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Original Article

Influence of Thinning on the Stem Shape of Narrow-Leaved Ash (*Fraxinus angustifolia* Vahl.) Trees

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ABSTRACT

Narrow-leaved ash (*Fraxinus angustifolia* Vahl.) with its capacity for fast growth is a valuable wood crop. In 2005, a trial of thinning was established out in a narrow-leaved ash plantation in Sakarya, Turkey, and three different intensities were applied: strong (28% of basal area removed), moderate (19% of basal area removed), and unthinned. The 7-year effect of thinning intensity on the stem shape of narrow-leaved ash trees was evaluated in the present study. A total of 25 sample trees representing the quadratic mean diameter of the stand (T_{QMD}) and the 100 largest trees per hectare (T_{100}) were taken for cross-sectional analysis. Results showed that the 7 years breast-height diameter ($d_{1.30}$) increments of sampled trees were increased with increasing thinning intensity, and thinning intensity had no effect on height increments of the trees. The 7-year $d_{1.30}$ increment of the T_{100} was greater than that of the T_{QMD} trees. Over 7 years, the numerical definition of stem shape was not affected by the thinning intensity. However, the stem shape was improved with increasing stem diameter/age, especially in the T_{100}. In conclusion, the NLA T_{100} trees, as a result of thinning, did not develop conically but rather became more cylindrical with an increase in diameter and age; therefore, it can be recommended that in future, heavy thinning treatments can be applied in narrow-leaved ash plantations.

Keywords: Fraxinus angustifolia, stem form, thinning, Turkey

Introduction

Stem taper (slenderness) and stem form can be very important when evaluating stem shape (Snowdon et al., 1981). It defines the ratio of the total tree height to the diameter at breast height as the slenderness coefficient (Wang et al., 1998). Taper equations or form quotients are often used to describe the stem form (Karlsson, 2000). A correct understanding of the change in the shape of the stem is very important for more accurate estimation of stem volume (Muhairwe, 1994) and for efficient use of logs obtained from the stem for timber production (Tong & Zhang, 2008). Variation in the shape of the stem gradually develops as a result of the change in diameter along the stem and the development of the tree height (Muhairwe, 1994).

Because many environmental factors and silvicultural practices may change stem shape (Gray, 1956; Larson, 1963; Yen, 2015), much research has been focused on the positive influence of thinning and its effect on stem shape and growth. Stem shape also impacts timber quality (Macdonald & Hubert, 2002; Mäkinen & Isomäki, 2004a; Tong & Zhang, 2008), vulnerability to snow and wind damage (Mitchell, 2000; Valinger & Pettersson, 1996), and accuracy of stand volume estimations (Brooks et al., 2008; Muhairwe, 1999; Sakici et al., 2008).

It is thought that as trees continue to grow, they develop full-sized stems (Kalıpsız, 1998). However, when a large number of shade-intolerant trees are grown in stands, their weak stems with small diameter can be bent or broken as a result of mechanical events such as wind and snow. Furthermore, Smith et al. (1997) have indicated that dominant trees form a stronger and more conical body, while the bodies of suppressed trees take a weaker cylindrical form.

Many researchers have supported the theory that growth resources are allocated to the lower part of the stem (Karlsson, 2000; Larson, 1963; Myers, 1963). In general, it can be said that this theory is based on studies of conifer species, while there is no clear consensus on the influence of thinning on stem shape. As a matter of fact, several studies have found that the effect of thinning on stem shape was not significant (Hilt & Dale, 1979;

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Pérez & Kanninen, 2005). Moreover, some studies have found that the stem shape was cylindrical (Eler, 1988; Eler & Keskin, 1991; Morris et al., 1994), while other studies have found that the stem shape was tapered (Adegbeihn, 1982; Weiskittel et al., 2009).

Narrow-leaved ash (NLA) is gaining importance in European forestry due to its rapid growth and valuable wood (Çiçek et al., 2013). The species are growing naturally in the Balkans, the Caucasus, southern Europe, and Iran (Boshier et al., 2005; Klossas et al., 2012). It is also distributed in scattered or small groups in riparian sites and mountainous areas (Boshier et al., 2005; Davis, 1987). Although the natural habitats of this species are mostly confined to bottomlands regarded as marginal for plant growth, its stands are highly productive, with a mean annual increment approaching 15 and 25 m^3 ha^{-1} in natural stands and plantations in Turkey, respectively (Kapucu et al., 1999). In the past years, the mean stand diameter remained low due to inadequate thinning practices in the plantations, but in recent years, the frequency and intensity of thinning have begun to increase to a desirable level because it increases the need for large diameter (50–60 cm) and high-quality NLA timber in the Turkey market for the production of wood veneer and paneling. Thus, an analysis of thinning effects on NLA stem shape is especially important for forest managers, owners, and the Turkish wood industry.

