

Influence of Precommercial Thinning and Fertilization on Total Stem Volume and Lower Stem Form of Loblolly Pine

James D. Haywood, *USDA Forest Service, Southern Research Station, Pineville, LA 71360.*

ABSTRACT: Two cultural treatments were applied in an overstocked loblolly pine (*Pinus taeda* L.) plantation (2,900 trees/ha after eight growing seasons): precommercial thinning (Yes or No) to 747 trees/ha after the eighth growing season and broadcast fertilization (Yes or No) with diammonium phosphate (150 kg/ha of P and 135 kg/ha of N) early in the ninth growing season. Total height and diameter at breast height (dbh) measurements were taken periodically through the 14th growing season. Fertilization increased tree volume more than thinning in the 9th through 10th growing seasons, but thinning was most effective by the 13th growing season. Over the 6-year period, thinning was the most effective cultural practice: check, 110 dm³; fertilized only, 135 dm³; thinned only, 165 dm³; and thinned and fertilized, 220 dm³/loblolly pine tree. After the 14th growing season, the first 5 m of bole was divided into five sections beginning at a 15-cm stump height: 15–30, 30–60, 60–125, 125–250, and 250–500 cm, and the volume for each section was calculated. Outside-bark volume per section increased consistently with thinning and fertilization; therefore, cultural practices did not change stem form in the lower bole. *South. J. Appl. For.* 29(4):215–220.

Key Words: Intermediate harvesting, nitrogen, phosphorus, *Pinus taeda* L., precommercial thinning.

The degree that fertilization will increase volume increment in pole and sawlog loblolly pine (*Pinus taeda* L.) stands depends on the initial stand basal area per hectare (Moehring 1966, Windsor and Reines 1973, Wells et al. 1976), and so, fertilizing thinned stands often is more beneficial for increasing diameter and height increment than either fertilization or thinning alone (Ballard et al. 1981). The effect of thinning is to increase sawtimber yields, although total volume yields are reduced (Burton 1982). However, fertilization acts to speed up site reoccupancy, which increases yields thereby offsetting the adverse effect of harvesting growing stock on total stand volume (Ballard 1981).

Thinning initially suppresses height growth of loblolly pine trees (Ginn et al. 1991), but height growth in thinned stands may eventually surpass height growth in unthinned stands (Zhang et al. 1997). Diameter growth responds positively to thinning (Ginn et al. 1991), and thinning effects on diameter growth are relatively greater than on height growth (Zhang et al. 1997). Fertilization also can have a positive effect on loblolly pine growth and yield for many years

(Haywood and Burton 1990, Haywood and Tiarks 1990) without reducing the specific gravity of mature wood (Schmidting and Amburgey 1977, Sword Sayer et al. 2004).

Previous publications on this study reported that precommercial thinning suppressed height growth for two growing seasons (Haywood 1993), and it took the thinned trees 7 years to recover this initial loss in height growth (Sword Sayer et al. 2004). Fertilization did not increase height growth until the second growing season after nutrient amendment (Haywood 1993), but fertilization exhibited a significant and beneficial effect on loblolly pine tree height growth through age 17 years (Sword Sayer et al. 2004). Both thinning and fertilization increased diameter growth in the first year after treatment (Haywood 1993), and the two treatments together had a greater than additive effect on diameter growth (Haywood 1994). Annual tree volume growth responded to thinning and to the combination of thinning and fertilization, but fertilization alone had little effect (Yu et al. 1999). Here, I report on periodic volume growth of loblolly pine trees over a 6-year period beginning in the 9th growing season to determine when during the growing season cultural practices affected growth and whether cultural practices ultimately affected stem form in the lower bole after the 14th growing season.

NOTE: James D. Haywood can be reached at (318) 473-7226; Fax: (318) 473-7273; dhaywood@fs.fed.us. Manuscript received March 14, 2005, accepted July 29, 2005. Copyright © 2005 by the Society of American Foresters.

Methods

Study Area

The study site is located in Rapides Parish in central Louisiana, on a gently sloping Beauregard silt loam (Plinthtaquic Paleudults, fine-silty, siliceous, and thermic). Soil drainage is adequate, and slope is sufficient that water does not pond. It was planted with loblolly pine seedlings at a 1.83×1.83 -m spacing in May 1981. The planting stock was 14-week-old container-grown seedlings. More than 97% of the planted trees survived through 1987, or the seventh growing season, when this study was initiated. The 3% that died did not create openings in the stand canopy. Loblolly pine was the dominant vegetation (Helms 1998) as measured by basal area per hectare, frequency of occurrence, and occupancy of the canopy. Diameters at breast height (dbh) of all loblolly pine trees were measured in Sept. 1987, and based on a test of homogeneity (SAS Institute, Inc. 1985), the loblolly pine trees were determined to be evenly distributed across the site.

