Influences of Conventional and Low-Density Thinning on the Lower Bole Taper and Volume Growth of Eastern White Pine

Christopher H. Guiterman, Aaron R. Weiskittel, and Robert S. Seymour

ABSTRACT

Throughout the northeastern United States, thinning is a common management practice in stands of eastern white pine (*Pinus strobus* L.), but foresters lack clear information as to whether conventional B-line or low-density thinning will best achieve their growth and financial objectives. Conventional management consists primarily of light crown thinning, whereas low-density management uses heavy crown thinning to isolate selected crop trees. To better inform silviculturists of the effects of these thinning regimes on volume growth and taper of white pine, we compared the lower bole taper—quantified as Girard form class (GFC)—and volume growth between the two thinning regimes and a nonthinned control. Over the 17-year study period, GFC increased among all treatments from an overall average of 0.77 ± 0.01 (±SE) to 0.82 ± 0.00. Trees under the B-line thinning regime had the most taper (lowest GFC), owing to a thinning-induced growth response at breast height but not at the top of the butt log. Low-density thinning, on the other hand, resulted in substantially larger, less tapered butt logs with significantly higher growth rates at both breast height and the top of the butt log. The volume growth of low-density trees was significantly higher than that of trees in the other treatments. At the stand level, however, the overall volume growth of the low-density treatment was significantly lower than that of the B-line treatment. Thus, this study reveals that when implementing low-density thinning, there is a tradeoff between overall stand growth and larger, less tapered individual trees.

Keywords: Girard form class, *Pinus strobus*, silviculture, crop-tree management, taper equations

Eastern white pine (*Pinus strobus* L.) is a significant component of many forest types throughout the northeastern United States (Widmann and McWilliams 2004). As a result of agricultural land abandonment and the use of shelterwood regeneration systems, pure stands of white pine are common in the region. Because large-diameter white pine trees can be highly valuable, thinning is a widely recommended management practice for such stands. A consensus as to the optimal residual density for thinning, however, has not been reached after nearly 40 years of discussion (Leak 2004, Seymour 2007).

The two primary thinning regimes used for even-aged white pine stands in the northeastern United States are the conventional B-line and low-density thinning regimes. Conventional management follows regional guidelines (Lancaster and Leak 1978) that recommend maintaining stand densities between the A and B lines on the white pine stocking guide (Figure 1) through repeated thinning to the B line. The region between the A and B lines is a zone of optimal stand-level growth, where stands at the A line are fully stocked and those at the B line are at the lower limit of crown closure (Philbrook et al. 1973). Lancaster and Leak (1978) suggest that thinning below the B line would have deleterious effects on stand-level growth rates because of wasted growing space.

In contrast to conventional management, low-density management involves heavy crown thinning of young, dense stands to levels well below the B line to encourage rapid growth of individual crop trees by maintaining large crown sizes. Under this management regime, stands are initially thinned once the stand height reaches roughly 35 ft and crown bases have receded above the 17-ft butt log. Stand densities are maintained intentionally low by repeated thinnings to an approximate relative density of less than 0.1 or a spacing/height ratio of 0.5 (Seymour 2007), thereby minimizing crown competition. The ultimate objective of these repeated thinnings is to end up with roughly 30 pruned crop trees per acre at the final harvest. Under low-density management, any sacrifice in stand yield from heavy thinning is, in theory, offset by a greater financial return from large, high-quality crop trees.

Financial return from white pine trees is most influenced by the size, growth rate, and quality of the butt log because it contains a disproportionate amount of the tree volume and value. Thinning is likely to alter the form of the butt log because bole taper is highly sensitive to stand density (Larson 1963). Butt logs with little taper are more valuable and are thus desirable by managers. It remains unclear, however, whether this desirable bole taper is achieved through a light or a heavy thinning regime (Brinkman et al. 1965, Shearin et al. 1985).