Because there is limited information about silvicultural treatments, thinning trials were founded at the NLA plantation in 2005, and the 6-year tree diameter, height, and volume growth results were published (Çiçek et al., 2013). In that study, however, the effects of the thinning intensity on the stem shape of NLA, which is important for forest managers, owners, and the industry, were not discussed. The aim of the present study was to determine the 7-year effects of the thinning on the NLA stem shape and to compare separately the evolution of shape of the dominant and intermediate trees in a plantation in the Sakarya (Adapazarı) region of Turkey.

Methods

Study Site

This study was held in the Sakarya region (40º 45' N, 30º 35' E, 25 m) which covers nearly half of the NLA distribution in Turkey. While this field was a natural NLA field, it was cut down in 1984 and 1-year old NLA seedlings were planted at 3.7 × 3.7 m initial spacing in the same year. When the plantation was 22 years old, a thinning experiment was established according to the randomized complete block design with three blocks. Before thinning, the number of stem was 544 trees ha^{-1} and the basal area of the stands was 24.42 m^2 ha^{-1} on the plantation. Selective low thinning was applied by removing 0% (control), 18.9% (moderate), and 28.2% (heavy) of the initial basal area from October to November 2005. After thinning, the crowns of the residual trees were completely free in the heavy treatment plots, and a majority were free in the moderate treatment plots. The study areas were designated by experimental units of 63 × 63 m (0.397 ha) in which the plots, measuring 33 × 33 m (0.109 ha), were centered (Çiçek et al., 2013).

The soil of the study site is heavily textured, the Ah horizon is rather thin due to rapid decomposition, and the soil pH ranges from 7.0 to 7.8. The drainage of the site, which is located in the bottomland and has alluvial soil, is very low. Depending on the distribution of precipitation, the groundwater level can rise above the surface between February and April. According to the closest Meteorological Station of Adapazarı (40˚ 46' N, 30º 23' E, 30 m), the mean annual temperature is 14.3°C and annual precipitation is 846 mm. Approximately half of the annual precipitation falls between April and October. Summer drought can occur in the site between July and October (Çiçek et al., 2010).

Data Collection

In December 2012, 7 years after thinning, the $d_{1.30}$ and heights of all the trees in the thinning experiment were measured. Three trees, two trees representing the quadratic mean diameter (T_{QMD}) class and one tree representing the 100 largest trees per hectare (T_{100}) class, were identified in each plot. The T_{100} was designated as the final crop trees. The selected trees were marked on the north orientation and they were felled. The branches on the stem were removed and then samples of stem sections with a thickness of about 5 cm were taken from different section heights (0.30 m, 1.30 m, 3.30 m, 5.30 m, 7.30 m, ...21.30 m). The stem section samples were transferred to the laboratory for stem analysis. The ring widths of the last 7 years were measured in all samples by cross-sectioning in north-south and east-west directions (Kalıpsız, 1999).

The bark thickness of the trees before thinning was estimated by determining the tree diameter (*d,* cm) and double-bark thickness (*b,* mm) relationship of the felled-year samples ($R^2 = 0.738$; Eq. 1).

$$b = 0.0012d^2 + 0.3456d + 1.2375 \quad (1)$$

The 7-year $d_{1.30}$ and height increments were calculated as the difference between the value after thinning (in 2005) and the 7-year after thinning (in 2012) value. In addition, the slenderness index, stem fullness coefficient, and natural and breast-height form factors were determined using the formulae shown in Table 1.

Statistical Analyses

Variance analysis (ANOVA) was applied to determine the response of the $d_{1.30}$ and height increments, slenderness index, stem fullness, natural form factor, and breast-height form factor of the NLA trees to the thinning intensity ($p < .05$). Prior to the ANOVA, the normality distribution for all variables was tested and controlled. Where significant differences occurred, paired comparisons among treatments were determined

Table 1.
Equations Used to Define Stem Shape Parameters (Assmann, 1970; Kalıpsız, 1999)

Stem Shape Parameters	Equations
Slenderness index	$H/D = \frac{h}{d_{1.3}}$
Stem fullness	$q = \frac{d_1}{d_{1.3}}; \frac{d_3}{d_{1.3}}; ...; \frac{d_n}{d_{1.3}}$
Natural form factor	$f_{0.1} = \frac{V}{\frac{\pi}{4} x (d_{0.1h})^2 xh}$
Breast-height form factor	$f_{1.3} = \frac{V}{\frac{\pi}{4} x (d_{1.3})^2 xh}$

where *h* is tree height (m), $d_{1.3}$ is diameter at breast height (cm), $d_{0.1h}$ is diameter at 1/10 tree height (cm), *l* is the distance from breast height (m), *V* is the real volume of every tree (m^3), d_1, d_2, d_3… are tree diameters (cm) at 0.30, 1.30, 3.30 m… of tree total height.

