of pure aspen stands, with 22.3% (4,637.5 ha) of this being in the first thinning stage. A significant portion of mixed stands dominated by aspen includes aspen+other deciduous species. Additionally, stands with aspen+oak and aspen+Scots pine are also quite prevalent. Despite Erzurum RFDs being known for Scots pine forests, the spread area of Scots pine+aspen stands is only 2,180.3 hectares. When examining the stand structure of aspen forests throughout the regional directorate, 78.2% (36,194.3 ha) are found to have degraded, while 21.8% (10,102.6 ha) exhibit normal structure. This emphasizes the significance of managing productive aspen forests from a silvicultural perspective. During the examinations conducted in aspen forests, it was found that in the current state, aspen+oak mixtures generally appear as pure stands of European aspen, with oak being beneath the crown closure of aspen during its youth stage. Evaluating the tree species involved in the mix, it's evident that the region is dominated by climax species like oak and Scots pine. Additionally, in the Ardahan Posof region, increasing instances were noted where aspen mixed with other deciduous species, along with findings showing mixtures with oriental spruce during on-site examinations.

In Trabzon RFDs, encompassing a spread area of 43,739 hectares for aspen, 66% of this species lies within Gümüşhane and 44% within the boundaries of the Torul Forest Management Directorate. Among the European aspen stands in the region, 16% are pure stands, while 12% exhibit aspen dominance in mixed stands. Areas where aspen mixes with other species like

Scots pine, oak, and oriental spruce constitute 72% of the total. According to the planning data, it's understood that 69.2% of the existing areas have a normal structure.

In Kayseri RFDs, the 31,763 hectares of aspen stands are in 15,467.7 hectares (49%) degraded and 16,295.3 hectares (51%) normal structure. Pure stands dominate within the Kayseri and Sivas Forest Management Directorate boundaries. In the foothills of Mount Erciyes, since 2019, thinning interventions have been conducted annually, and wood has been produced. The 20,891.5 hectares of aspen forests located in Giresun RFDs are situated in the regions of Şebinkarahisar, Suşehri, and Koyulhisar. 85% of the existing aspen forests are of normal structure, while 15% are degraded. In mixed forests, the dominant species are Scots pine+aspen and oak+aspen.

The spatial distribution of stands dominated by pure and European aspen in Türkiye, according to their developmental stages, is illustrated in Figure 3. Accordingly, 34,916.6 hectares of pure European aspen stands and 13,745.6 hectares of stands dominated by European aspen are of degraded structure. Based on their developmental stages, the highest spatial distribution in both pure (8,886.3 ha) and European aspen-dominated (6,071.3 ha) stands is identified in the ab stage.



	DF	a	ab	b	bc	c	cd
Pure	34916.6	5806.5	8886.3	3142.6	3633.8	483.3	93.3
Aspen + Other	13745.6	3853.2	6071.3	1854.2	5576.4	157.8	144.1

Figure 3. Distribution area (ha) of pure and aspen-dominated stands in Türkiye based on their developmental stages (DF: Degraded forest).

3.2. Ecological Features

Climate: When examining the climatic characteristics of European aspen in their natural habitats worldwide, including Türkiye, they are found to thrive in areas ranging from humid and oceanic climates to moist cold continental regions. Therefore, the species extends its distribution towards humid-cold areas in Eurasia and North America, reaching as far as the northern polar circle. Accordingly, in terms of climate requirements, it is not a highly selective species. It prefers temperate and cool climates while being adaptable to various climatic conditions. The European aspen is modest in its requirements for both rainfall and temperature, exhibiting resilience against frost. It holds significant importance in high-mountain forestry (Atalay, 2019; Velioğlu et al., 2023). Atalay (2019) mentions that in Türkiye, European aspen demonstrates a wide distribution from semi-arid to semi-humid continental, humid temperate, and moist to semi-moist cold climates, where relative humidity ranges between 60 and 70% and annual average rainfall exceeds 450 mm up to over 1000 mm. There's a linear relationship between days covered with snow and the optimal distribution of European aspen. It's been observed that European aspen proliferates and site increase in locations with over 100 days of snow cover. Velioğlu et al. (2023) report an annual average rainfall of 604 mm in the European aspen areas of Mount Erciyes. In the areas where European aspen spreads, the annual average temperature ranges between -30 °C and 12 °C. However, in optimal distribution areas, these values range between 8 °C and 30 °C (Atalay, 2019). Accordingly, it appears that European aspen forests are not resistant to high temperatures; rather, they thrive in locations with cold winters and cool summers. Indeed, examinations and observations

conducted in its natural habitats indicate its ability to thrive in almost every climate type. It has low temperature requirements and is resilient against frost.