In addition to the importance of taper in the value of white pine, volume growth is also of considerable interest, both at the tree and at the stand levels. In examining 10 years of volume growth in a white pine thinning study (WPTS) that compared the B-line and low-density thinning regimes, Seymour (2007) determined that

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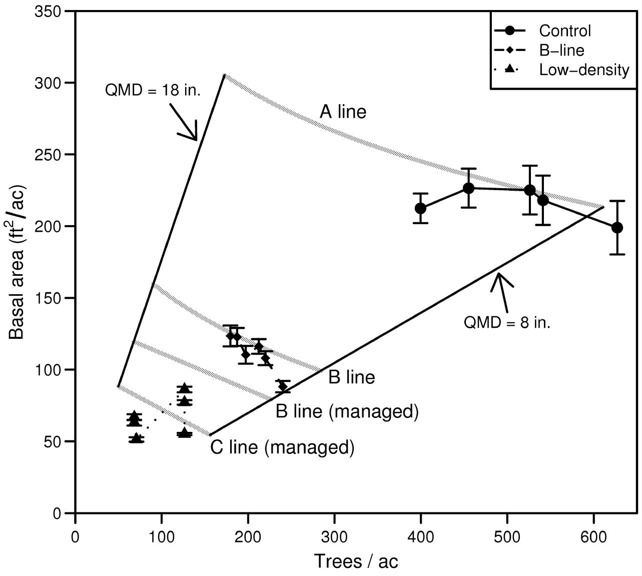

Figure 1. The Philbrook et al. (1973) eastern white pine stocking guide showing 17 years of stand development for each WPTS treatment. Error bars are ±1 SE. Revised (managed) B and C lines are from Leak and Lamson (1999). QMD, quadratic mean diameter of the stand.

Table 1. Stand attributes of the eastern white pine thinning study treatments during the study period.

	Control	B-line	Low-density
1992 Postharvest			
ht[a] (ft)	50 (0.2)	50 (0.4)	52 (0.5)
LCR[a] (%)	32 (0)	30 (1)	33 (1)
QMD[a] (in.)	8.6 (0.7)	8.5 (0.6)	9.2 (0.2)
LAI[b] (m^2/m^2)	4.7 (0.3)	2.0 (0.0)	1.9 (0.2)
2001 Preharvest			
ht (ft)	61 (0.3)	58 (0.5)	61 (0.6)
LCR (%)	33 (1)	42 (1)	46 (1)
QMD (in.)	9.8 (0.7)	10.4 (0.6)	11.5 (0.3)
LAI (m^2/m^2)	4.8 (0.3)	3.4 (0.1)	3.0 (0.1)
2008			
ht (ft)	68 (0.4)	68 (0.6)	69 (1.1)
LCR (%)	31 (1)	34 (1)	45 (1)
QMD (in.)	10.7 (0.6)	11.4 (0.5)	13.4 (0.4)
LAI (m^2/m^2)	4.3 (0.2)	3.0 (0.2)	2.6 (0.1)

Values are means of four plots per treatment with SEs in parentheses.

[a] Dominant and codominant trees only.

[b] From two plots per treatment in 1992.

ht, total tree height; LCR, live crown ratio; QMD, quadratic mean stand diameter; LAI, leaf area index.

low-density thinning produces significantly higher individual tree growth than B-line thinning, with only a slight reduction in overall stand growth. Given this finding, Seymour (2007) challenged the use of the B line as a target residual density for thinning.

Seymour's (2007) analyses relied on stemwood volumes estimated using the Honer (1967) regional volume equation, which does not explicitly address the influence of thinning and has been shown to be significantly biased in other species (Pitt and Lanteigne 2008). A taper equation was recently developed for white pine within the Northeast region (Li and Weiskittel 2010) that was found to account for changes in bole form caused by thinning (Guiterman 2009). Such an equation could more precisely determine stemwood volume, thereby warranting a reevaluation of volume growth within Seymour's (2007) thinning study.

