Abstract

The effects of precommercial thinning 56-year-old lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) are reported 25 growing seasons after treatment. Four post-thinning stand densities of 500, 1000, 1500, and 2000 trees per hectare, plus unthinned controls, were established on plots in central British Columbia. Both individual-tree and per-hectare data were analyzed. With the exceptions of mean height and periodic height growth, thinning had a statistically significant effect on all of the characteristics examined. Although this report provides only short-term information on the effects of thinning on the growth and yield of lodgepole pine, it does indicate the need to optimize individual-tree growth rates with levels of growing stock to maximize yield per unit area.

Introduction

Lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) frequently regenerates in excessively dense stands following wildfire and logging. Excessive density can reduce average stand height, diameter, and merchantable volume, and increases mortality losses, rotation lengths, and harvesting costs. Precommercial thinning (thinning semi-mature stands) and juvenile spacing (thinning young stands) have frequently been shown to mitigate many of the adverse effects of excessive density (Cole 1975; Johnstone 1985; Johnstone and Cole 1988). Unfortunately, the information from existing spacing and thinning studies is fragmented and of limited value for identifying the optimum stand density management regimes for lodgepole pine.

The present study, B.C. Ministry of Forests and Range Experimental Project (EP) 922.04, is one of a series of long-term experiments that was undertaken to: (1) determine the effects of precommercial thinning and juvenile spacing on the growth and yield of lodgepole pine stands growing under a variety of age, site, and stand conditions; and (2) provide a local data source for the calibration and validation of growth and yield models (Johnstone and van Thienen 2004). This paper presents the effects, for the first 25 growing seasons after treatment, of various post-thinning densities on the development of a dense naturally regenerated, stand of 56-year-old lodgepole pine growing in central British Columbia.
Methods

Study Area
This trial was established in an essentially pure lodgepole pine stand, and is located on a relatively level site, at an elevation of 1150 m, approximately 19 km southwest of Topley Landing, near Baboon Lake, in the Nadina Forest District (Figure 1).

This mesic SBSmc2/01 site (Meidinger et al. 1991) is on a loamy Orthic Dystric Brunisol that developed on a level morainal blanket overlying a compacted basal till. The present stand regenerated naturally following a severe wildfire in 1925; at the time of study establishment, in the fall of 1983, the trees averaged 56 years total age. At that time, the average stand height was 11.1 m, the average diameter at breast height outside bark (dbhob) was 8.1 cm, and the average stand density was 9334 trees per hectare. Isolated infections of stem rust (Atropellis piniphila [Weir] Lohman and Cash), as well as small patches of hare (Lepus americanus Erxleben) damage, were present in the stand. An attempt was made to remove the affected trees during the thinning operation.

Study Design and Establishment
This experiment uses a randomized complete-block design with three blocks. Each block contains five treatments: an unthinned control, and post-thinning densities of 500, 1000, 1500, and 2000 trees per hectare (tph). Plot sizes varied with treatment because a constant number of 144 trees (12 rows of 12 trees) were contained in each thinned plot. The grid distances and variable plot sizes were determined by the various levels of residual growing stocks (Table 1). A 10-m treated buffer surrounded each thinned plot. Crop tree selection was based on size (dominant and codominant trees favoured), bole form, crown length, and tree health. In the thinned plots, all trees in the first and last two rows, and the first and last two trees in the remaining rows (i.e., the two perimeter rows of trees in each plot) also serve as buffer trees, and the remaining 64 inner trees are "sample trees." A minimum of 140 trees was targeted for inclusion in each unthinned control plot. Each control plot was surrounded by a 10-m untreated buffer, and all living trees surrounded by this buffer are "sample trees." All crop trees in the thinned and unthinned plots were systematically tagged with serially numbered tags.

Tree Measurement and Compilation
Following plot establishment, in the fall of 1983, the dbh (diameter outside bark at 1.30 m), total height, and height to live crown were measured for each crop tree. In the fall of 1988 and 1993, the total height and dbh of each sample tree were measured. The dbh, total height, and crown length of all crop trees were measured in the fall of 1998, 2003, and 2008. Crown widths were also measured on all crop trees in 2003 and 2008. At each measurement time, the condition of all tagged trees was examined, and the presence of any defect or damaging agent was recorded for each tree.