Soil: European aspens spread on soils that belong to zonal, azonal, and intrazonal groups, especially on soils resembling andosols found on basalt-andesites and high mountain-meadow soils (Atalay, 2019). It favors soils that are fresh, permeable, and have good drainage, showing a preference for sandy loam and loamy soils while disliking very dry and heavy clay soils. It also spreads over rocky slopes with substantial physiological depth, gravelly slopes, and loose rockslides. Atalay et al. (2021) indicated that in the vicinity of Mount Erciyes, the pH values of the soil and parent materials range between 6.14-6.44, the lime content varies from 1.15% to 26.47%, and the organic matter content ranges from 0.2% to 4.8%. These values suggest that European aspen forests are not highly selective in terms of soil properties. Indeed, research conducted by Meier et al. (2012) in the Alps concluded that soil properties do not significantly impact the natural distribution of European aspen, as it can thrive in almost any soil type.

Topographic Features: The elevation, aspect, slope, and hillside shapes are influential in the distribution and stand structure of the species. Throughout Türkiye, the natural habitats of the species are found in various aspect groups and at different elevation levels. The European aspen extends from sea level to the upper limit of the forest, but its main distribution occurs above 1800 meters.

In the Black Sea region, it ranges from 30-50 meters above sea level to as high as 2000 meters. Due to the humid climate in these areas, the distribution appears as individual-tree mixture or group rather than in stands. Beyond the Black Sea region and in the Inner Anatolia, the lower limit for forest stands is generally around 1100-1400 meters, particularly around Mount Erciyes, Gümüşhane, Elazığ, and Sivas. European aspen forests have been observed at elevations of 2537 meters in Mount Yıldız, Sivas. Throughout Türkiye, it reaches up to the upper forest limit. Depending on geographical regions, it extends from 2000-2600 meters on Mount Erciyes to 2400-2500 meters in the Northeast Anatolia region (Turna & Atar, 2019; 2022). Additionally, Velioğlu et al. (2020) report that the European aspen species in Türkiye exists within the natural forests within the altitude range of 0-2900 meters, sometimes appearing as pure forest stands, but primarily as groups or individual trees, often as the initial form of forest communities.

It is understood that the European aspen spreads across nearly all aspect groups in terms of individual-tree or stand structure. Especially in shaded aspect groups, it establishes higher-quality stands; however, both pure and mixed stands are found across all aspect groups. As water availability increases, the best stands are typically found on north, west, south, and east-facing aspects. According to Bilgili (2007), a yield study conducted in the Erzurum and Şebinkarahisar regions indicated that among European aspen stands, 33% were on the northern, 28% on the eastern, 26% on the southern, and 13% on the western aspects. Additionally, Dinca and Vechiu (2020) reported that in their study, 32% were southeast, 26% northeast, 13% west, 14% north, and 14% east-facing aspects.

The European aspen is a light-demanding species with no tolerance for shade. Its youth cannot develop under its own crown closure (Turna & Atar, 2022). These characteristics are crucial in silvicultural interventions. Indeed, one of the reasons for the European aspen's natural growth in forest gaps, disturbed or vacant areas, and abandoned agricultural fields is this requirement. When evaluating the natural distribution areas of the European aspen in Türkiye, it has been observed that it forms stands across all slope categories. Particularly in the natural pure European aspen stands within the boundaries of Giresun, Trabzon, Erzurum, and Kayseri RFDs, our examinations and observations revealed its growth in areas with higher slopes that are less accessible. Additionally, it has been determined that it establishes pure, clump, or group stands in low-slope areas such as abandoned agricultural lands.

3.3. Stand Structures and Silvicultural Technique

The characteristics of stand structure are important indicators in making decisions regarding silvicultural interventions. Based on various site inspections conducted by us at different times, along with the existing forest management plan data, it has been observed that European aspen forests exhibit development under significantly different ecological conditions.