Given the important management implications of both stem taper and volume growth of the B-line and low-density thinning regimes for white pine stands, we evaluated 17 years of growth between white pine thinned under each regime and an unthinned control. Our objectives were to examine the effects of B-line and low-density thinning treatments on the lower bole form of crop trees and to further understand the influence of thinning on tree and stand volume growth. This study reexamines the volume growth data from Seymour's (2007) thinning study by calculating volume using an alternative equation and including an additional 7 years of growth data.

Methods

The study site is located in central Maine (44°55′N, 68°41′W) on the University of Maine's Dwight B. Demeritt Forest. It is a 1-ha eastern white pine plantation on somewhat poorly drained silt-loam soils with an average site index of 65 ft (base age, 50 years; Frothingham 1914). In 1991, 42 years after planting, the WPTS was initiated to evaluate tree and stand responses to both the conventional B-line and the low-density management regimes. As described by Seymour (2007), the WPTS consists of replicate blocks grouped according to initial basal area and density. Each block is composed of three 0.04-ha (20 × 20 m; slightly under 0.1 ac) plots, including a conventional B-line thinned plot, a low-density thinned plot, and a nontreated control plot. All analyses in this study were based on four of the replicate blocks (Table 1). The B-line thinning treatment was executed according to the Lancaster and Leak (1978) guidelines where crop trees were selected based on bole form and competitive dominance at a spacing of roughly 20 ft and then released via crown thinning on three to four sides by removing adjacent and competing trees until B-level stocking on the Philbrook et al. (1973) stocking guide was achieved. In the low-density thinning treatment crop-tree selection was identical to the B-line treatment, but the crop trees were fully released by removing all noncrop trees.

After the initial thinning in the fall of 1991, a second thinning was implemented 10 years later in the fall of 2001. On conventional B-line plots, the 2001 harvest removed codominant trees that were competing with crop trees until the target B-line density was achieved. On low-density plots, crop trees showing little response to the initial treatment were removed if their crowns were touching adjacent, more desirable crop trees.

Plot inventories commenced before the 1992 growing season with tallies including dbh (nearest 0.1 in.; 4.5 ft aboveground), total tree height (ht; nearest 0.1 ft), and height to crown base—defined as the lowest live branch—for all trees in thinned treatments. All control trees were measured for dbh; however, only a subset (roughly equal to the per plot number of trees on thinned plots) of upper crown class trees received the height and crown base measurements. Missing heights were later estimated with plot-specific, height-over-dbh regression equations. Remeasurement inventories of all living trees were conducted in August or September of the years 1999, 2001, 2006, and 2008.

Girard Form Class

In 2008, 21 trees within each treatment were selected for reconstructing changes in Girard form class (GFC; Girard 1933) over the study period. Crop trees on low-density plots were paired with equivalent trees on B-line and control plots based on their pretreatment dbh, crown ratio, and crown class. In addition, only control trees with desirable bole form were selected for more accurate comparability with thinned crop trees. Each of the 63 trees was climbed to 17 ft and measured for diameter outside bark and bark thickness (nearest 0.04 in.) to calculate diameter inside bark (dib). Increment cores were used to estimate dib for inventory years 1992, 1999, 2001, and 2006. Each tree was bored through the center of the entire bole, generating two cores from bark to pith at 180° from each other. Ring widths on the cores were measured to the nearest 0.0001 in. and normalized to account for possible noncircularity of the boles. GFC was calculated as the quotient of dib at 17 ft and dbh outside bark in the same year.

Stemwood Volume Estimation

Stemwood volumes were estimated using a regional taper equation for eastern white pine. The equation was modified from the Kozak (2004) "Model 02" by Li and Weiskittel (2010) to include crown length (CL) and is expressed as

$$
\begin{aligned}
dib &= \alpha_0 dbh^{\alpha_1} ht^{\alpha_2} \\
&\times Xexp\left[\beta_1 z^4 + \beta_2\left(\frac{1}{e^{dbh/ht}}\right) + \beta_3 X^{0.1} \right. \qquad (1) \\
&\left. + \beta_4\left(\frac{1}{dbh}\right) + \beta_5 ht^Q + \beta_6 X + \beta_7 CL\right],
\end{aligned}
$$

