Response of Pinus nigra subsp. pallasiana to Precommercial Thinning in a Humid Region Under the Oro-Mediterranean Climatic Conditions

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Abstract
Precommercial thinning is the basic management practice in young Anatolian black pine (Pinus nigra Arn. subsp. pallasiana) stands. The aim of this study was to address the lack of knowledge with regard to the impact of the intensity of precommercial thinning on tree growth and stability in Anatolian black pine forest in a humid region under the oro-mediterranean climatic conditions. The field experiment was established in late April 2015 by three precommercial thinning treatments, unthinned control (4941 stems ha−1), 2–2.5 m spacing (PCT 2–2.5 m) = 2133 stems ha−1, and 3–3.5 m spacing (PCT 3–3.5 m) = 1093 stems ha−1, and monitored for three growing seasons. Tree diameter (diameter at breast height), basal area, and crown radius increments showed a positive response to precommercial thinning, especially in the PCT 3–3.5 m plots. The height increment was highest in the unthinned plots. Height:diameter (h/d) ratio of trees grown at the PCT 3–3.5 m plots was lower than the other precommercial thinning treatments. The negative correlation between DBH and h/d ratio was slightly decreased for the PCT 3–3.5 m plots in the 3 years after precommercial thinning. The percentage of trees damaged by snow or wind in the second year of the PCT was not significantly affected by precommercial thinning. Precommercial thinning promotes diameter at breast height and crown growth by reducing competition between neighboring trees for natural resources. In addition, findings indicate that precommercial thinning increased stand stability with increasing diameter against snow/wind damage likely to occur at high altitudes of the oro-mediterranean belt.

Keywords: Diameter increment, height, stand density, stand stability

Introduction
Turkey has a rich plant biodiversity due to its geographic position, topography, and climate. The total area of forest in Turkey is 22.9 million hectares, which consists of pure and mixed forests. Anatolian black pine (Pinus nigra Arn. subsp. pallasiana) is the most important and valuable commercial tree species in Turkey. It has 4.2 million hectares of forest distribution area (OGM, 2020). One of the tending operations is precommercial thinning (PCT). The purpose of the PCT is to provide enough spacing and resources for best trees (Varmola & Salminen, 2004) and to adjust production of the best individuals at an early stage (Fahlvik et al., 2005). Moreover, the arrangement of stand density with PCT affects the properties of individual trees and stand (Varmola & Salminen, 2004). Thinning, that is control of stand density, has been an important tool for raising the growth of individual trees (Mäkinen et al., 2006). Generally, commonly used tree growth parameters are stem diameter and tree height (Sumida et al., 2013). Varmola and Salminen (2004) found that the intensity of PCT had an effect on diameter, and heavy thinning resulted in a greater diameter at breast height (DBH) compared to moderate thinning. In addition, Mäkinen and Isomäki (2004a) signified that diameter increment of the largest trees increased with increasing thinning intensity. Increased growing space had an effect on diameter and volume growth and structural features like crown architecture (Özçelik & Eler 2009; Simard et al., 2004; Sullivan et al., 2006). On the other hand, Huuskonen and Hynynen (2006) defined that intensive PCT speed up the volume growth of the trees, but it can result in considerable yield losses. The future yield is related to the present stand properties (Pettersson, 1993).
The young stands with high density can increase susceptibility to wind and snow damage (Oliver, 1997). This damage can also lead to loss of merchantable timber by increasing the risk of secondary damages from disease and pests in damaged stands. The proportion of trees damaged by snow was affected by thinning in *Pinus sylvestris* L. stands, and the densest stands were damaged the most (Valinger et al., 1994). Precommercial thinning can be an appropriate management practice to avoid major losses from this damage by increasing the resistance to snow and wind (Achim et al., 2005). However, snow damage is also observed especially after too late and heavy early thinning, that is, it is related to the high height:diameter ratios of trees (Zubizarreta-Gerendiain et al., 2012). Height:diameter ratios are frequently used to measure tree and stand stability for conifer (Wonn & Q’Hara, 2001). Greater space is related to diameter growth (Ferguson et al., 2011), rotation age (Morris et al., 1994), wood quality (Fleming et al., 2005), and tree crowns (Varmola & Salminen, 2004). The main aim of this study was to analyze the effect of PCT intensities on growth parameters in Anatolian black pine stand of the oro-mediterranean belt in humid region. Our hypotheses are that (1) although PCT will reduce stand basal area, it will increase diameter growth of trees and would improve the quality of wood production with proper management option; (2) crown growth, which has potential effects on wood quality, differs among PCT treatments, and that (3) there is an effect of PCT on height:diameter ratios, and PCT can increase the stability at high-altitude Anatolian black pine forests of the oro-mediterranean belt against a more extreme climate.