The seeds of European aspen are capable of being dispersed over extensive distances via wind and subsequently germinating in favorable habitats. Particularly in areas left bare due to various causes such as deforestation, wildfires, abandoned agricultural lands, or rocky terrain unsuitable for other plant species, the germination of European aspen seeds leads to the emergence of distinct young populations. Subsequently, owing to robust root suckers production, European aspen gradually proliferates, forming clumps, groups, and extensive stands of trees (Figure 4). The area covered, supported by interconnected root suckers, varies between 500 and 1200 square meters, contingent upon ecological circumstances. The merging of young populations arising from shared root suckers results in the formation of groups or extensive stands constituting European aspen stands.

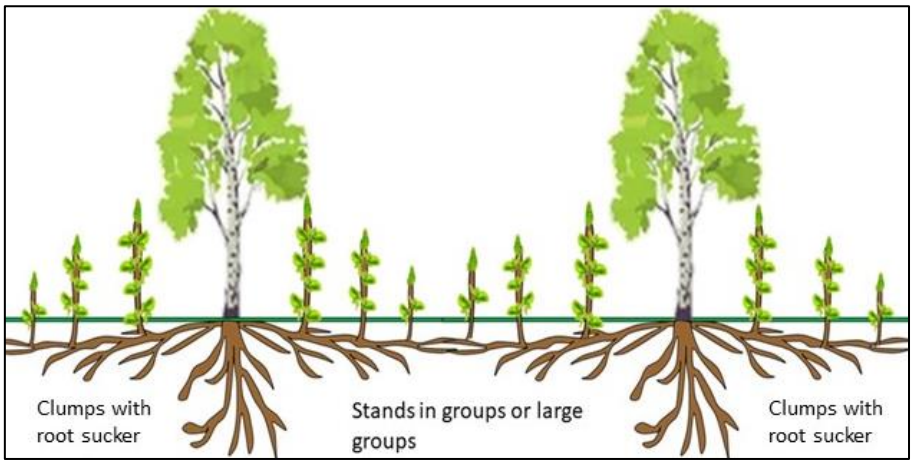


Figure 4. Clumps or groups of European aspen originating from root suckers.

When considering the development of European aspen stands in Türkiye, it's understood that they initially expand through seeds (generative) and then continue to grow through vegetative means (root suckers). Due to the formation of European aspen stands through both seed and root sucker-originated individuals, in terms of silviculture techniques, they can be defined as coppice with standards. However, considering the wood preferred for use in industry, they can be classified as high forests. Indeed, in the natural forests situated in both shaded and sunny exposures around Mount Erciyes, investigations conducted by Turna and Atar (2022) determined that aspen seeds, falling among the rocky patches on the slopes, germinate and spread by producing root suckers within the fissured and cracked soil structure containing sand, silt, and fine gravel. These areas, as indicated in numerous literature sources, are not a result of anthropogenic effects (such as the removal of climax species like oak or Scots pine from the area). Instead, they are naturally occurring forests that have been abandoned or have grown due to a decrease in livestock and agricultural activities. This situation leads aspen forests to initially start as small clumps or groups in pure form and later transition into mixed stands with some elements of the natural flora blending in. For instance, the majority of aspen forests on Mount Erciyes in Kayseri consist of pure stands, while in regions like Erzurum and Gümüşhane, some are pure and others are mixed stands.

When examining the developmental stages of stands, in the same area, stands in stages a, b, and c are observed, appearing in clumps, groups, and larger groups. European aspen forests, which have a high demand for light, form single-storied as crown closure occurs. As one moves away from the central focal point, stands in stages c, b, and a are encountered. Therefore, the age of the forest, whether individual, clumped, or grouped, varies based on the location within the area, ranging from 1 to 170 years, and after 40-50 years, they are susceptible to internal decay. Hence, for forests intended for production, the rotation age could be related to operational goals but is recommended to be between 40 and 50 years old due to the onset of internal decay.

In European aspen stands, the storied structure varies depending on whether they are pure or mixed stands. For instance, in pure European aspen forests or those mixed with light-demanding tree species like aspen + oak or aspen + Scots pine, a single-storied is observed. However, in mixtures such as aspen + fir or aspen + spruce, rare instances of multi-storied can be seen. Crown closure generally exhibits horizontal density, encompassing various levels such as dense, regular, loose, and open. European aspen, naturally distributed across a wide geographical area in Türkiye, naturally blends with a diverse range of tree species. Therefore, apart from the mixture type, determining the storied structure and crown closure according to local conditions is crucial during silvicultural decision-making. Dinca and Vechiu (2020) conducted a study in European aspen forests in the Carpathian Mountains of Romania, where they found that 47% were individual, 48% were in clumps, and 5% were in groups in terms of mixture type.