Experimental Design and Treatments

In Apr. 1988, the understory brush and herbaceous plants were cut down with a tractor-drawn rotary mower. Twelve research plots were established with each plot containing 13 rows of 13 loblolly pine trees each (0.06 ha).

Treatments were randomly assigned to the 12 plots in a 2×2 -factorial arrangement with three replications as follows:

Thinning (THIN). Either the plots were left uncut with an original planting density of 2,990 trees per hectare or plot stocking was reduced to 747 trees per hectare in Nov. 1988, after the eighth growing season.

Fertilization (FERT). Either no fertilizer was applied or diammonium phosphate was broadcast at 750 kg/ha (150 kg/ha of P and 135 kg/ha of N) in Apr. 1989 at the beginning of the ninth growing season. This choice and rate of fertilizer was based on prior knowledge of loblolly pine response to fertilization on a Beauregard silt loam soil (Tiarks 1982).

This formed four treatments: check (NO THIN–NO FERT), thinned (THIN–NO FERT), fertilized (NO THIN–FERT), and the treatment combination (THIN–FERT). After the plots were established and treatments were assigned, dbh of the loblolly pine trees were measured again in Nov. 1988 before the plots were thinned. The diameter distribution among the four treatment combinations was subjected to a test of homogeneity, and tree diameters were determined to be uniformly distributed across the four treatment combinations (SAS Institute, Inc., 1985).

On the thinned plots, the trees were removed to leave a 3.66×3.66 -m spacing by cutting every other row of trees and every other tree in the remaining rows. This left 12 pines on the interior measurement area of each thinned plot. Plots were not selectively thinned to avoid biasing the comparison of the thinned and unthinned plots. The purpose of thinning was not to improve the population of trees, but

rather to compare growth between like populations of trees growing under different management practices. On the unthinned plots, 12 trees were likewise systematically selected as sample trees. The 12 sample trees on each plot were banded with red paint at about 2 m to ensure relocation, and they were marked with blue paint at dbh for consistent resampling.

Competing vegetation was controlled on all plots to avoid the confounding influences of differences in competing plant cover among treatment levels. Intensively managed plantations are likewise weeded to concentrate resources in the crop trees (Allen et al. 2005). Therefore, a series of vegetation management treatments that included cutting of arborescent vegetation and vines, applications of glyphosate herbicide to the regrowth, and rotary mowing were applied in 1989 through 1992 (Haywood 1994). Thereafter, no further treatments were needed.

On the 12 sample trees per plot, periodic diameter and height measurements were taken over a 6-year period on the following dates: Mar. 27, July 5, and Oct. 2, 1989; Mar. 19, June 13, Oct. 29, and Dec. 14, 1990; Mar. 8, June 24, Sept. 24, and Dec. 4, 1991; Mar. 23, June 17, Sept. 17, and Dec. 3, 1992; Mar. 14, June 21, Sept. 22, and Dec. 12, 1993; and Mar. 28, June 23, and Sept. 5, 1994. On each of these 22 dates, dbh was taken to the nearest 0.25 cm with a diameter tape and total heights were measured with a clinometer to the nearest 0.15 m. Total height and dbh measurements were used to calculate total outside-bark stem volume per tree from a 15-cm stump using Baldwin and Feduccia's formulas for unthinned and thinned loblolly pine (Baldwin and Feduccia 1987).

In Sept. 1994, additional stem measurements were made on the loblolly pine sample trees. The first 5 m of bole, or first log, was subdivided into five sections beginning at a 15-cm stump height: 15–30, 30–60, 60–125, 125–250, and 250–500 cm. At each division, outside-bark diameter was taken with a diameter tape and bark thickness was measured on opposite sides of the stem with a bark gauge. Outside- and inside-bark volumes for each section were calculated using the formula for a frustum of a cone (Dell et al. 1984). In addition, a form class was calculated for each pine tree based on the ratio between inside-bark diameter at the top of the first log divided by dbh multiplied by 100 (Helms 1998).