**Methods**

**Site Description**

The data set was collected in natural Anatolian black pine stand located in humid region in Burdur (Gölhisar) province in western Mediterranean region of Turkey (36°54'N, 29°22'E; Figure 1). The average altitude of stands is 1700 m on the northeastern-eastern aspect, with an average slope of 35%. The soil textures of this area are sandy loam and sandy clay loam soil, and average stand age was 21 years. Stands under study included pure even-aged natural stands of yield class (site II). Detailed information about the study site is given in the publication of Deligöz et al. (2019). Climatic data were collected at 30-min intervals from 2015 to 2017 using Watchdog 2000 Series Weather Stations (Spectrum Technologies, Inc., USA) to characterize the climatic conditions in the study area. The annual total rainfall was 1035 mm for 2016. This annual total rainfall was 19% lower than the long-term mean annual rainfall of 1276 mm. The average annual temperature for 2016 was 10°C, and average annual humidity was 60% in the same period. Maximum and minimum temperatures were 33°C (July) and −17°C (January), respectively, for 3 years in the study area.

**Experimental Design**

Treatments were applied in three replicates using a complete randomized block design. The experimental plots were established in late April 2015. Each experimental plot was randomly assigned to one of the three PCT treatments: (1) unthinned (control) = 4941 stems ha⁻¹, (2) 2–2.5 m spacing (PCT₂–2.5 m) = 2133 stems ha⁻¹, and (3) 3–3.5 m spacing (PCT₃–3.5 m) = 1093 stems ha⁻¹. Each plot varied between 150 and 200 m² in size with a 3-m wide buffer zone. DBH was measured within the treatment plots prior to PCT. Mean DBH measured before the thinning was 8.6 cm. Thinning activities were carried out manually, and the good-quality trees (healthy, strong, and tall stems) were favored. The stems selected among the dominant and co-dominant trees were left in the plots. Poor-quality stems (small, forked, damaged, dead, dying, or suppressed stems) were removed from the plots. All leave trees located in the plots were identified with numbered tags.

**Stand and Tree Measurements**

Stem density (stem ha⁻¹) was calculated by recording the number of stems in each plot. Each numbered stem was marked at the height of 1.30 m, and DBH was measured from one direction of tree at the height of 1.30 m four times with 1-mm accuracy immediately after PCT and after each growing season up to autumn 2017. Individual tree basal area was calculated by the cross-sectional area [CSA = (π/4) × DBH², in cm²] at 1.30 m of this tree. Stand basal area was determined as the sum of individual tree basal areas and converted into m² ha⁻¹. Total tree height (m) measurements were obtained using a telescoping height pole. The height and crown radius of trees were measured in the same period for 3 years (2015–2017). Diameter, height, crown radius (north, south, east, and west directions), and individual tree basal area increment (BAI) were then calculated for each stem using the repeated measurement data in the plot. The height/diameter, h/d ratio was calculated to quantify the tree stability. The total number of trees damaged (up-rooted, leaning, or snowbend) by wind or snow for each plot was determined over three growing seasons after...
PCT, and the percentage of damaged trees per plot was then calculated.

Data Analysis
All data analyses were conducted using multivariate statistical analysis methods (SPSS 20.0, SPSS Inc., Chicago, IL, USA). Tree and stand variables (DBH (cm), height (m), total basal area (m²/ha), h/d ratio, percentage of trees damaged (%), and crown radius (m)) were compared among PCT treatments using a general linear model analysis of variance following establishment. Significant means were separated by Duncan's test at \( p < .05 \). Preliminary analysis indicated that DBH, height, total basal area, and crown radius were significantly different. So, analysis of covariance (ANCOVA) was used to adjust for initial differences among treatments. Several researchers have used ANCOVA due to initial differences (Lindgren & Sullivan 2013; Lindgren et al. 2007; Sullivan et al. 2006). The difference among PCT treatments depending on DBH, height, crown radius, and individual tree BAI was tested by ANCOVA. If the ANCOVA revealed a significant treatment effect, then the \( p \) values were adjusted with the Bonferroni test. Multiple comparisons were performed between treatments. Furthermore, regression analysis was performed to determine the relationship between DBH and h/d ratio.