European aspen develops a taproot in its youth. During later developmental stages, it develops a permanent root system. Moreover, due to the species developing very strong and long lateral roots, it is not heavily affected by storms in its natural distribution areas. Its ability to produce strong root suckers and being a thrifty species is important for soil conservation and ecosystem improvement. The lateral root spread is more directed towards open areas. Gifford (1966) mentions that the horizontal root spread of *Populus tremuloides* can exceed 30 meters, while the vertical distance reaches 2.7 meters, and the species has a very dense network of fine roots.

Planned forestry requires that any silvicultural interventions in a forest stand be applied according to silvicultural plans in harmony with forest management plans. Therefore, in European aspen stands, where a significant portion is designated for high mountain ecosystem function and another

part is allocated for soil and nature conservation within the forest management plans, it is crucial to meticulously examine them, especially pure stands. The management objective should be determined accordingly.

In order to determine silvicultural interventions to be applied in European aspen forests, it is crucial to have a good understanding of the species' stand structures, management objectives, yield tables (determining relationships between site productivity and growth for identifying optimal stand structures), and the biology of the species. Apart from the general ecological and stand structure characteristics mentioned above, the functions of European aspen stands should be identified to commence silvicultural interventions accordingly. It's important to note that silvicultural interventions should be determined based on the succession stages of the species and, particularly, the growing conditions of the environment, ensuring interventions are aligned with these stages and management objectives. It is a known fact in terms of forestry techniques that silvicultural interventions in an ecologically functional forest will differ from those in a production forest. However, the sustainability of stands that have reached the end of their rotation age can only be achieved through the regeneration of these stands.

3.3.1. Regeneration

In Türkiye, there hasn't been any scientific or applied work for regeneration purposes in European aspen forests. One reason is that existing management plans prioritize ecological functions over timber production. Another reason is the perception of European aspen as a pioneer species. The regeneration process of European aspen occurs either through seed-based generative methods or vegetative methods from shoots, similar to other tree species. European aspen has a high light requirement, especially in open areas (clear-cutting or fire-affected), making it feasible to regenerate through seeds under highly suitable conditions (where the soil is open and warm, devoid of live ground cover, including root and stem shoots). As European aspen's seed properties enable them to travel long distances and germinate well under ample light, they can be regenerated through seeds in such areas. Young stands unaffected by frost create pure forest stands.

According to preliminary information obtained from our field inspections and project studies, it appears that the young stands arriving in the area are predominantly root-sprout-based natural stands. For mature European aspen stands, the regeneration method in small areas could potentially rely on a natural regeneration method based on clear-cut. Indeed, Worrell (1995) suggests that although seed-based regeneration is possible due to seed production capacity and ecological compatibility, there are practical difficulties. Most research has focused on vegetative production. Through root suckers, multiple sprouts emerge from the same root, and in subsequent years (around 20-30 years old), the number of individuals in the stand ranges from 2500 to 3700 per hectare, depending on light competition. Therefore, it is stated that the regeneration method in pure European aspen stands is based on clear-cut. It is noted that a single-parent European aspen tree can produce hundreds of root suckers. Börset (1985) emphasizes that, as a result of clear-cutting a mature stand, the number of sprouts per hectare can exceed 50,000 to 100,000. Krasny and Johnson (1992) stated that 98% of the young sprouts that emerge in the clear-cutting area occur during the first vegetation period following cutting.

Boydak and Çalışkan (2014) define regeneration through root, stem, and trunk sprouts as vegetative natural regeneration. In European aspens, particularly due to the high potential for root sucker formation and the ability of their seeds to travel long distances, forests can form in nature through both seed and sprout sources. (Latva-Karjanmaa et al., 2003) mention that although both *Populus tremula* and *Populus tremuloides* species have high seed yield potential, seed-based regeneration practices are rarely observed. Instead, the primary mode of reproduction is stated to be asexual (vegetative) production based on root suckers.