Data Analysis

For the loblolly pine sample trees, periodic volumes per tree were compared using a repeated measures completely randomized 2×2 -factorial design model ($\alpha = 0.05$) with the initial volume in Mar. 1989 as the contrast variable or covariate (SAS Institute, Inc. 1985). For measurement date (DATE) and interaction-with-date (DATE–THIN, DATE–FERT, and DATE–THIN–FERT) effects, the Huynh-Feldt correction was used in tests of significance. The correction made miniscule differences in the probabilities. Percentages were arcsine transformed before analysis (Steel and Torrie 1980).

Stem volume among the five sections of the first log (15–30, 30–60, 60–125, 125–250, and 250–500 cm) was

compared by using a repeated measures completely randomized 2×2 -factorial design model ($\alpha = 0.05$) with the mean volume of all sections as the covariate (SAS Institute, Inc. 1985). The base section was specified as the reference level for the analyses, and, therefore, the contrast for the base section was not calculated.

Comparisons of the Sept. 1994 bark volume, inside-bark volume, outside-bark volume, and percentage of wood in the first log were made using a completely randomized 2×2 -factorial design model ($\alpha = 0.05$; SAS Institute, Inc. 1985). Total outside-bark stem volume per tree from a 15-cm stump, percent volume per tree in the first log, and form class of the first log were compared also. Percentages were arcsine transformed before analysis (Steel and Torrie 1980).

Results and Discussion

Periodic Volume Growth

In the 9th through 14th growing seasons, there were significant thinning and fertilization effects (Table 1). Initially, the treatment combination (THIN-FERT) had less volume per tree than the check (NO THIN-NO FERT), thinned (THIN-NO FERT), and fertilized (NO THIN-FERT) treatments (Figure 1). This outcome, which resulted from the systematic selection of the sample trees, was no longer significant at the end of the ninth growing season because loblolly pines on the treatment combination were beginning to catch up with the trees on the other treatments. There were no significant treatment differences on each measurement date in the 10th growing season. By the June 24th measurement of the 11th growing season, both the thinned and the fertilized treatments significantly increased volume per loblolly pine tree: check, 79 dm³/tree; thinned, 86 dm³/tree; fertilized, 89 dm³/tree; and the treatment combination, 102 dm³/tree.

This pattern of treatment response continued through the 14th growing season. In the final measurement, the thinning and fertilization main effects each significantly increased

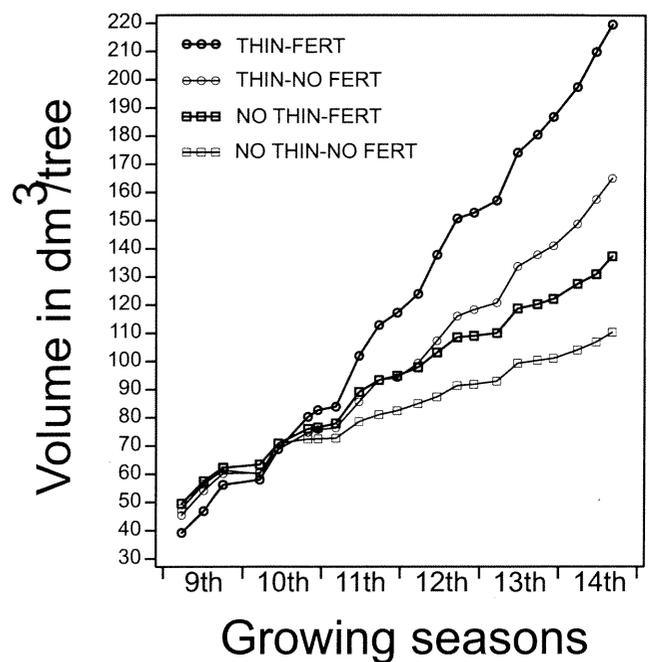


Figure 1. Periodic volume per loblolly pine tree (dm³/tree) from the 9th through 14th growing seasons; the plots were thinned and fertilized after eight growing seasons in a 2×2 -factorial arrangement, which formed four treatments: check (NO THIN-NO FERT), thinned (THIN-NO FERT), fertilized (NO THIN-FERT), and the treatment combination (THIN-FERT).

total outside-bark stem volume per tree (Table 2): check, 110 dm³/tree; thinned, 165 dm³/tree; fertilized, 135 dm³/tree; and the treatment combination, 220 dm³/tree (Figure 1). However, neither main effect treatment significantly affected form class (Table 2). Form classes by treatment were check, 70; thinned, 72; fertilized, 67; and the treatment combination, 76.