Results

Diameter Growth
There were statistical significances in the differences among PCT treatments for DBH immediately after PCT in 2015 (\( p < .01 \)), and mean DBH was 8.45 cm in control plots, 9.44 cm in the PCT\(_{2-2.5\,\text{m}}\) plots, and 9.38 cm in the PCT\(_{3-3.5\,\text{m}}\) plots (Figure 2a). Precommercial thinning treatments had significant effects on breast diameter increment in 2015 (immediately after PCT)–2015 (\( p < .001 \)), 2015–2016 (\( p < .001 \)), and 2015–2017 (\( p < .001 \)). In 2015–2017, diameter increment was 1.14 cm in control plots, 1.62 cm in the PCT\(_{2-2.5\,\text{m}}\) plots, and 2.09 cm in the PCT\(_{3-3.5\,\text{m}}\) plots (Figure 2b). Diameter increment reached its largest value in the PCT\(_{3-3.5\,\text{m}}\) plots, and the control treatments had significantly lower diameter increment from 2015 to 2017 (\( p < .001 \)) as determined by the Bonferroni test, with differences in increment ranging from .46 to 1.14 cm from 2015 to 2017 (Figure 2b). At the end of 3 years, DBH in the PCT\(_{3-3.5\,\text{m}}\) was statistically greater (\( p < .001 \)) than the control by 1.97 cm, but similar to the PCT\(_{2-2.5\,\text{m}}\) by .4 cm (Figure 2A).

Height Growth
Precommercial thinning treatment effects were found to be significant for height in 2015 (\( p < .001 \)), 2016 (\( p < .001 \)), and 2017 (\( p < .001 \)). Trees in the 2–2.5 m plots were significantly taller than trees in control and PCT\(_{3-3.5\,\text{m}}\) plots (Figure 3a). The mean height for control, PCT\(_{2-2.5\,\text{m}}\), and PCT\(_{3-3.5\,\text{m}}\) plots increased from 5.30, 6.10, and 5.14 m in 2015 to 6.61, 7.20, and 6.11 m in 2017, respectively. When the mean height increment was evaluated, statistically significant differences were found in the second (\( p < .05 \)) and third year (\( p < .001 \); Figure 3B). At the end of 2017, height increment of PCT\(_{2-2.5\,\text{m}}\) and PCT\(_{3-3.5\,\text{m}}\) was significantly different from control. The highest height increments were determined in the control (Figure 3b).

Basal Area Development
Total basal area was affected by PCT treatments (\( p < .001 \)), and the control plots had the highest basal area. Total basal area was significantly lower in the PCT\(_{3-3.5\,\text{m}}\) plots compared to the

![Image](https://example.com/image.png)
control plots at the end of 3 years (Figure 4a). Precommercial thinning significantly affected individual tree BAI in 2015–2015, 2015–2016, and 2015–2017 ($p < .001$). Tree BAI was similar between the PCT$_{2–2.5\, m}$ plots and the PCT$_{3–3.5\, m}$ plots in 2015, and the control plots had significantly lower BAI (Figure 4b). Tree BAI increased with increasing PCT intensity in 2015–2017. Trees in the PCT$_{3–3.5\, m}$ plots had larger BAI than the control and the PCT$_{2–2.5\, m}$ plots at the end of 3 years by 15.57 and 8.28 cm$^2$, respectively (Figure 4b).

Stand Stability

The $h/d$ ratio of individual trees differed significantly among PCT treatments from 2015 to 2017 ($p < .001$). At the beginning of the growing season of 2015, the mean $h/d$ ratio was highest in trees in the PCT$_{2–2.5\, m}$ plots and lowest in trees in the PCT$_{3–3.5\, m}$ plots. The $h/d$ ratio in trees in the PCT$_{2–2.5\, m}$ plots showed a clear decrease since 2016, and it was similar with trees in the control plots in 2017 (Figure 5). The $h/d$ ratio was significantly negatively correlated with DBH in 2015, 2016, and 2017 in all the treatments (Figure 6). The mean $h/d$ ratio decreased with increasing DBH. While correlations between diameter and $h/d$ ratio increased in the control plots from 2015 ($R^2 = .63$, $p < .001$) to 2017 ($R^2 = .70$, $p < .001$), it was decreased in the PCT$_{3–3.5\, m}$ plots from 2015 ($R^2 = .43$, $p < .001$) to 2017 ($R^2 = .37$, $p < .001$). Namely, it has been found that the relationship between diameter and $h/d$ ratio decreased in the PCT$_{2–2.5\, m}$ and the PCT$_{3–3.5\, m}$ plots in 2017 (Figure 6). In the control plots, the percentage of damaged trees by wind or snow was high in 2016. For 3 years, snow or wind losses were observed only in the second growing season following PCT, and the percentage of damaged trees was not significantly affected by PCT ($p > .05$; Figure 7).
Crown Radius Growth