where all units are in metric (1 in. = 2.54 cm; 1 ft = 0.3048 m), h is height (m) along the stem, $X = [1 - (h/\mathrm{ht})^{1/3}/1 - p^{1/3}]$, $p = 1.3/\mathrm{ht}$, $Q = 1 - z^{1/3}$, $z = h/\mathrm{ht}$, $\alpha_0 = 1.055$, $\alpha_1 = 0.991$, $\alpha_2 = -0.027$, $\beta_1 = 0.366$, $\beta_2 = -0.824$, $\beta_3 = 0.305$, $\beta_4 = 4.978$, $\beta_5 = 0.112$, $\beta_6 = -0.552$, and $\beta_7 = 0.002$. (Parameter estimates are given here because they were not provided by Li and Weiskittel (2010) for this particular equation.) Equation 1 estimates stem profile; therefore, stemwood volumes were determined through numerical integration using Smalian's formula (and converted to English units; 1 $\mathrm{ft}^3 = 0.0283\ \mathrm{m}^3$). The inclusion of CL was desirable for this study because crown size asserts a strong influence over bole form (Larson 1963) and both thinning treatments significantly increased the CLs of upper crown class trees.

This taper equation is more precise in estimating volume than the widely used Honer (1967) equation (Li and Weiskittel 2010). Li and Weiskittel (2010) found that the taper equation root mean square error was 40% lower than that of the Honer (1967) equation. Guiterman (2009) validated the taper equation for use in the WPTS by showing that its estimates were unbiased by tree size and treatment. Furthermore, he compared the results of the analyses presented in this article using both the taper equation and the Honer (1967) equation. The taper equation volume estimates were on average 4% higher than the Honer estimates. Statistical comparisons of the volume growth estimates revealed that the differences between the WPTS treatments were equally detectable using either volume equation (Guiterman 2009). Thus, for most users, the Honer (1967) equation provides reliable volume estimates in a variety of stand densities, but where greater precision is desired we recommend using the taper equation.

Volume growth rates are reported in both cubic feet of total stemwood and merchantable bd ft using the Leak et al. (1970) equation for white pine. We assumed merchantability limits of >8.5-in. dbh to a 6-in. top diameter.

Analyses

Analysis of variance (ANOVA) was used to test for differences in GFC, dbh, and dib at 17 ft among the treatments. Volume growth rates were calculated for two different growth periods separated by the harvest entry in 2001. The growth periods were 1992–2001 (10 years) and 2002–2008 (7 years). All stand-level volume growth rates were calculated as annual gross growth per acre. Differences in the volumes and volume growth rates among the three treatments were tested using ANOVA and included orthogonal contrasts that directly compared the B-line treatment to the low-density treatment and the unthinned control to the thinning treatments combined. Mean separations were done using Tukey's honestly significant difference post hoc tests that maintained 95% familywise error rates. Statistical significance of all tests was considered at the 95% level of confidence.

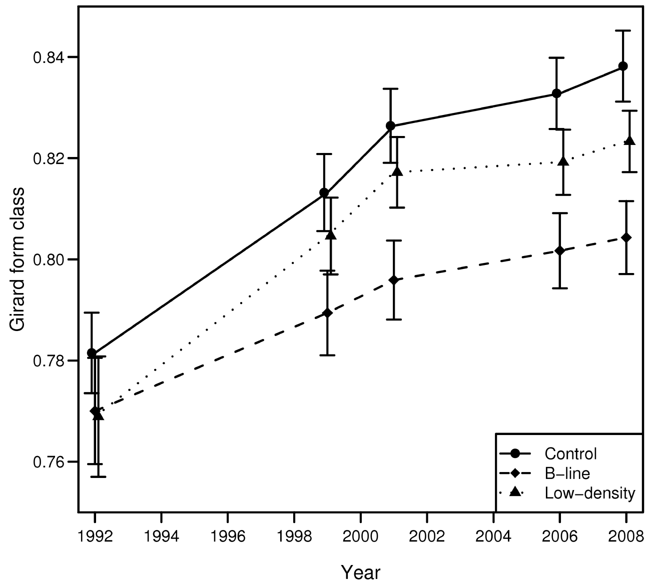

Figure 2. Mean GFCs by treatment of the 63 climbed trees. Error bars are ±1 SE.