Interestingly, there was not a significant THIN-FERT interaction for volume per loblolly pine tree on any of the measurement dates (Table 1). Previously, Haywood (1994)

Table 1. Repeated measures analyses for periodic volume per loblolly pine tree in the 9th through 14th growing seasons and comparisons of wood and bark volumes among five sections of the first log after the 14th growing season; the plots were thinned and fertilized after eight growing seasons.

Sources in the repeated measures analyses	df ^a	Periodic volume per tree (dm ³)	P > F values			
			Comparisons among sections in the first log			
			Bark volume (dm ³)	Inside-bark volume (dm ³)	Outside-bark volume (dm ³)	Percent wood
Thinned (THIN)	1	0.0017	<0.0001	<0.0001	<0.0001	0.0286
Fertilized (FERT)	1	0.0093	0.1653	0.0038	0.0066	0.0306
THIN-FERT interaction	1	0.3385	0.9469	0.0393	0.0860	0.0711
EMS ^a	8	1,772.92713	1.10073	9.96486	15.44828	0.00170 ^a
Within subjects ^b						
Dates/sections	21/4 ^c	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Dates/sections-THIN	21/4	<0.0001	<0.0001	<0.0001	<0.0001	0.0284
Dates/sections-FERT	21/4	<0.0001	0.1009	0.0015	0.0011	0.6624
Dates/sections-THIN-FERT	21/4	0.0389	0.9272	0.0339	0.0560	0.6295
EMS (dates/sections)	168/32	26.1246	0.15252	1.59821	1.91432	0.00016 ^a

^a df, Degrees of freedom; EMS, error mean squares; and percentages were arcsine transformed into radians before analysis.

^b The loblolly pine trees were periodically measured 22 times (dates) over six growing seasons, or else, comparisons were made across all five sections of the first log beginning at 15 cm above ground line as follows: 15–30, 30–60, 60–125, 125–250, and 250–500 cm (sections).

^c Degrees of freedom for within-subjects analyses were either 21 or 168 for dates or either 4 or 32 for sections.

Table 2. Analyses of variance for volumes of wood and bark in the first log and total outside-bark volume per 14-year-old loblolly pine tree; the plots were thinned and fertilized after eight growing seasons.

Variables P > F values								
Analysis sources	df ^a	First log						
		Bark volume (dm ³)	Inside-bark volume (dm ³)	Outside-bark volume (dm ³)	Percent of wood in the first log (%)	Outside-bark volume per tree (dm ³)	Percent volume per tree in the first log	Form class of the first log
THIN ^b	1	<0.0001	<0.0001	<0.0001	0.1137	0.0001	0.0031	0.0740
FERT	1	0.1653	0.0038	0.0066	0.0664	0.0042	0.0095	0.7707
THIN-FERT	1	0.9469	0.0393	0.0860	0.0966	0.1666	0.8624	0.2356
EMS ^a	8	5.5037	49.8243	77.2414	0.00044 ^a	303.1133	0.00059 ^a	21.89037

^a df, Degrees of freedom; EMS, error means squares; and percentages were arcsine transformed into radians before analysis.

^b THIN and FERT are the thinned and fertilized main effects, respectively, and THIN-FERT is the thinning-fertilization interaction term.

reported that diameter growth was influenced by a significant THIN-FERT interaction effect at the ends of the 10th, 11th, and 12th growing seasons, but he did not analyze volumes. In addition, height and basal area per hectare growth were not influenced by a THIN-FERT interaction in his work.

However, when the initial volume per loblolly pine tree was used as a covariate in the repeated measures analysis, interpretation of results changed (Table 1). There were significant periodic (DATE) and interaction-with-date (DATE-THIN, DATE-FERT, and DATE-THIN-FERT) effects on volume per tree (Table 1). From the first measurement of the 11th growing season (Mar. 8, 1991) through the first measurement of the 13th growing season (Mar. 23, 1992), the relative importance of the two main effect treatments reversed (Figure 1). Fertilization was the more effective treatment at the beginning of this period (check, 73 dm³/tree; thinned, 76 dm³/tree; fertilized, 78 dm³/tree; and the treatment combination, 84 dm³/tree) and thinning was the more effective treatment at the end of this period (check, 93 dm³/tree; thinned, 121 dm³/tree; fertilized, 110 dm³/tree; and the treatment combination, 157 dm³/tree). This suggested that there was a diminishing fertilizer response, and, in fact, the fertilized plots were refertilized after the 14th growing season (Sword Sayer et al. 2004).