Table 2.
Effect of Thinning on $d_{1.30}$ and Height and Their Increments in the T_{QMD} and T_{100}

Tree Social Classes	Treatment	$d_{1.30}$ 2005, cm	$d_{1.30}$ 2012, cm	$d_{1.30}$ Increment, cm	Height 2005, m	Height 2012, m	Height Increment, m
T_{QMD}	Control	22.8 (1.2)[a]	26.4 (1.0)[a]	3.6 (0.4)[a]	22.55 (2.03)[a]	26.99 (1.82)[a]	4.44 (0.49)[a]
	Moderate	24.2 (0.5)[a]	29.4 (0.7)[b]	5.2 (0.5)[b]	23.22 (0.98)[a]	27.57 (0.97)[a]	4.35 (0.40)[a]
	Heavy	24.2 (1.4)[a]	29.8 (1.6)[b]	5.6 (0.5)[b]	22.52 (0.55)[a]	27.02 (0.70)[a]	4.50 (1.01)[a]
	p	.1985	.049	.0072	.779	.772	.876
T_{100}	Control	28.2 (2.1)[a]	34.4 (2.5)[b]	6.1 (0.6)[a]	24.97 (1.05)[a]	28.80 (0.61)[a]	3.84 (0.51)[a]
	Moderate	26.7 (1.6)[a]	32.4 (1.6)[a]	5.7 (0.1)[a]	23.80 (0.44)[a]	27.54 (0.69)[a]	3.74 (0.46)[a]
	Heavy	28.6 (1.0)[a]	35.5 (1.6)[b]	6.9 (1.0)[b]	23.90 (0.10)[a]	27.27 (1.06)[a]	3.37 (1.03)[a]
	p	.053	.006	.048	.077	.053	.759

Note: Within each experiment, means followed by a different letter in the column are significantly different ($p < .05$); standard deviation in parentheses. $d_{1.30}$ = diameter at breast height; T_{QMD} = trees of quadratic mean diameter; T_{100} = 100 largest trees per hectare.

using Duncan's new multiple range test ($p < .05$). Statistical Package for the Social Sciences (SPSS) packet software (International Business Machines SPSS 22.0 Inc.) was used for statistical analysis of data.

Results

Increments in $d_{1.30}$ and Height

After thinning, the mean residual $d_{1.30}$ values of T_{100} and T_{QMD} were 23.6 cm and 27.0 cm, respectively. Thinning significantly affected the $d_{1.30}$ in 2012. The $d_{1.30}$ increment of the T_{QMD} in the thinned plots was 43% greater than in the control plots. The $d_{1.30}$ increment of the T_{100} in the heavy thinning plot was 20% greater than in the other treatment plots. In addition, thinning had no effect on the residual height in 2005, the height in 2012, or the height increments ($p > .05$; Table 2).

Slenderness Index

The slenderness indices of trees in both social classes in 2005 were similar ($p > .05$). Seven years after thinning, there was no significant difference in the slenderness index of T_{QMD} according to treatment intensity ($p > .05$), whereas the slenderness index of T_{100} in the heavy treatment plots was 10% lower than with the other two treatments ($p < .05$; Table 3).

Table 3.
Thinning Effects on Slenderness Index of Quadratic Mean Diameter Trees (T_{QMD}) and 100 Largest Trees Per Hectare (T_{100})

Tree Social Class	Treatment	Slenderness Index (H/D) 2005	Slenderness Index (H/D) 2012	Average Change
T_{QMD}	Control	.99 (.11)[a]	1.05 (.09)[a]	.05 (.04)[a]
	Moderate	.96 (.09)[a]	.93 (.09)[a]	−.03 (.01)[a]
	Heavy	.95 (.04)[a]	.93 (.04)[a]	−.03 (.03)[a]
	p	.6778	.0868	.0578
T_{100}	Control	.91 (.04)[a]	.86 (.05)[b]	−.05 (.03)[a]
	Moderate	.93 (.06)[a]	.89 (.03)[b]	−.04 (.04)[a]
	Heavy	.86 (.03)[a]	.79 (.02)[a]	−.07 (.04)[a]
	p	.1165	.027	.4467

Note: Within each experiment, means followed by a different letter in the column are significantly different ($p < .05$); standard deviation in parentheses.

The effect of thinning on the average 7-year change in the slenderness index was insignificant for both tree social classes ($p > .05$), whereas the change in the slenderness index between 2005 and 2012 was positive for T_{QMD} and negative for T_{100} (Table 3).

Stem Fullness

The effect of thinning on the stem fullness at different cross-section heights for both social classes in 2005 and 2012 was found to be similar ($p > .05$; Table 4). Moreover, no significant effect of thinning intensity on the average change of stem fullness was observed in the trees of either social class.