According to our research conducted on pure European aspen stands in Türkiye, the most suitable method for species regeneration is the vegetative natural regeneration method, which focuses on sprout development. The equivalent term for this practice in silviculture literature is the clear-cutting method. However, large-scale clear-cutting operations can harm the ecological functions associated with European aspen, particularly causing negative impacts on wildlife, and thus, they should not be preferred. Therefore, regeneration methods should be implemented in small areas (clumps or groups). Clear-cut in clumps might often be insufficient. Maintaining an open crown closure is desired to meet the light requirements. Renewal of the area is ensured through clear-cutting in groups or large clumps, resulting in the emergence of new stands primarily through root suckers. For instance, Crouch (1981) conducted a study in Northwest Colorado on the effects of the clear-cutting method on regeneration in *Populus tremuloide*s (70 years old stand). Within the first three years after the removal, the condition of the newly emerged stands was assessed. The number of individuals per hectare in the experimental area was 1327, with total basal area of 13600 cm^2/ha. Approximately half of the trees had a diameter at breast height greater than 14 cm. The stand had a normal density, with 62 dead trees per ha and crowded individuals. The average diameter was 15-16 cm, with a few individual pine trees within the area. At the beginning of vegetation after cutting (July), a few sprouts were observed, which decreased from 18120 to 3280 by September.

After tending interventions carried out in pure European aspen stands in the Sakarciftligi region of Mount Erciyes in Kayseri, the dense young growth originating from root suckers

in the ground cover will gain independence following subsequent cuttings (either tending or clear-cuttings for regeneration purposes). Preliminary research data from a tending worked 40-45-year-old pure European aspen stand in the area indicate that the number of root suckers at 3-4 years old ranges between 100,000 and 200,000, with average heights of 0.5-1.5 meters and root collar diameters between 2 and 8 mm (Turna & Atar, 2022). Therefore, the abundance of young sprouts obtained after the final tending interventions in pure aspen stands indicates that sprout-originated regeneration is a suitable method for aspen stands (Figure 5).

Figure 5. The youth formed from root suckers after tending interventions.

In the regeneration of mixed stands of aspen+Scots pine or aspen+black pine, it's crucial to ensure the preservation of the primary species. Aspen cuttings in favor of pine species within the scope of tending interventions in stands aspen+Scots pine or Scots pine+aspen encourage root sucker development in aspens. This phenomenon has been observed in mixed stands of Scots pine and aspen managed by the Sivas Forest Management Directorate (Figure 6). Therefore, after tending interventions aimed at preserving the climax species in mixed stands of aspen+Scots pine, aspen+black pine, Scots pine+aspen, or black pine+aspen, young aspen growth coming into the area should be treated as an ground cover and removed from the site. The successful regeneration of primary species should be the primary consideration here.

Figure 6. The dominance of young European aspen growth in the area following tending interventions against aspen in mixed stands of Scots pine and European aspen (Sivas).

3.3.2. Tending

In Türkiye, there are intensely pure and mixed stands of Euroepan aspen found in developmental stages a, ab, b, and bc. However, the management objectives for these stands have not been clearly stated or they have only been included for ecological functions in plans. Therefore, no explanation has been provided regarding the silvicultural interventions that should be applied to stands subject to tending interventions. However, as highlighted in Worrell (1995)'s study in Scotland, in forests managed for timber production, the rotation length ranges between 40 and 60 years. For the production of small-diameter materials, it is recommended to conduct maintenance at age intervals of 8-15 years, with average heights of 6-10 meters, thinning interventions spacing at 2x3 meters. It is also suggested to conduct thinnings at intervals of 5 years between ages 15 and 30, followed by intervals of 7-8 years in subsequent years, reducing the number of individuals per hectare to 300-400 at the final harvest stage. These data emphasize the importance of defining management objectives in determining the intensity of tending interventions.

There is no scientific study conducted regarding tending interventions in European aspen stands naturally distributed in Türkiye based on stand development stages. In recent times, tending works aimed at enhancing stability and establishing healthy stands against biotic and abiotic factors have been addressed both by forest managers and scientific studies, especially in stands at the "b" developmental stage.