The results presented in this report were based only upon data from the sample trees in each plot. Furthermore, sample trees that were unlikely to become future crop trees because of dead or broken tops, or because of severe leans, were also excluded from the analyses. Percent live crown was determined for each tree by dividing the length of live crown by total height and multiplying by 100%. Mean-tree and per-hectare stand values of each plot were calculated for each measurement period. Mean-tree periodic increments (p.i.) are based on the measured growth of the sample trees alive at the end of each measurement interval. Individual-tree volumes are inside-bark volumes calculated from Kozak's taper functions (Kozak 1997). Merchantable volume is the bole volume between a 30-cm stump and a 10-cm diameter inside bark top for all trees 12.5 cm dbh and

<table>
<thead>
<tr>
<th>Treatment number</th>
<th>Treatment (tph)</th>
<th>Spacing (grid) interval (m)</th>
<th>Plot size (ha)</th>
<th>Length of side (m)</th>
<th>Number of crop trees per plot</th>
<th>Number of sample trees per plot</th>
</tr>
</thead>
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<tr>
<td>0 (Bl. 1)</td>
<td>Control</td>
<td>–</td>
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<tr>
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<td>Control</td>
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<td>0.0100</td>
<td>10.00</td>
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<tr>
<td>0 (Bl. 3)</td>
<td>Control</td>
<td>–</td>
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<td>140</td>
</tr>
<tr>
<td>1</td>
<td>500</td>
<td>4.47</td>
<td>0.2880</td>
<td>53.66</td>
<td>144</td>
<td>64</td>
</tr>
<tr>
<td>2</td>
<td>1000</td>
<td>3.16</td>
<td>0.1440</td>
<td>37.95</td>
<td>144</td>
<td>64</td>
</tr>
<tr>
<td>3</td>
<td>1500</td>
<td>2.58</td>
<td>0.0966</td>
<td>30.98</td>
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<td>64</td>
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<tr>
<td>4</td>
<td>2000</td>
<td>2.24</td>
<td>0.0720</td>
<td>26.83</td>
<td>144</td>
<td>64</td>
</tr>
</tbody>
</table>

a tph = trees per hectare
Access Descriptions

KM     Descriptions
0.0     From Topley, east of Houston on Hwy.16, turn left (north)
20.9    Turn right on Tachek Creek Road
To Blocks 1 and 2:
22.9    Turn right on spur road into powerline R/W
23.3    Plot 1-1 on the left
To Blocks 3:
22.9    Stay on Tachek Creek Road
23.2    Trail to Block 3 starts at Research Plot sign on the right side of the road

FIGURE 1 Location map and access notes for E.P. 922.04.
larger. Per-hectare values are net values (i.e., exclude mortality) and were determined for each thinned plot by multiplying the mean value of the sample trees (volume per tree or basal area per tree) times the treatment level times the number of living sample trees as a decimal fraction of 64. Net per-hectare values for the control plots were based on the area of each plot. Data from the three blocks were combined to produce the summary data shown in the figures.

Analyses

Analysis of variance was used to determine the effects of the treatments on mean-tree and per-hectare stand values. All analyses were limited to the observations made following 25 growing seasons. Before analysis, percentage data for percent live crown and survival were converted with an inverse sine transformation (i.e., \( z = \sin^{-1}(\sqrt{p}) \)). All analyses were performed using SAS statistical procedures (SAS Institute Inc. 1990).

**Results**

Table 2 summarizes the analyses of the effects of the thinning treatments on the various individual-tree and per-hectare stand characteristics. Except for mean height and periodic height growth, thinning had a statistically significant \((p \leq 0.05)\) effect on all of the individual-tree values examined. In general, the significance of differences in pairwise treatment comparisons increased as the differences in spacing intensity between the treatments increased. Thinning also had a statistically significant effect on all of the stand characteristics examined. However, differences between the various thinning intensities were variable for these per-hectare values.