After the Mar. 23, 1992 measurement, the two main effect treatments continued to have a significant effect on per tree volume, but there were no significant THIN-FERT interactions. Apparently, the loblolly pine trees were in a stable growth pattern in the 13th and 14th growing seasons (Figure 1).

In other work, heavy thinning lengthened the growing season (Zahner and Whitmore 1960). Although there were important growth response trends in this study, none of them was associated with an obvious extension of the growing season (Figure 1). In other work on a similar soil, Haywood et al. (1997) were unable to detect a treatment-related change in periodic growth pattern among seedling loblolly pines after fertilization, weeding, or mulching.

Comparing Volumes by Sections in the First Log

After the 14th growing season and 6 years after treatment, differences in bark volume among the five sections of the first log (15-30, 30-60, 60-125, 125-250, and 250-500 cm) were significantly affected by thinning, sec-

tion (SECTION), and a SECTION-THIN interaction when the mean volume was used as a covariate in the repeated measures analysis (Table 1). The differences among the five sections were obvious (Figure 2). However, the SECTION-THIN interaction was more subtle, in which the treatment combination had a less than additive effect in the 125- to 250-cm and 250- to 500-cm sections and a greater than additive effect in the 30- to 60-cm and 60- to 125-cm sections.

Thinning and fertilization significantly increased the percentage of inside-bark volume per section. Across all five sections, the percent increase in wood ranged from 73 to 81% from thinning and 23 to 27% from fertilizing the plots

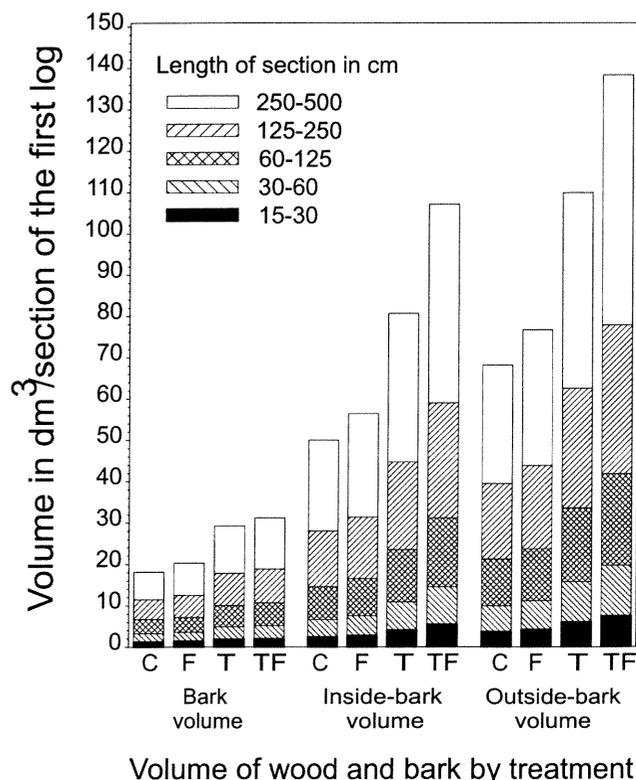


Figure 2. Volume of wood and bark by sections of the first log of 14-year-old loblolly pine trees; the plots were thinned and fertilized after eight growing seasons in a 2 × 2-factorial arrangement, which formed four treatments: check (C), thinned (T), fertilized (F), and the treatment combination (TF).

(Table 1 and Figure 2). Inside-bark volume was influenced by a THIN–FERT interaction (Table 1), and the treatment combination resulted in a 106–121% gain in wood volume across all five sections when compared with the check (Figure 2).

Thinning and fertilization significantly increased the percentage of outside-bark volume per section. Across all five sections, the percent increase ranged from 67 to 75% from thinning and 19 to 23% from fertilizing the plots (Table 1 and Figure 2). However, outside-bark volume was not significantly affected by a THIN–FERT interaction. Therefore, outside-bark volumes increased consistently with thinning and fertilization across all five sections, and thinning was the most beneficial individual treatment.

When comparing volumes of wood versus bark, thinning resulted in a three-percentage point gain in wood and the gain ranged from 1 to 4% across all five sections (Table 1 and Figure 2). Likewise, fertilization resulted in a two-percentage point gain in wood and the gain ranged from 2 to 3% across all five sections.