Juvenile stage: The implementation of protective measures and the thinning of naturally occurring youth are crucial tending practices, depending on the development of the youth when applying measures for youth care. In European aspen stands in Türkiye, due to the lack of suitable natural or artificial regeneration studies, there is no specific work related to youth tending. However, thinning the youth originating from sprouts, particularly due to anthropogenic effects like fire or land degradation, should be considered, especially considering variations in water scarcity and temperature degrees. Moreover, regulating the mixture, removing diseased individuals from the area, and, most importantly, implementing protective measures can enable healthier youth development in the area. Perala et al. (1999) mentioned that in the same-aged pure Euroepean aspen stands over a rotation period of 50 years, if the number of individuals per hectare decreases below 1,000 due to natural competition, maintenance cuttings, or events like fire, the number of youth coming from root suckers could range between 10,000 and 100,000 per hectare.

Thicket stage: Pre-commercial thinning interventions during the thicket stage are crucial for the future of European aspen stands. Particularly in uniformly aged, single-storied pure European aspen stands, having extensive areas subject to pre-commercial thinning interventions is crucial based on management objectives. Natural pruning and stem dissociation occur rapidly in aspen stands with high light requirements. There is no completed study on pre-commercial thinning in European aspen stands in Türkiye. However, within the scope of the "Effects of Thinning Interventions on the Development of European Aspen (*Populus tremula* L.) Stands (Erciyes Example)" project initiated in 2023 under the Central Anatolia Forestry Research Directorate, the silvicultural interventions that should be applied to European aspen stands are examined. In a study investigating the silviculture of Kayseri-Erciyes European aspen stands (Turna & Atar, 2022), it was determined that in stands at the thicket stage, diameter values ranged from 2.80 cm to 12.30 cm, with an average diameter of 7.42 cm, and the number of live trees per hectare was 7500. The number of standing dead individuals (45%) was reported at 6150 per hectare.

In stands intended for paper production, a density of 1100 individuals per hectare is considered adequate for growth, production, and quality. However, for high-quality log production, more intense interventions (550 individuals/ha) through pre-commercial thinning are recommended. For bioenergy production facilities, it is stated that no thinning interventions are necessary (6000 individuals per hectare) or only light thinning interventions with a count of 3000 individuals/ha are sufficient (Ha, 2018). Therefore, the intensity of interventions in European aspen stands subject to pre-commercial thinning varies according to the management objectives. Measurements conducted in European aspen stands by the Gümüşhane Forest Management Directorate revealed an average of 15,000 individuals per hectare and an average height of 5 meters during the thicket stage. This indicates severe natural pruning and stem dissociation in European aspen stands in full crown closure. A before-and-after comparison of a pure European aspen stand subject to pre-commercial thinning conducted by the Sivas Forest Management Directorate in 2007 is presented in Figure 7. It was determined that silvicultural interventions were carried out under the guise of rehabilitation.

Figure 7. Before and after pre-commercial thinning intervention in a pure European aspen stand.

Sapling, Pole and Wood Stage: Thinning interventions are carried out as part of tending works during the young, mature, and over-mature development stages. In the Erciyes region under the Kayseri Forest Management Directorate, initial thinning interventions in European aspen stands commenced in 2020 and 2021, while in the Develi region, they began in 2020. The total timber volumes obtained from these initial thinning interventions were determined. Accordingly, within the scope of the thinning interventions in Erciyes, 2505 m^3 was harvested from 29.1 hectares in 2020, and in 2021, 3194 m^3 was obtained from a 51.1-hectare area. In Develi, a total of 4482 stere of wood chips were obtained, equivalent to an average of 42 m^3 per hectare (Turna & Atar, 2022). Jones and Shepperd (1985) indicated in their study that if a stand is to be thinned once, it is advisable to wait until dominant individuals reach a height of 8 m and a diameter of 5-8 cm. They suggested thinning to leave 1730 individuals per hectare with a spacing of 2.5 × 2.5 m. Additionally, they recommended thinning at a spacing of 4.6 × 4.6 m when dominant and codominant individuals reach a height of 11 meters, aiming for 494 individuals per hectare. On the other hand, Börset (1976) generally suggested that thinning should commence when the crown of the top tree exceeds 40-50% of the tree height in European aspen. They advocated for thinning to occur only 2-3 times, with an initial thinning leaving 700-1000 individuals per hectare, a second thinning when the trees reach 16-17 m in height, resulting in 350-700 individuals, and a third thinning when the average height is 20-23 m, with 350-400 individuals per hectare.