Results

Girard Form Class

Over the 17-year study period, the GFC of the 63 climbed trees was strongly influenced by thinning (Figure 2). Initially in 1992, there were no GFC differences among the treatments ($P > 0.66$); however, after 17 years, the B-line crop trees had significantly lower GFC (i.e., greater butt log taper) than comparable control trees ($P < 0.01$) and somewhat lower GFC than low-density trees ($P = 0.12$). There was no significant difference between the GFC of low-density trees and control trees ($P = 0.28$). GFC increased among all treatments from an overall average of 0.77 ± 0.01 (±SE) in 1992 to 0.82 ± 0.00 in 2008.

GFC was calculated using dbh and dit at the top of the butt log, therefore we examined the components separately (Figure 3). There were no differences in dbh or dib at 17 ft among the treatments in 1992 ($P > 0.87$). By 2008, the dbh of climbed trees in the B-line and low-density treatments were significantly higher than the dbh of the control trees ($P < 0.01$). The dib's at the top of the butt log in 2008 were not significantly different for B-line trees and control trees ($P = 0.92$); however, the low-density trees were significantly larger at 17 ft than either other treatment ($P < 0.01$). The diameter growth rate at 17 ft of low-density trees was on average 97 ± 6% higher than the control and 65 ± 5% higher than the B-line treatment.

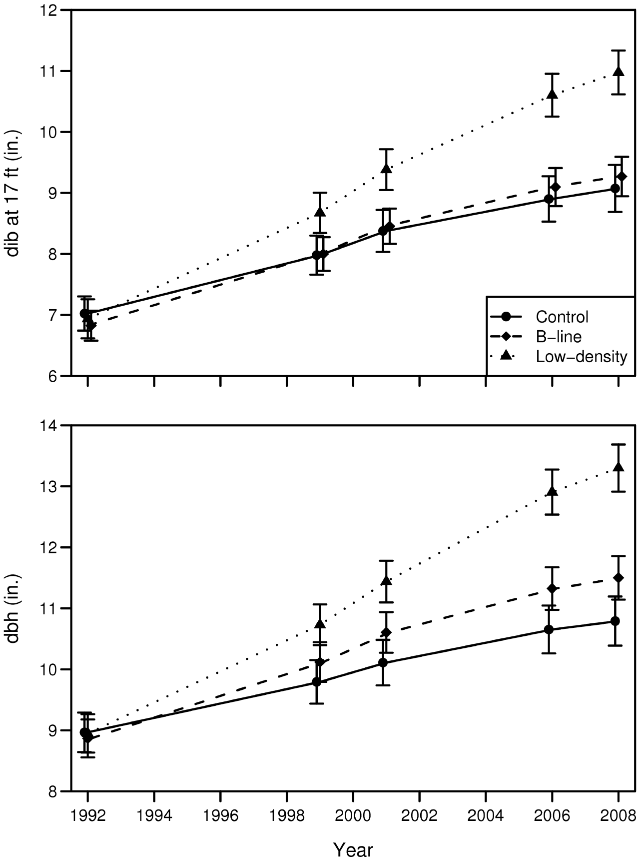

Figure 3. Mean diameters outside bark at breast height (dbh) and dib at 17 ft for the 63 climbed trees. Error bars are ±1 SE.