**Individual-tree Values**

**Crown Development**

Thinning has had a pronounced effect on crown development in this study (Figures 2 and 3). After 25 years, crown length and crown width are directly proportional to the amount of available growing space.

**Diameter**

The expected trend of the largest trees at the widest spacing continues to develop. Over the last 25 years, thinning intensity has had a direct effect on periodic diameter growth (Figure 4).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>ANOVA results</th>
<th>0-1</th>
<th>0-2</th>
<th>0-3</th>
<th>0-4</th>
<th>1-2</th>
<th>1-3</th>
<th>1-4</th>
<th>2-3</th>
<th>2-4</th>
<th>3-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual tree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Mean % live crown (25 yr)</td>
<td>0.001</td>
<td>&lt;0.001 &lt;0.001 &lt;0.001</td>
<td>0.006</td>
<td>0.110</td>
<td>0.012</td>
<td>0.001</td>
<td>0.190</td>
<td>0.006</td>
<td>0.053</td>
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</tr>
<tr>
<td>Mean crown width (25 yr)</td>
<td>&lt;0.001</td>
<td>&lt;0.001 &lt;0.001 &lt;0.001</td>
<td>&lt;0.001</td>
<td>0.053</td>
<td>0.001 &lt;0.001</td>
<td>0.025</td>
<td>0.004</td>
<td>0.229</td>
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<td></td>
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<tr>
<td>Arithmetical mean dbhob (25 yr)</td>
<td>&lt;0.001</td>
<td>&lt;0.001 &lt;0.001 &lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
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<td>&lt;0.001</td>
<td>0.024</td>
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<tr>
<td>Mean dbhob p.i. (0–25 yr)</td>
<td>&lt;0.001</td>
<td>&lt;0.001 &lt;0.001 &lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
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<tr>
<td>Mean height (25 yr)</td>
<td>0.710</td>
<td>0.363</td>
<td>0.423</td>
<td>0.221</td>
<td>0.721</td>
<td>0.908</td>
<td>0.725</td>
<td>0.569</td>
<td>0.641</td>
<td>0.648</td>
<td>0.366</td>
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<tr>
<td>Mean height p.i. (0–25 yr)</td>
<td>0.409</td>
<td>0.860</td>
<td>0.730</td>
<td>0.173</td>
<td>0.935</td>
<td>0.865</td>
<td>0.132</td>
<td>0.925</td>
<td>0.101</td>
<td>0.792</td>
<td>0.153</td>
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<tr>
<td>Mean total volume/tree (25 yr)</td>
<td>&lt;0.001</td>
<td>&lt;0.001 &lt;0.001 &lt;0.001</td>
<td>0.006</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.061</td>
<td>0.002</td>
<td>0.046</td>
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<tr>
<td>Mean merch. volume/tree (25 yr)</td>
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<td>&lt;0.001 &lt;0.001 &lt;0.001</td>
<td>0.001</td>
<td>0.001</td>
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<td>0.026</td>
<td>0.001</td>
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<td>Mean height/dbhob ratio (25 yr)</td>
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<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.046</td>
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Per hectare