The average stem fullness over the years showed an increase as the cross-sectional height increased, especially after 15 m, at the beginning of the branching. The mean stem fullness of the trees increased in both social classes, with the improvement of T_{100} being 60% greater than that of T_{QDM}.

Natural and Breast-Height Form Factors

In 2005, after thinning, neither the natural or breast-height form factors of T_{QMD} nor those of T_{100} showed any significant differences according to treatments ($p > .05$). Seven years after thinning, neither form factor of T_{QMD} differed between the treatments ($p > .05$), while those of T_{100} were significantly different ($p < .05$). The natural form factor was statistically similar in the thinned plots and 15% higher than in the control plot. Additionally, the breast-height form factor of T_{100} was similar in the control and the heavily thinned plots but lower in the moderately thinned plot (Table 5).

Thinning had no effect on the 7-year average change in form ($p > .05$), and while the natural form factor of T_{QMD} increased with increasing age, the breast-height form factor decreased. In contrast, both form factors of T_{100} increased with age.

Discussion

The highest $d_{1.30}$ increase in response to thinning intensity in the NLA plantation was in the thinned plots for T_{QMD} and in the heavily thinned plots for T_{100}. This positive effect of thinning on diameter increment can be explained by the increase in the light, water, and nutrients used by the remaining trees on the thinned plots (Çiçek et al., 2013; Özbayram, 2019). Özbayram (2019) evaluated the detailed information on the effect of thinning on the 7-year $d_{1.30}$ increment. On the other hand, the

Table 4.
Thinning Effects on Stem Fullness of Quadratic Mean Diameter Trees (T_{QMD}) and 100 Largest Trees Per Hectare (T_{100})

		Stem Fullness of T_{QMD}			Stem Fullness of T_{100}		
Cross-Section Height	Treatment	2005	2012	Average Change	2005	2012	Average Change
3.30	Control	.85 (.04)[a]	.86 (.05)[a]	.01 (.05)[a]	.83 (.04)[a]	.86 (.03)[a]	.04 (.03)[a]
	Moderate	.91 (.03)[a]	.84 (.03)[a]	−.08 (.01)[a]	.91 (.06)[a]	.91 (.03)[a]	−.01 (.04)[a]
	Heavy	.87 (.06)[a]	.81 (.11)[a]	−.06 (.16)[a]	.81 (.06)[a]	.81 (.07)[a]	−.01 (.03)[a]
	p	.257	.809	.628	.126	.081	.351
5.30	Control	.76 (.05)[a]	.82 (.03)[a]	.06 (.02)[a]	.71 (.06)[a]	.73 (.07)[a]	.02 (.03)[a]
	Moderate	.76 (.07)[a]	.78 (.04)[a]	.02 (.03)[a]	.85 (.04)[a]	.86 (.06)[a]	.02 (.03)[a]
	Heavy	.80 (.08)[a]	.73 (.1)[a]	−.07 (.14)[a]	.79 (.08)[a]	.81 (.06)[a]	.02 (.03)[a]
	p	.308	.417	.173	.115	.095	.990
7.30	Control	.70 (.04)[a]	.74 (.05)[a]	.04 (.01)[a]	.69 (.08)[a]	.72 (.05)[a]	.03 (.05)[a]
	Moderate	.74 (.06)[a]	.74 (.06)[a]	.01 (.05)[a]	.77 (.03)[a]	.78 (.01)[a]	.02 (.02)[a]
	Heavy	.73 (.02)[a]	.70 (.11)[a]	−.03 (.12)[a]	.69 (.05)[a]	.72 (.03)[a]	.04 (.05)[a]
	p	.615	.782	.596	.290	.169	.811
9.30	Control	.64 (.06)[a]	.70 (.05)[a]	.06 (.04)[a]	.56 (.03)[a]	.65 (.04)[ab]	.10 (.06)[a]
	Moderate	.68 (.04)[a]	.71 (.04)[a]	.04 (.04)[a]	.69 (.08)[b]	.73 (.06)[b]	.04 (.03)[a]
	Heavy	.68 (.01)[a]	.68 (.11)[a]	.01 (.11)[a]	.62 (.04)[ab]	.68 (.04)[ab]	.06 (.02)[a]
	p	.477	.922	.644	.018	.124	.252
11.30	Control	.54 (.08)[a]	.63 (.06)[a]	.10 (.05)[a]	.57 (.04)[a]	.64 (.02)[a]	.07 (.05)[a]
	Moderate	.63 (.03)[a]	.67 (.03)[a]	.05 (.03)[a]	.61 (.04)[a]	.68 (.04)[a]	.07 (.01)[a]
	Heavy	.59 (.07)[a]	.60 (.07)[a]	.02 (.12)[a]	.54 (.06)[a]	.61 (.05)[a]	.08 (.02)[a]
	p	.253	.410	.440	.112	.029	.917
13.30	Control	.43 (.08)[a]	.56 (.06)[a]	.14 (.07)[a]	.53 (.08)[a]	.61 (.04)[a]	.09 (.05)[a]
	Moderate	.52 (.03)[a]	.59 (.03)[a]	.08 (.01)[a]	.55 (.05)[a]	.64 (.04)[a]	.09 (.02)[a]
	Heavy	.51 (.08)[a]	.55 (.05)[a]	.04 (.11)[a]	.50 (.06)[a]	.57 (.05)[a]	.08 (.03)[a]
	p	.121	.578	.324	.661	.107	.872
15.30	Control	.35 (.11)[a]	.48 (.07)[a]	.14 (.05)[a]	.4 (.07)[a]	.53 (.01)[a]	.13 (.07)[a]
	Moderate	.43 (.05)[a]	.54 (.02)[a]	.11 (.04)[a]	.42 (.07)[a]	.57 (.08)[a]	.15 (.09)[a]
	Heavy	.43 (.09)[a]	.50 (.05)[a]	.08 (.11)[a]	.4 (.03)[a]	.52 (.04)[a]	.12 (.05)[a]
	p	.442	.465	.616	.790	.502	.929
17.30	Control	.29 (.11)[a]	.45 (.07)[a]	.17 (.04)[a]	.28 (.07)[a]	.46 (.04)[a]	.18 (.07)[a]
	Moderate	.32 (.06)[a]	.48 (.05)[a]	.16 (.03)[a]	.33 (.15)[a]	.50 (.08)[a]	.17 (.08)[a]
	Heavy	.27 (.05)[a]	.43 (.05)[a]	.16 (.07)[a]	.34 (.06)[a]	.47 (.05)[a]	.13 (.03)[a]
	p	.543	.660	.898	.772	.705	.595
19.30	Control	.15 (.1)[a]	.35 (.1)[a]	.20 (.02)[a]	.18 (.05)[a]	.34 (.03)[a]	.16 (.06)[a]
	Moderate	.20 (.05)[a]	.35 (.05)[a]	.15 (.04)[a]	.22 (.07)[a]	.41 (.03)[a]	.19 (.06)[a]
	Heavy	.15 (.04)[a]	.31 (.05)[a]	.17 (.08)[a]	.24 (.03)[a]	.39 (.07)[a]	.15 (.06)[a]
	p	.294	.756	.559	.102	.117	.543
21.30	Control	.18 (.03)[a]	.30 (.11)[a]	.16 (.08)[a]	.14 (.07)[a]	.28 (.04)[a]	.14 (.06)[a]
	Moderate	.10 (.02)[a]	.24 (.04)[a]	.14 (.05)[a]	.09 (.04)[a]	.27 (.02)[a]	.18 (.03)[a]
	Heavy	.06 (.03)[a]	.21 (.05)[a]	.15 (.04)[a]	.10 (.03)[a]	.26 (.1)[a]	.17 (.09)[a]
	p	.032	.404	.940	.226	.941	.809
Mean		.64 (.39)	.69 (.32)	.05 (.12)	.63 (.36)	.70 (.3)	.08 (.08)