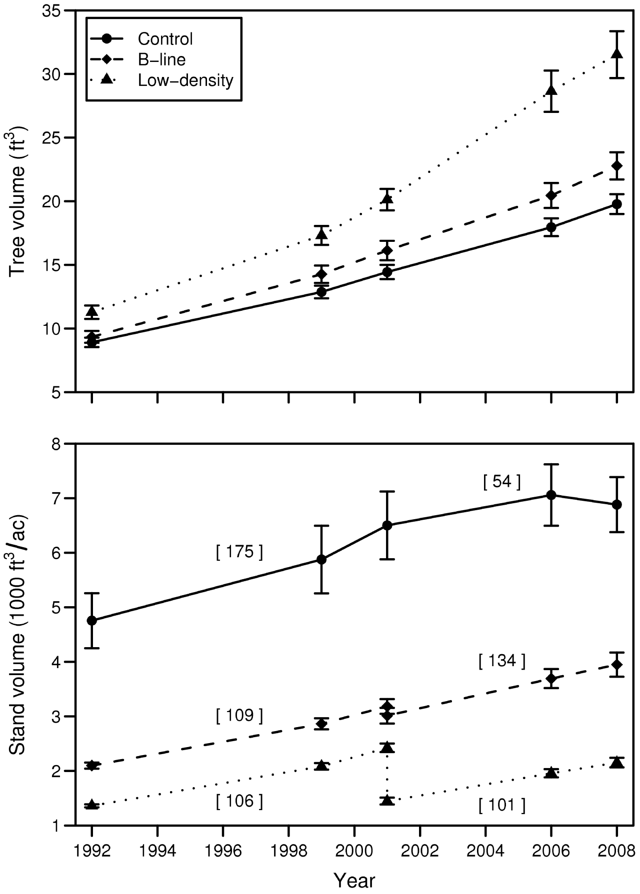

Figure 4. Mean stemwood volumes by treatment throughout the study period. Tree volumes include only dominant and codominant trees. Numbers in brackets are net volume growth (ft^3/ac per year) corresponding to the growth periods 1992–2001 and 2002–2008. The 2001 thinning removed 343 ± 100 ft^3/ac (mean ± SE) from the B-line treatment and 900 ± 86 ft^3/ac from the low-density treatment.

Table 2. Mean periodic annual volume growth of total stemwood and merchantable sawlogs.

	Stemwood volume growth		Sawlog growth	
Treatment	Tree-level (ft^3/yr)	Stand-level (ft/ac per year)	Tree-level (bd ft/yr)	Stand-level (bd ft/ac yr^{-1})
1992–2001 Growth period				
Control	0.45 (0.02)	197 (22)	2.9 (0.1)	1042 (89)
B-line	0.60 (0.03)	119 (5)	3.8 (0.2)	762 (68)
Low-density	0.88 (0.04)	106 (5)	6.0 (0.3)	731 (45)
2002–2008 Growth period				
Control	0.55 (0.03)	186 (15)	3.6 (0.2)	1160 (99)
B-line	0.88 (0.04)	152 (13)	5.4 (0.3)	918 (86)
Low-density	1.54 (0.11)	105 (3)	10.0 (0.7)	704 (19)

SEs are in parentheses. Sawlog volumes were estimated using the Leak et al. (1970) equation for trees >8 in. dbh to a 6-in. top. Tree-level values are for dominants and codominants only; stand-level values are gross growth.

Stemwood Volumes and Volume Growth

Over the 17-year study period, low-density trees became significantly larger than trees in the other treatments ($P < 0.01$), with no significant difference detected between the average volumes of B-line trees and control trees ($P = 0.35$; Figure 4). The average growth rate of B-line trees (Table 2), however, was significantly higher than control trees during both the 1992–2001 and the 2002–2008 growth periods (Table 3). Low-density trees grew at the highest rates throughout the study period. On average, the low-density tree volume growth rate was 96 ± 9% higher than the control and 47 ± 7% higher than the B-line from 1992 to 2001, and then from 2002 to 2008 the average growth rate increased to be 181 ± 19% higher than the control and 75 ± 12% higher than the B-line.