Thinning interventions related to European aspen are performed in line with the demands of the industry, aiming for well-formed materials for short-term management, including quality pole and timber production for telegraph poles and mine props. For industries such as paper and oriented strand board, where the evaluation of thin material is essential, the focus lies more on volume than wood quality. Therefore, silvicultural interventions aimed at maximizing production within short rotation age are preferred over thinning practices (Hamilton, 1976).

4. Conclusion

Rather than solely considering the European aspen species as a pioneer species and therefore not envisioning any silvicultural intervention, it would be more appropriate to reconsider the functions attributed to this species, taking into account its significant spatial expansion and the increasing prevalence of pure stands in Türkiye. Reassessing the functions attributed to the species and determining the most suitable functions would be pertinent. In line with the determined function and management objectives, silvicultural interventions related to the species must be implemented without interruption.

The biological, ecological, and socio-cultural characteristics of the species should be thoroughly analyzed alongside silvicultural techniques, and appropriate interventions should be implemented accordingly. Particularly in pure stands, tending works will not only enhance the resilience of existing European aspen forests against biotic and abiotic stressors but will also ensure more productive and sustainable forests through interventions favoring superior-quality individuals.

In mixed stands where European aspen is part of the mix, delicate management is necessary to ensure both the continuity of climax species and the preservation of biodiversity. It would be better to choose interventions against European aspen in such stands. However, if creating gaps within the stand, leaving European aspen individuals in the area is advised, while individuals located at the edges of the forest stand and within streamside vegetation should not be removed from the area.

In summary, it is essential to redefine management objective for same-aged pure and mixed European aspen forests based on both succession stages and growing conditions, ensuring timely interventions in line with silvicultural needs. It is a known fact in terms of forestry techniques that protective and moderate interventions are different in ecological function areas compared to production function areas, varying based on

research outcomes. European aspen forests play crucial roles within the ecosystem. Therefore, abandoned or potentially inhabitable areas, initially populated and then improving within the habitat conditions, should be ecologically planned and managed to serve various functions.

Managing European aspen forests in line with the requirements of silviculture according to their developmental stages is necessary for ensuring sustainability. Identifying superior stands for improvement efforts, conducting genetic conservation, and establishing seed orchards are essential in the context of breeding programs and conserving genetic resources.

In mixed forests, interventions favoring the dominant species are recommended until research outcomes are obtained. Specifically, in European aspen stands mixed with pine, interventions against European aspen should be conducted.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

Atalay, İ. (2019). *Titrek kavak topluluklarını ekolojik özellikleri ile tohum transferi ve ağaçlandırma açısından bölgelere ayrılması*. Kavak ve Hızlı Gelişen Orman Ağaçları Araştırma Enstitüsü Müdürlüğü. (In Turkish)

Atalay, İ., Kozan, H., Altunbaş, S., & Tamyüksel, H. (2021). *Erciyes dağı ve Sivas dolayında Titrek kavağı (Populus tremula l.) yetiştirme ve geliştirme olanakları*. Kayseri Orman Bölge Müdürlüğü, Başak Matbaacılık. (In Turkish)

Bilgili, F. (2007). *Titrek kavak (Populus tremula L.) meşcereleri için normal hasılat tablosu* (Master's thesis, Karadeniz Technical University). (In Turkish)

Börset, O. (1976). *Birch, aspen and alder; A guide to practical forestry*. Nor. Landbrukshogsk.

Börset, O. (1985). *Bjørk osp or - Veiledning for det praktiske skogbruk*. Institutt for skogskjøtsel, Norges lantbrukshøgskole. (In Norwegian)

Boydak, M., & Çalışkan, S. (2014). *Ağaçlandırma*. OGEM-VAK Yayınları. (In Turkish)

Crouch, G. L. (1981). *Regeneration on aspen clearcuts in northwestern Colorado*. United States Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. https://core.ac.uk/download/pdf/19687352.pdf

Dinca, L., & Vechiu, E. (2020). The aspen (*Populus tremula* L.) from the southern Carpathians. *Current Trends in Natural Sciences*, *9*(17), 168-174. https://doi.org/10.47068/ctns.2020.v9i17.020

Gifford, G. F. (1966). Aspen root studies on three sites in northern Utah. *American Midland Naturalist*, *75*(1), 132-141. https://doi.org/10.2307/2423485

Ha, T. N. (2018). *Effects of thinning on growth and development of second poplar generations* (Master thesis, Swedish University).