Note: Within each experiment, means followed by a different letter in a column are significantly different ($p < .05$); standard deviations are in parentheses.

Table 5.
Thinning Effects on Natural and Breast-Height Form Factors of Quadratic Mean Diameter Trees (T_{QMD}) and 100 Largest Trees Per Hectare (T_{100})

Social Tree Class	Treatment	Natural Form Factor 2005	Natural Form Factor 2012	Average Change in Form	Breast-Height Form Factor 2005	Breast-Height Form Factor 2012	Average Change in Form
T_{QMD}	Control	.345 (.09)[a]	.408 (.08)[a]	.063 (.03)[a]	.357 (.09)[a]	.343 (.09)[a]	−.015 (.01)[a]
	Moderate	.401 (.04)[a]	.467 (.03)[a]	.066 (.04)[a]	.429 (.04)[a]	.407 (.04)[a]	−.023 (.04)[a]
	Heavy	.419 (.02)[a]	.511 (.05)[a]	.092 (.03)[a]	.441 (.04)[a]	.424 (.03)[a]	−.018 (.04)[a]
	p	.326	.1987	.5220	.0993	.2269	.9495
T_{100}	Control	.394 (.02)[a]	.427 (.04)[a]	.034 (.05)[a]	.365 (.01)[a]	.371 (.03)[a]	.006 (.02)[a]
	Moderate	.416 (.03)[a]	.504 (.05) b	.089 (.05)[a]	.440 (.05)[a]	.444 (.05)[b]	.004 (.02)[a]
	Heavy	.417 (.04)[a]	.475 (.04) b	.059 (.01)[a]	.381 (.05)[a]	.386 (.04)[a]	.006 (.02)[a]
	p	.5813	.1987	.1291	.0520	.0285	.7712

Note: Within each experiment, means followed by a different letter in a column are significantly different ($p < .05$); standard deviation is in parentheses. T_{QMD} = trees of quadratic mean diameter; T_{100} = 100 largest trees per hectare.

pre-thinning and 7-year post-thinning height increments of T_{QMD} and T_{100} were not affected by thinning intensity (Table 2). Similar results have been found, where thinning intensity did not affect height growth in various broadleaved species (Çiçek et al., 2013; Graham, 1998; Medhurst et al., 2001; Özbayram & Çiçek, 2018; Rytter & Werner, 2007).