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<th>Characteristic</th>
<th>ANOVA results</th>
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<th>0-3</th>
<th>0-4</th>
<th>1-2</th>
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<th>1-4</th>
<th>2-3</th>
<th>2-4</th>
<th>3-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% survival (25 yr)</td>
<td>&lt;0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.043</td>
<td>0.471</td>
<td>0.154</td>
<td>0.139</td>
<td>0.434</td>
<td>0.436</td>
</tr>
<tr>
<td>Basal area/ha (25 yr)</td>
<td>&lt;0.001</td>
<td>&lt;0.001 &lt;0.001 &lt;0.001</td>
<td>0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.010</td>
<td>&lt;0.001</td>
<td>0.017</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basal area p.i. (0–25 yr)</td>
<td>0.011</td>
<td>0.093</td>
<td>0.012</td>
<td>0.003</td>
<td>0.002</td>
<td>0.227</td>
<td>0.059</td>
<td>0.031</td>
<td>0.396</td>
<td>0.227</td>
<td>0.692</td>
</tr>
<tr>
<td>Total volume/ha (25 yr)</td>
<td>&lt;0.001</td>
<td>&lt;0.001 &lt;0.001 &lt;0.001</td>
<td>&lt;0.001</td>
<td>0.022</td>
<td>0.001</td>
<td>&lt;0.001</td>
<td>0.070</td>
<td>0.010</td>
<td>0.234</td>
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<tr>
<td>Total volume/ha p.i. (0–25 yr)</td>
<td>0.008</td>
<td>0.305</td>
<td>0.307</td>
<td>0.013</td>
<td>0.009</td>
<td>0.060</td>
<td>0.003</td>
<td>0.002</td>
<td>0.071</td>
<td>0.049</td>
<td>0.823</td>
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<tr>
<td>Merchantable volume/ha (25 yr)</td>
<td>0.011</td>
<td>0.001</td>
<td>0.025</td>
<td>0.172</td>
<td>0.306</td>
<td>0.071</td>
<td>0.010</td>
<td>0.006</td>
<td>0.245</td>
<td>0.135</td>
<td>0.696</td>
</tr>
<tr>
<td>Merch. volume/ha p.i. (0–25 yr)</td>
<td>0.003</td>
<td>0.001</td>
<td>0.067</td>
<td>0.889</td>
<td>0.615</td>
<td>0.021</td>
<td>0.001</td>
<td>&lt;0.001</td>
<td>0.053</td>
<td>0.030</td>
<td>0.715</td>
</tr>
</tbody>
</table>

a Analyses of variance (ANOVA) based on 4 and 8 degrees of freedom. Pairwise comparisons based on Bonferroni t tests
b p.i. = net periodic increment
This response is undoubtedly related to the size and persistence of crowns, which increased directly with available growing space. This has resulted in large differences in mean diameter (Figure 5) and, assuming that the trends in periodic growth continue, these differences are likely to continue to widen for the foreseeable future. Although the results in Figure 4 suggest a decline in diameter growth with time, this radial increment occurred on larger trees; indeed, the amount of wood laid down, in terms of individual-tree basal area, has increased.

**Height**

Unlike diameter, spacing-related patterns in height development are less clear (Figures 6 and 7). The average height of the unthinned plots continues to be less than that of the thinned plots (Figure 6). However, with the exception of the plots thinned to 1500 tph, the height growth in the unthinned plots exceeded that in the thinned plots during the first 15 years after thinning (Figure 7). The superior height growth observed in the unthinned plots during those 15 years is probably due to several factors, including heavy mortality of subordinate crown classes in the control plots, and accelerated dbh growth at the expense of height growth in the thinned plots.

**Individual-tree Volume**

Because of larger stem diameters, and despite a lack of a clear height response, individual-tree volume was much larger in the thinned plots than in the controls, and the expected direct size-spacing relationship has developed (Figures 8 and 9). Future observations of bole form will be required to determine how much of this additional volume is recoverable.

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**FIGURE 2** Mean percent live crown 25 years after thinning.

**FIGURE 3** Mean crown width 25 years after thinning.

**FIGURE 4** Periodic diameter growth following thinning of lodgepole pine.

**FIGURE 5** Diameter development following thinning of lodgepole pine.
indication of the direct effect of spacing on bole taper is given by the height/diameter ratios shown in Figure 10.

**Stand Values**

**Survival and Damage**
During the first 25 years of this study, the rate of mortality was much lower in the thinned plots than in the unthinned controls (Figure 11), where heavy competition-related mortality occurred, particularly in the subordinate crown classes. In the thinned plots, the heaviest mortality was observed in the most widely spaced (500 tph) plots, and was due mainly to wind and snow damage. When this trial was established, the average slenderness coefficient of pine trees in the control plots was 146. Thinning from below resulted in an immediate reduction in the average slenderness coefficients, from a low of 103 at 500 tph to a high of 121 at 2000 tph. However, despite these improved coefficients, the mortality and damage results indicate that trees in the most widely spaced stands are initially at greater risk of wind damage than trees in less intensively thinned stands.