Volume Response in the First Log

In the first log, thinning significantly affected bark volume and increased it by 11 dm³, and fertilization did not have a significant effect on bark volume 6 years after treatment (Table 2 and Figure 2). Tiarks and Haywood (1993) also found that fertilization did not affect bark thickness in the lower bole of fertilized 11-year-old loblolly pine trees.

A THIN–FERT interaction significantly affected inside-bark volume of the first log (Table 2): check, 50 dm³/log; thinned, 81 dm³/log; fertilized, 56 dm³/log; and the treatment combination, 107 dm³/log (Figure 2). However, outside-bark volume per log was significantly affected by thinning and fertilization but there was not a significant THIN–FERT interaction (Table 2): check, 68 dm³/log; thinned, 110 dm³/log; fertilized, 77 dm³/log; and the treatment combination, 138 dm³/log (Figure 2). Although there was no interaction effect, logs on the treatment combination had twice the outside-bark volume as the check (Figure 2).

When comparing wood versus bark, thinning and fertilization did not significantly affect the percentage of wood in the first log (Table 2): check, 73%; thinned, 73%; fertilized, 74%; and the treatment combination, 77%. This was contrary to the per section analyses for percentage of wood (Table 1). Tiarks and Haywood (1993) found that fertilization at planting reduced bark weight per unit of bole volume in the lower stem of 11-year-old loblolly pine trees and increased wood yield by 3%. Their findings were similar to the modest 2–3% increases in wood volume reported in the by-section analyses.

When comparing first-log versus total-tree volumes, the percentage of volume in the first log was significantly affected by both main effect treatments (Table 2): check, 62%; thinned, 67%; fertilized, 57%; and the treatment combination, 63%. Fertilization reduced the ratio because it shifted stem volume to the upper stem, presumably because the fertilized trees were increasing leaf area, which resulted

in more upper stem development (Sword Sayer et al. 2004). Thinning increased the ratio because it increased lower stem development. Jack et al. (1988) reported that fertilization of unthinned loblolly pine stands shifts volume growth to the upper stem initially, but the effect became less pronounced after several years. Although thinning shifted stem volume to the lower bole and fertilization shifted stem volume to the upper bole, neither main effect treatment significantly affected form class (Table 2).

Management Implications

Precommercial thinning and fertilization both influenced the periodic growth of loblolly pine trees over a 6-year period, and thinning had a greater effect than fertilization. However, it was the 3rd year after thinning and fertilization that growth differences became obvious (Figure 1). From then on, growth accelerated especially on the thinned plots. To the casual observer, tree growth would appear stagnant for the first 2 years, and on many sites, there might be an initial reduction in growth after thinning followed by a rapid increase in growth rate (Amateis 2000).

Therefore, when an overstocked stand is precommercially thinned and fertilized, time will likely lapse before it responds to release and nutrient amendment. Despite a slow start, precommercial thinning eventually can result in 12–17% internal rates of return (Moorhead et al. 1998), and fertilization stimulates volume growth in larger diameter classes more so than in smaller diameter classes (Ballard et al. 1981).

Thinning and fertilization increased volume in the first log, and because both treatments had a similar effect across all five sections of the first log, the treatments alone or in combination did not change stem form. Therefore, it was possible to both thin and fertilize to increase volume without adversely affecting stem form, with the added economic bonus of producing higher-value products earlier in the rotation. Although thinning and fertilization increases loblolly pine growth, the actual financial benefits of cultural practices will depend on product market (fiber versus sawtimber), if another series of treatments are needed to maintain growth responses (Yu et al. 1999, Sword Sayer et al. 2004), and ensuring the stand is harvested at economic maturity (Burton 1982, Stearns-Smith et al. 1992).

However, the high initial costs of precommercial thinning may prohibit action entirely or greatly limit the number of hectares treated per year, and the danger of losses to bark beetles and wildfires rises with each year's increment in overstocked stands (Cain 1999). Rather than leaving the debris in the woods, as done in a normal precommercial thinning operation, the chips may be marketable as boiler fuel to local mills if fossil fuel prices continue to rise. Faced with historically high fuel costs, mills may be willing to buy chips to reduce the use of fossil fuels because they have the facilities for burning biofuels and they have fully allocated their own supplies of wood and bark byproducts (Bentley et al. 2002). The opening of such a market for wood fiber would likely benefit both landowners and timber buyers (Snider et al. 2001). Because chips sold for boiler fuel have

some economic worth, more stands could be treated at a reasonable fee or profit than could be precommercially thinned and the chips left on site. This would increase the number of treatable hectares on a fixed budget.

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