The effect of thinning on the $d_{1.30}$ and height of the trees can affect the change of the stem shape differently. The slenderness index (H/D) is an important indicator of the stem shape, especially for the base of the stem (Muhairwe, 1999). In the present study, the thinning intensity did not have a significant effect on the change of the slenderness index. However, contrary to the results found in this study, many studies have reported that thinning decreases the slenderness index (Mäkinen & Isomäki, 2004a, 2004b; Weiskittel et al., 2009). The tree slenderness index has been positively correlated with the stand density level, species composition, and site index (Wang et al., 1998). Rytter (2013) reported that in a mixed forest consisting of five broadleaved species (*Betula pendula, B. pubescens, Populus tremula, Alnus glutinosa, and Tilia cordata*), the slenderness index of *Populus tremula* was the least affected by thinning.

On the other hand, there was a decrease in the slenderness index between the years 2005 and 2012. The slenderness index has been negatively correlated with tree age (Nykänen et al., 1997; Pérez & Kanninen, 2005; Wang et al., 1998). This reduction was more pronounced for T_{100} than for T_{QMD}. Mäkinen and Isomäki (2004a) noted that the slenderness index of dominant trees in particular can decrease as the age of the tree increases. The slenderness generally declined over the years, while the T_{QMD} exhibited a positive change in the control plots. This can be attributed to the fact that the control plots had similar height increments compared to the other plots but had lower diameter increases. Lanner (1985) stated that the opposite results in height and diameter growth after thinning could be explained by the development of different competitive abilities by the apical and cambium meristem for available nutrients. Moreover, a slenderness index value of less than 1 is preferred for stem stability against abiotic stresses such as snow and wind (Nykänen et al., 1997; Pérez & Kanninen, 2005). In the current study, all slenderness indices of the trees except for T_{QMD} in the control plots were below 1. In particular, the T_{100} trees showed higher stability than the T_{QMD}. Therefore, no abiotic damage was found in any plots, or, in particular, in the thinned plots.

The effect of the thinning intensity on the stem fullness of T_{100} and T_{QMD} over 7 years was not significant. Studies on *Quercus alba* (Hilt & Dale, 1979) and *Pinus pinea* (Eler, 1988) species have shown that thinning intensity did not affect the fullness. However, there were positive changes in the tree fullness due to an increase in age/diameter. It can be said that the diameter increment at the upper part of the stem was greater than at the lower part because the average change of the stem fullness between measurement years generally increased as the stem section height increased. Some studies on conifer trees have suggested that the diameter increases because after thinning or wide spacing treatments, the lower part of the stem grows relatively faster than the upper part (Deans & Milne, 1999; Karlsson, 2000; Mäkinen & Isomäki, 2004a, 2004b; Muhairwe, 1994; Peltola et al., 2002). In the present study, the stem of NLA trees was seen to become cylindrical with increasing age due to the similar or greater diameter increments that occurred in the upper parts compared with the lower parts.

The natural and breast-height form factors of T_{100} and T_{QMD} did not change depending on thinning intensity. Similarly, it was found that thinning intensity had no effect on the stem form factors of *Quercus alba* (Hilt & Dale, 1979) and *Tectona grandis* (Pérez & Kanninen, 2005) species. The effect of thinning intensity on stem form factors may vary depending on the species, age, and stand density. The breast-height form factors of T_{100} and the natural form factors of both T_{100} and T_{QMD} increased with increasing tree diameter. However, the breast-height form factors of T_{QMD} decreased from 2005 to 2012. Thus, with increasing diameter, the stems of the dominant NLA trees became more cylindrical.

Conclusion and Recommendations

The thinning treatments increased the $d_{1.30}$ of the NLA trees but did not affect the height increment. The 7-year $d_{1.30}$ diameter increment of the T_{100} was greater than that of the T_{QMD} trees. The stem shape (slenderness index, stem fullness, and natural and breast-height form factors) was not significantly affected by thinning; however, it was improved by becoming more cylindrical with increasing stem diameter, especially in T_{100}.

The NLA trees also directed the source distribution for the diameter increment not only to the lower part of the stem but also to the middle and upper parts of the stem. In order to fully understand the effect of thinning on the NLA stem shape, more extensive investigations must be carried out over a longer time because stem shape may vary over short and long periods depending on thinning or age.