Mean crown radius in three directions (north, south, and east) showed significant differences in PCT treatments at the end of the first growing season after treatment, but crown radius in west direction was not significantly affected by PCT (Figure 8). At the end of year 3, crown radius values in four directions were greater in thinned trees when compared to control trees ($p < .001$). Crown radius values in all the directions increased markedly with thinning intensity. At the end of the first growing season after treatment (2015–2015), there were no statistically significant treatment effects on the crown radius increment, except in north direction (Table 1). At the end of the second (2015–2016) and third (2015–2017) growing seasons, there were significantly affected crown radius increments in all the four directions ($p < .001$). Crown radius increment in all the directions was higher in the PCT$_{3–3.5}$ m plots compared to the control and the PCT$_{2–2.5}$ m plots at the end of year 3 (2015–2017). While there was no difference between the control and the PCT$_{2–2.5}$ m plots at the end of the first year ($p > .05$), this difference was found only in south ($p < .01$) and west ($p < .05$) direction increments at the end of year 3. In the same way, the crown radius increment in the PCT$_{2–2.5}$ m plots was higher compared to control plots in south and west directions. The crown radius increment of trees in the thinned plots was larger than that in the control plots except for north and east direction.

Discussion, Conclusion, and Recommendations

Precommercial thinning significantly raised the diameter growth, as reported by others (Bayar & Deligoz, 2020, ...
Precommercial thinning reduced the stocking levels in overstocked stand, and diameter increment of the trees increased with decreasing stand density, as expected. The results were similar with the finding reached by Bayar and Deligöz (2019) in the Anatolian black pine stand in a semi-arid region. Sullivan et al. (2006) found that low-density stand has maintained faster diameter growth than the medium- and high-density stands. High stand density slows down the diameter development.

Early and intensive PCT on Scots pine (*P. sylvestris* L.) trials located in Southern and Central Finland resulted in the greatest diameter development response (Huuskonen & Hynynen, 2006). When trees are removed, growing space has been evenly distributed among the remaining trees (Mäkinen et al., 2006). Competition decreases among individual trees, and increased

### Table 1.

*Crown Radius Increment (m) for Four Directions According to ANCOVA and Bonferroni Post Hoc Test Results for 3 Years.*

| Crown Radius Increment (m)/Years Following PCT | Unthinned (Control) | PCT2–2.5 m | PCT3–3.5 m | p  |
|-----------------------------------------------|---------------------|-------------|-------------|----|
| **North**                                    |                     |             |             |    |
| 1 (2015–2015)                                | .08 ± .01ab         | .06 ± .01a  | .13 ± .01a  | .002 |
| 2 (2015–2016)                                | .30 ± .04a          | .31 ± .04a  | .52 ± .04b  | <.001 |
| 3 (2015–2017)                                | .44 ± .04a          | .55 ± .04a  | .80 ± .04b  | <.001 |
| **South**                                    |                     |             |             |    |
| 1 (2015–2015)                                | .10 ± .02a          | .13 ± .02a  | .14 ± .02a  | ns   |
| 2 (2015–2016)                                | .22 ± .03a          | .40 ± .03b  | .50 ± .03a  | <.001 |
| 3 (2015–2017)                                | .40 ± .03a          | .67 ± .03b  | .80 ± .03b  | <.001 |
| **East**                                     |                     |             |             |    |
| 1 (2015–2015)                                | .11 ± .02a          | .09 ± .02a  | .13 ± .02a  | ns   |
| 2 (2015–2016)                                | .28 ± .03a          | .34 ± .03a  | .47 ± .03a  | <.001 |
| 3 (2015–2017)                                | .46 ± .04a          | .58 ± .04a  | .77 ± .04a  | <.001 |
| **West**                                     |                     |             |             |    |
| 1 (2015–2015)                                | .09 ± .01a          | .08 ± .01a  | .11 ± .01a  | ns   |
| 2 (2015–2016)                                | .32 ± .03a          | .38 ± .03a  | .60 ± .03a  | <.001 |
| 3 (2015–2017)                                | .49 ± .03a          | .62 ± .03b  | .85 ± .03b  | <.001 |