Hamilton, G. J. (1976). Effects of line thinning on increment, aspects of thinning. *Forestry Commission Bulletin*, *55*, 1-138.

Jobling, J. (1990). Poplars for wood production and amenity. *Forest Commission Bulletin*, *92*, 1-84.

Jones, J. R., & Shepperd, W. D. (1985). Intermediate treatments. In N. V. DeByle & R. P. Winokur (Eds.), *Aspen: Ecology and management in the western United States* (pp. 209-216). United States Department of Agriculture Forest Service, Rocky Mountain Forest and Range Experiment Station.

Kayacık, H. (1981). *Orman ve park ağaçları özel sistematiği Angiospermae (kapalı tohumlular) II. cilt*. Kutulmuş Matbaası. (In Turkish)

Krasny, M., & Johnson, E. (1992). Stand development in aspen clones. *Canadian Journal of Forest Research*, *22*(9), 1424-1429. https://doi.org/10.1139/x92-190

Latva-Karjanmaa, T., Suvanto, L., Leinonen, K., & Rita, H. (2003). Emergence and survival of *Populus tremula* seedlings under varying moisture conditions. *Canadian Journal of Forest Research*, *33*(11), 2081-2088. https://doi.org/10.1139/x03-129

Meier, E. S., Lischke, H., Schmatz, D. R., & Zimmermann, N. E. (2012). Climate, competition and connectivity affect future migration and ranges of European trees. *Global Ecology and Biogeography*, *21*(2), 164-178. https://doi.org/10.1111/j.1466-8238.2011.00669.x

Özel, H. B. Ayan, S., Erpay, S., & Simovski, B. (2018). The new natural distribution area of aspen (*Populus tremula* L.) marginal populations in Pasinler in the Erzurum province, Türkiye, and its Stand Characteristics. *South-east European Forestry*, *9*(2), 131-139. https://doi.org/10.15177/seefor.18-15

Perala, D. A., Leary, R. A., & Cieszewski, C. J. (1999). *Self-thinning and stockability of the circumboreal aspens (Populus tremuloides Michx., and P. tremula L.)*. United States Department of Agriculture Forest Service.

Saatçioğlu, F. (1976). *Silvikültür I / silvikültürün biyolojik esasları ve prensipleri*. İstanbul Üniversitesi Orman Fakültesi Yayın Evi. (In Turkish)

Turna, İ., & Atar, F. (2019). *Silvicultural evaluation of European aspen (Populus tremula L.) forests in Erciyes mountain*. III. International Mediterranean Forest and Environment Symposium. Kahramanmaraş.

Turna, İ., Öncül, Ö., Öksüz, S., & Uğurlu, Ç. (2021). Erzurum horasan yöresi titrek kavak (*Populus Tremula* L.) ormanlarının silvikültürü. IV. Ulusal Karadeniz Ormancılık Kongresi. Trabzon. (In Turkish)

Turna, İ., & Atar, F. (2022). Titrek kavak (*Populus tremula* L.) meşcerelerinin ekolojik ve silvikültürel açıdan irdelenmesi: Erciyes Dağı örneği. *Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi*, *23*(2), 37-49. https://doi.org/10.17474/artvinofd.1102566 (In Turkish)

Velioğlu, E., Bostancı, Y. S., & Akgül, S. (2020). poplars and other fast-growing trees in türkiye: country progress report for the international poplar commission. General Directorate of Forestry, Poplar and Fast Growing Forest Trees Research Institute.

Velioğlu, E., Güney, Ş. T., Karakurt, H., Taştan, Y., Yavuz, Z., & Tuğrul, D. (2023). Relationships between site index and ecological variables of trembling poplar forests (*Populus tremula* L.) in Türkiye. *Environmental Monitoring and Assessment*, *195*, 308. https://doi.org/10.1007/s10661-023-10933-3

Worrell, R. (1995). European aspen (*Populus tremula* L.): A review with particular reference to Scotland II. Values, silviculture and utilization. *Forestry: An International Journal of Forest Research*, *68*(3), 231-244. https://doi.org/10.1093/forestry/68.3.231

Yaltırık, F. (1993). *Dendroloji ders kitabı 2 Angiospermae (kapalı tohumlular) bölüm 1*. İstanbul Üniversitesi Orman Fakültesi Yayın Evi. (In Turkish)