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References

- Adegbeihn, J. (1982). Preliminary results of the effects of spacings on the growth and yield of *Tectona grandis* Linn. *Indian Forester*, *108*(6), 423–430.
- Boshier, D., Cordero, J. s., Harris, S., Pannell, J., Rendell, S., Savill, P., … Slobodník, B. (2005). *Ash species in Europe: Biological characteristics and practical guidelines for sustainable use*. Oxford Forestry Institute, University of Oxford.
- Brooks, J. R., Jiang, L., & Ozçelik, R. (2008). Compatible stem volume and taper equations for Brutian pine, Cedar of Lebanon, and Cilicica fir in Turkey. *Forest Ecology and Management*, *256*(1–2), 147–151. [CrossRef]
- Çiçek, E., Yılmaz, F., Özbayram, A. K., Efe, M., Yılmaz, M., & Usta, A. (2013). Effects of thinning intensity on the growth of narrow-leaved ash (*Fraxinus angustifolia* subsp. *oxycarpa*) plantations. *Turkish Journal of Agriculture and Forestry*, *37*, 97–104. [CrossRef]
- Çiçek, E., Yılmaz, M., Yılmaz, F., & Usta, A. (2010). *Effects of thinning on growth and some soil properties in narrow-leaved ash (Fraxinus angustifolia) plantations*. Project Report, TÜBİTAK TOVAG 105O519, Düzce.
- Davis, P. H. (1987). *Flora of Turkey and the east Aegean islands*. Edinburgh University Press.
- Deans, J. D., & Milne, R. (1999). Effects of respacing on young Sitka spruce crops. *Forestry*, *72*(1), 47–58. [CrossRef]
- Eler, Ü. (1988). *Antalya bölgesi doğal kızılçam (Pinus brutia Ten.) meşcerelerinde aralama ve hazırlama kesimlerinin artım ve büyüme yönünden etkileri*. Ormancılık Araştırma Enstitüsü Yayınları.
- Eler, Ü., & Keskin, S. (1991). *Antalya Yöresi Kızılçam (Pinus Brutia Ten.) Ağaçlandırma Alanlarında Geçikmiş İlk Aralamalarda Uygulanacak Silvikültürel Işlemlerin Gelişme Durumu Üzerine Etkileri* (pp. 1–124). Ormancılık Araştırma Enstitüsü Yayınları.
- Graham, J. S. (1998). Thinning increases diameter growth of paper birch in the Susitna Valley, Alaska: 20 year results. *Northern Journal of Applied Forestry*, *15*(3), 113–115. [CrossRef]
- Gray, H. R. (1956). *The form and taper of forest tree stems*. Imperial Forestry Institute, University of Oxford.
- Hilt, D. E., & Dale, M. E. (1979). *Stem form changes in upland oaks after thinning* (pp. 1–7). Forest Service Research Paper Ne-433.
- Kalıpsız, A. (1998). *Orman Hasılat Bilgisi*. İstanbul Üniversitesi Yayın No, 3052(328).
- Kalıpsız, A. (1999). *Dendrometri*. İstanbul Üniversitesi Orman Fakültesi Yayın No: 3194-354.
- Kapucu, F., Yavuz, H., & Gül, A. (1999). Dişbudak Meşcerelerinde Hacım, Bonitet Endeks ve Normal Hasılat Tablosunun Düzenlenmesi. *KTÜ, Fen bilimleri Enstitüsü, Araştırma Fonu Başkanlığı, Sonuç Raporu. Proje Kod No.96.113.001.4*, 46.
- Karlsson, K. (2000). Stem form and taper changes after thinning and nitrogen fertilization in *Picea abies* and *Pinus sylvestris* stands. *Scandinavian Journal of Forest Research*, *15*(6), 621–632. [CrossRef]
- Klossas, G., Kyriazopoulos, A. P., & Koukoura, Z. (2012). Post-planting treatments and shading effects in a *Fraxinus angustifolia* Vahl. silvopastoral system. *Annals of Forest Research*, *56*(1), 179–186.
- Lanner, R. M. (1985). On the insensitivity of height growth to spacing. *Forest Ecology and Management*, *13*(3–4), 143–148. [CrossRef]
- Larson, P. R. (1963). Stem form development of forest trees. *Forest Science*, *9*(suppl_2), a0001–a0042. [CrossRef]
- Macdonald, E., & Hubert, J. (2002). A review of the effects of silviculture on timber quality of Sitka spruce. *Forestry*, *75*(2), 107–138. [CrossRef]
- Mäkinen, H., & Isomäki, A. (2004a). Thinning intensity and long-term changes in increment and stem form of Norway spruce trees. *Forest Ecology and Management*, *201*(2–3), 295–309. [CrossRef]
- Mäkinen, H., & Isomäki, A. (2004b). Thinning intensity and long-term changes in increment and stem form of Scots pine trees. *Forest Ecology and Management*, *203*(1–3), 21–34. [CrossRef]