At the stand level, volumes per acre of the thinned treatments were significantly less than the control throughout the study period (Figure 4). The residual standing volumes of the B-line and low-density treatments were not significantly different from each other until after the 2001 thinning. This divergence was paralleled by their stand-level volume growth rates (Table 2), which were similar from 1992 to 2001 and then became significantly different during the 2002–2008 growth period (Table 3). Between growth periods, the B-line treatment increased its stand-level growth rate by 28 ± 11%, and the low-density stand growth rate remained constant. Despite having the highest gross growth rate during the 2002–2008 period, tree mortality within the control offset most of this volume growth, causing the net volume growth rate to be less than the thinned treatments (Figure 4). Growth of merchantable volumes at the tree and stand levels in the WPTS generally paralleled the rates of total stemwood volume growth (Table 2).

Discussion

Girard Form Class

In a summary of stem form development patterns, Larson (1963) postulated that taper is largely influenced by crown size. Trees in

Table 3. ANOVA results for tests of differences in total stemwood volume growth rates among the treatments.

Parameter	df	SS	*F*-value	*P*-value	R^2	RSE
1992–2001 Growth period						
Tree level						
Block	3	1.08	5.25	<0.01	0.29	0.26
Treatment	2	6.59	48.18	<0.01		
B vs LD	1	1.31	19.15	<0.01		
C vs thin	1	5.28	77.21	<0.01		
Residual	276	18.88				
Stand level						
Block	3	2,872	1.68	0.27	0.87	23.89
Treatment	2	19,312	16.92	<0.01		
B vs LD	1	297	0.52	0.50		
C vs Thin	1	19,015	33.31	<0.01		
Residual	6	3425				
2002–2008 Growth period						
Tree level						
Block	3	1.14	2.83	0.04	0.45	0.37
Treatment	2	22.84	85.00	<0.01		
B vs LD	1	2.18	16.25	<0.01		
C vs Thin	1	20.66	153.75	<0.01		
Residual	214	28.75				
Stand level						
Block	3	2,979	2.96	0.12	0.89	18.31
Treatment	2	13,122	19.56	<0.01		
B vs LD	1	4,246	12.66	0.01		
C vs Thin	1	8,876	26.47	<0.01		
Residual	6	2,012				

The treatment parameter was divided into orthogonal contrasts between the B-line (B) and low-density (LD) treatments, and between the two thinning treatments combined (Thin) and the unthinned control (C). Only dominants and codominants are included in tree-level tests.
df, Degrees of freedom; SS, sum of squares; RSE, residual standard error.

dense stands are less tapered because of higher rates of crown recession with age and height growth. More open-grown trees have greater bole taper because their crowns remain long and wide over time. In this study, lower bole taper was least in the nonthinned control as would be expected by Larson (1963); however, the taper of low-density trees was less than that of conventionally thinned B-line trees, which is contradictory to Larson (1963).

The patterns of change in the bole forms of crop trees in the WPTS may be related to the "stimulatory" growth concept described by Larson (1965). Stimulatory growth is diameter growth at any height along the bole that is generated in response to wind stress. Such growth concentrates in physically stressed areas and provides support for the tree. Trees in dense stands (Larson 1963) and trees that are experimentally guyed (Jacobs 1954) have expressed few signs of stimulatory growth; however, on free swaying trees a stimulatory diameter growth response has been observed on the bole as high as 15 ft (Jacobs 1954).

The variation in tree spacing among the three treatments in the WPTS resulted in each experiencing differing degrees of wind exposure. Minimal self-stabilization was required for trees in the control plots because of the shielding effect of neighboring trees. Thus, a lack of stimulatory growth resulted in similar amounts of diameter growth at breast height and at 17 ft. The B-line crop trees, which likely experienced more wind sway than control trees because of thinning, showed greater bole taper. This growth form could be explained by stimulatory growth that was triggered at breast height, but not at the top of the butt log. The widely spaced trees in the low-density treatment likely experienced the greatest amount of wind exposure. Stimulatory growth resulting from this intensified wind stress produced the largest observed diameters at breast height and at 17 ft. This caused the low-density trees to have greater uniformity of growth along the butt log than was found on B-line trees.