Twenty-five years after thinning, a marked improvement was observed in the slenderness coefficients in all of the thinned plots compared to the controls where the ratios were virtually unchanged (Figure 10). The results suggest that the risk of blowdown will decline with time following thinning.

**Basal Area and Stand Volumes**
In spite of larger and faster growing trees, stand basal area and stand volume are much lower at the wider
spacings (Figures 12–14). Despite continued high mortality, the net stand volume of the control plots was still higher than that of the thinned plots. In the absence of heavy mortality in the control plots, it is doubtful that, given the late age at which the thinning was undertaken, enough time remains before final harvest for the thinned plots to accumulate sufficient total volume to equal that contained in the unthinned plots. This may not be the case for merchantable volume as the 1500- and 2000-tph treatments are quickly approaching the control plot levels.

Discussion and Conclusions

This study clearly demonstrates the extent to which precommercial thinning can affect the growth and development of lodgepole pine trees and stands. In general, the results agree with earlier research conducted in fire-origin stands (Johnstone 1985; Johnstone and Cole 1988). On an individual-tree basis, spacing had a direct effect on the size and persistence of the tree crowns, and thus has had a direct effect on several bole characteristics, particularly dbh and volume. The positive, direct effect of thinning on dbh growth has resulted in a major upward shift in the dbh distribution of the thinned plots. The effect of spacing on height growth is less clear and less dramatic, and the trees with the widest spacings were neither the tallest nor the fastest growing. A comparison of the height/diameter ratios indicates that for a given diameter, trees at the wider spacings are substantially shorter than trees at the closer spacings and in the unthinned controls. Thinning, because of its effect on diameter and even in the absence of a concomitant height effect, has had direct, positive effect on bole volume, particularly merchantable volume.

The main causes of mortality and damage in this study were attributed to wind and snow. The degree to which trees are susceptible to wind damage depends on a variety of site, stand, and tree characteristics. For example, the risk of blowdown is greatest in shallow-rooting situations characteristic of some soil types and/or species' rooting habits. A combination of stand and tree characteristics may have contributed to the damage (including broken, leaning, and sweeping boles, and broken and dead tops) and mortality, particularly in the 500-tph plots, experienced in the present study. Thinning may have altered the wind patterns within the plots and reduced the mutual sheltering and root anchoring among the individual trees. Because they were grown under high stand density conditions, which resulted in short crowns and low bole taper, the trees were highly susceptible to windthrow and breakage. The ratio of tree height to dbh (slenderness coefficient) appears to provide a simple estimate of a tree's potential to resist wind damage (Navratil 1997). The smaller the coefficient, the greater the wind stability and resistance to breakage of the tree. The results suggest that, had thinning been delayed, the risk of damage from wind and snow would have increased.

This study also demonstrates the need for forest managers to clearly identify and define their future timber management objectives. Despite larger and faster growing trees at the wider spacings, both stand basal area and stand volume were inversely related to spacing level. This study is still too young to permit the identification of a spacing level that will optimize individual tree size while maximizing...
the yield of desired products on an area basis. This study does show how thinning can accelerate the accumulation of merchantable volume, thereby shortening technical rotations; consequently, it may be a useful technique for addressing age-class imbalances in the timber supply or may help mitigate the impact of catastrophic loses to wildfire or pests, such as mountain pine beetle (*Dendroctonus ponderosae* Hopkins).

This study has provided detailed, short-term information on the effects of precommercial thinning on the growth and development of semi-mature lodgepole pine. Continued periodic remeasurement and analysis of the study will verify and expand the conclusions reached to date.

**Acknowledgements**

This trial was initiated by John Pollack and the Research Section of the former Prince Rupert Forest Region, with the assistance of staff from the former Morice Forest District (particularly Ivan Lister and Guenter Stahl). Peter Ott’s advice on the statistical analyses is gratefully acknowledged. Thanks are extended to Rob Brockley and Gordon Nigh for providing review comments on an earlier draft of this manuscript. Funding for the establishment and measurement of this trial was provided by various sources, including the Canada – British Columbia Forest Resource Development Agreements (FRDA I and II), Forest Renewal BC, and the Forest Innovation Investment research program.
**Literature Cited**


**Citation**


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