*Note:* Data are shown as mean ± SE. Different letters (a,b,c) indicate significant differences among treatments. ns = non-significant (*p* > .05); ANCOVA = analysis of covariance; PCT = precommercial thinning.
Height growth in Anatolian black pine stand was influenced by PCT. All trees in the PCT2–2.5 m plots were significantly taller than the control and PCT3–3.5 m plots because trees in the PCT2–2.5 m plots had larger height at the beginning of the experiment. This could be explained by resource allocation and site productivity. In the first year after PCT, the height increment was not influenced by PCT. In the third year after PCT, height increment decreased significantly with PCT, but differences between PCT2–2.5 m and PCT3–3.5 m were not significant. This was unexpected taking into account that the height is not commonly influenced by spacing (Ferguson et al., 2011; Lindgren & Sullivan, 2013; Prévost & Gauthier, 2012; Simard et al., 2004; Sullivan et al., 2006). However, similar to our results, Hamilton (1981) found that different thinning intensities had no significant effect on height growth, and the highest height increment was found in the unthinned control plots in P. sylvestris. The main reason for this can be light competition. Under light competition, trees allocate their resources to increase height increment (Linkevičius et al., 2014). Kuliešis et al. (2010) showed that competition among trees has a positive influence on height growth. Ruha and Varmola (1997) reported that in very widely spaced stands, height increment decreased in Scots pine because tree growth is tended to branches due to reducing competition for light. Rytter and Werner (2007) reported that height growth was little affected by PCT.

Tree mortality caused by winter storms and bark beetles has been reported to be related to the high stand density (Oliver, 1997). The h/d ratio has been used for susceptibility to snow and wind damage for many years (Wonn & O’Hara, 2001). Previous studies have reported that probability of damage increased with increases in h/d ratios, and lower h/d ratios indicate higher stability (Weiskittel et al., 2009; Yılmaz et al., 2010). Ferguson et al. (2011) reported that the h/d ratio was increased on narrower spacing. In this study, the h/d ratio of trees in the PCT2–2.5 m plots immediately after PCT was higher for control and PCT3–3.5 m plots but have decreased since the end of the second year following PCT. In the second year following PCT damage by snow or wind was observed. The percentage of damaged trees increased with increasing density, but this difference was statistically insignificant. In previous studies, while the proportion of damaged trees by wind was not significantly affected by thinning and fertilization treatments, the effect on snow damage was found significant (Valinger et al., 1994). At the end of 3 years, the h/d ratio was lower in the PCT3–3.5 m plots compared with trees growing in the control and PCT2–2.5 m plots. Conversely, control plots reached higher values of h/d ratio over time, as was expected. An inverse relationship was determined between diameter and h/d ratio. The similar result was found by Wallentin and Nilsson (2014). From 2015 to 2017, negative correlations between diameter and h/d ratio were decreased in the PCT3–3.5 m and the PCT2–2.5 m plots and increased in the control plots. The inverse relationship was weaker in the PCT3–3.5 m plots because the diameter growth is more than the height growth, due to the decrease in competition.

The crown growth of the trees was affected by PCT. Crown radius in all directions increased markedly with thinning intensity. Similar findings were reported in other studies (Baldwin et al., 2000; Lindgren & Sullivan, 2013; Mäkinen & Isomäki, 2004b; Tong & Zhang 2005; Varmola & Salminen, 2004; Weiskittel et al., 2009). The expansion of the crown width in the remaining trees indicates that the trees tend to maximize their space and light interception (Sullivan et al., 2006). On the other hand, too heavy thinning can have negative effects on wood quality (Mäkinen & Isomäki, 2004a).

This study showed the effects of PCT on tree- and stand-level growth for the density management of young Anatolian black pine stands under humid climatic conditions. Precommercial thinning had a significant effect on mean DBH, height, total basal area, individual tree basal area, crown radius, and their increments. Diameter growth of individual trees increased following PCT. Competition among trees in the control plots had a positive effect on height growth. Trees in the PCT2–2.5 m plots were taller, but compared to thinned plots, trees in the control plots had higher height increment. The reason for the higher height in the PCT2–2.5 m plots was associated with the higher height at the beginning of the experiment. The total basal area decreased with increasing PCT intensity, but the individual tree BAI significantly increased. Results also indicated that the greatest diameter and tree BAI occurred in the PCT3–3.5 m plots, and it has a higher number of larger-sized stems. On the other hand, crown radius increment was also high. In the long period, the development of larger crowns in the PCT3–3.5 m plots may lead to bigger branches, and therefore, wood quality could be decreased due to the bigger branch diameter. Considering the stand age, we suggest a cautious approach to PCT in the natural Anatolian black pine stand, specifically on fertile sites (site index II).
at high altitudes. Thus, our finding suggest that a density of 2133 stems ha$^{-1}$ (2–2.5 m spacing/PCT$^{2–2.5 \text{ m}^2}$) may be suitable for tree growth and against the negative effects of snow or wind damage at high-altitude Anatolian black pine forests of the oro-
mediterranean belt according to the early results of PCT. PCT
should be done at the early stage of stand development so that
the remaining trees will grow faster.

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