The effects of thinning on GFC were able to be discerned in this study because of the pairing of trees before treatment based on size (dbh and crown ratio), crown class, and bole form, making this study of GFC unique within the literature. Previous studies have confounded the influences of tree size (Brinkman et al. 1965, Shearin et al. 1985) and pretreatment bole form (Hilt and Dale 1979) when analyzing the effects of thinning and, thus, are difficult to use for comparison with this study. Despite methodological differences, it was consistently shown that thinning to a low density does not cause increased lower bole taper, as was found in this study.

The differences in growth form between trees in the low-density and B-line thinning regimes elucidate some important management implications. It is often recommended to prune white pine crop trees to at least the top of the butt log to increase the final product value (Smith and Seymour 1986, Page and Smith 1994), because white pine has a poor branch-shedding ability (Wendel and Smith 1990). Exposed branch knots and pruning wounds are considered log defects (Ostrander 1971); therefore, rapid occlusion is essential for recovering pruning expenses and making a profit. The higher-diameter growth rate along the butt log of low-density trees when compared with B-line trees suggests that low-density trees will occlude wounds faster and begin growing valuable clear timber before B-line trees. Additionally, the less tapered form of the low-density trees indicates that a smaller portion of the butt log will be wasted during the milling process.

Stemwood Volumes and Volume Growth

Seymour (2007) concluded from the first 10 years of growth in the WPTS that conventional B-line thinning of eastern white pine stands is not an optimal management practice. Neither the objective of maximizing stand growth nor the objective of attaining the highest crop-tree growth was adequately met under the B-line regime.

Seymour used the Honer (1967) regional volume equation to generate the growth estimates on which he based his conclusions. Our results, which were generated using a more precise taper equation that accounted for thinning-induced stem form changes, support Seymour's conclusions. Some of the results, however, have changed given the additional 7 years of observation since Seymour's article. The trends observed by Seymour after the first 10 years of growth indicated that the growth rates of the B-line and low-density stands were similar, but in recent years the growth rates of the B-line stands have increased and are now significantly higher than the low-density stands (Table 3).

From 2002 to 2008, the B-line growth rate at the stand level was 43% higher than the low- density growth rate. However, crop-tree sizes in the low-density stands were significantly larger than in the B-line stands because of the higher individual tree growth rates in the low-density treatment. Despite 60% higher tree-level growth rates in the B-line treatment compared with the control, B-line trees were barely larger than the control trees in 2008. Thus, in accordance with Seymour (2007), thinning to a low density will diminish total stand yield; however, the gain in individual crop-tree growth may be worth the sacrifice for forest managers because of the high value of large white pine trees.

It should be noted that the increased B-line stand growth from 2002 to 2008 was largely driven by differing harvest removal volumes in the 2001 thinning. The B-line stands had not yet grown much above the stocking guide B level (Figure 1) and, therefore, only a light thinning entry was required to maintain B-line stocking. The 2001 low-density thinning, on the other hand, was substantially heavier, removing more than twice the volume of the B-line thinning (Figure 4) and reducing stand densities by one-half (Figure 1). Given this level of harvest in the low-density thinning, it seems remarkable that the stands were able to maintain nearly the same annual gross growth throughout the study period.

The annual bd ft growth of low-density trees was nearly twice that of comparable B-line trees (Table 2). Such differences in merchantable growth can have a substantial impact on financial returns. Page and Smith (1994) showed that white pine trees given space for unrestricted crown expansion, such as low-density crop trees, are able to earn a 13% compound interest return for at least 30 years after pruning and release. It was beyond our analysis to determine whether the financial earnings from the WPTS low-density treatment are or will be higher than the B-line treatment, but the increasing divergence in the growth of crop trees in each treatment should be considered when managers are developing financial objectives for white pine stands.

Conclusions

In these even-aged stands, low-density management clearly produced larger crop trees than conventional B-line thinning, with volume and diameter growth rates that showed substantial increases through time. Low-density management has the potential to greatly decrease the time required for crop trees to reach a target size. Although it was observed that the low-density regime may yield a lower total volume than B-line management, the tradeoff for higher initial cut volumes, better quality and form of crop trees, and a faster time to final harvest may make low-density thinning financially worthwhile.

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