- Medhurst, J. L., Beadle, C. L., & Neilsen, W. A. (2001). Early-age and later-age thinning affects growth, dominance, and intraspecific competition in *Eucalyptus nitens* plantations. *Canadian Journal of Forest Research*, *31*(2), 187–197. [CrossRef]
- Mitchell, S. J. (2000). Stem growth responses in Douglas-fir and Sitka spruce following thinning: Implications for assessing wind-firmness. *Forest Ecology and Management*, *135*(1–3), 105–114. [CrossRef]
- Morris, D. M., Hills, S. C., & Bowling, C. (1994). Growth and form responses to pre-commercial thinning regimes in aerially seeded jack pine stands: 5th year results. *Forestry Chronicle*, *70*(6), 780–787. [CrossRef]
- Muhairwe, C. K. (1994). Tree form and taper variation over time for interior lodgepole pine. *Canadian Journal of Forest Research*, *24*(9), 1904–1913. [CrossRef]
- Muhairwe, C. K. (1999). Taper equations for *Eucalyptus pilularis* and *Eucalyptus grandis* for the north coast in New South Wales, Australia. *Forest Ecology and Management*, *113*(2–3), 251–269. [CrossRef]
- Myers, C. A. (1963). Vertical distribution of annual increment in thinned ponderosa pine. *Forest Science*, *9*(4), 394–404. [CrossRef]
- Nykänen, M., Broadgate, M., Kellomäki, S., Peltola, H., & Quine, C. (1997). Factors affecting snow damage of trees with particular reference to European conditions. *Silva Fennica*, *31*(2), 193–213. [CrossRef]
- Özbayram, A. K. (2019). Diameter increment distribution along the stem of narrow-leaved ash in response to thinning intensity. *Šumarski List*, *143*(1–2), 45–51. [CrossRef]
- Özbayram, A. K., & Çiçek, E. (2018). Thinning experiments in narrow-leaved ash (*Fraxinus angustifolia* Vahl.) plantations: 10-year results. *New Forests*, *49*(5), 585–598. [CrossRef]
- Peltola, H., Miina, J., Rouvinen, I., & Kellomäki, S. (2002). Effect of early thinning on the diameter growth distribution along the stem of Scots pine. *Silva Fennica*, *36*(4), 813–825. [CrossRef]
- Pérez, D., & Kanninen, M. (2005). Effect of thinning on stem form and wood characteristics of teak (*Tectona grandis*) in a humid tropical site in Costa Rica. *Silva Fennica*, *39*(2), 217–225. [CrossRef]
- Rytter, L. (2013). Growth dynamics of hardwood stands during the precommercial thinning phase – Recovery of retained stems after competition release. *Forest Ecology and Management*, *302*, 264–272. [CrossRef]
- Rytter, L., & Werner, M. (2007). Influence of early thinning in broadleaved stands on development of remaining stems. *Scandinavian Journal of Forest Research*, *22*(3), 198–210. [CrossRef]
- Sakici, O. E., Misir, N., Yavuz, H., & Misir, M. (2008). Stem taper functions for *Abies nordmanniana* subsp. *bornmulleriana* in Turkey. *Scandinavian Journal of Forest Research*, *23*(6), 522–533. [CrossRef]
- Smith, D. M., Larson, B. C., Kelty, M. J., & Ashton, P. M. S. (1997). *The practice of silviculture: Applied forest ecology* (9th ed). Wiley.
- Snowdon, P., Waring, H., & Woollens, R. (1981). *Effect of fertilizer and weed control on stem form and average taper in plantation-grown pines*. Australian Forest Research.
- Tong, Q. J., & Zhang, S. Y. (2008). Stem form variations in the natural stands of major commercial softwoods in eastern Canada. *Forest Ecology and Management*, *256*(6), 1303–1310. [CrossRef]
- Valinger, E., & Pettersson, N. (1996). Wind and snow damage in a thinning and fertilization experiment in *Picea abies* in southern Sweden. *Forestry*, *69*(1), 25–34. [CrossRef]
- Wang, Y., Titus, S. J., & LeMay, V. M. (1998). Relationships between tree slenderness coefficients and tree or stand characteristics for major species in boreal mixedwood forests. *Canadian Journal of Forest Research*, *28*(8), 1171–1183. [CrossRef]
- Weiskittel, A., Kenefic, L. S., Seymour, R. S., & Phillips, L. M. (2009). Long-term effects of precommercial thinning on stem form, volume, and branch characteristics of red spruce and balsam fir crop trees. *Silva Fennica*, *43*(3), 397–409. [CrossRef]
- Yen, T.-M. (2015). Relationships of *Chamaecyparis formosensis* crown shape and parameters with thinning intensity and age. *Annals of Forest Research*, *58*(2), 323–332. [CrossRef]