THE COOPERATIVE FORESTRY RESEARCH UNIT COMMERCIAL THINNING RESEARCH NETWORK: 9-YEAR RESULTS

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Abstract.—The Commercial Thinning Research Network (CTRN) was established throughout the spruce-fir forest of Maine beginning in 2000 with substantial funding from the University of Maine's Cooperative Forestry Research Unit. One of six replicates of the precommercially thinned stand condition in the CTRN is located in compartment 23A in the U.S. Department of Agriculture, Forest Service's long-term silviculture experiment on the Penobscot Experimental Forest (PEF), in which the experimental treatments are the timing of the first thinning entry and relative-density reduction. This paper presents 9-year results of this study, including detailed stand trajectories for the plots in compartment 23A. Contrary to expectations, there was no difference in periodic annual volume increment among the early-thinning treatments, owing to a much greater-than-expected growth response from the heavily thinned (50 percent reduction) plots. The study has provided valuable calibration data for the Forest Vegetation Simulator, and has informed landowner thinning decisions for a large area of northern Maine that was regenerated in the 1970s and 1980s during the spruce budworm salvage era. The study is actively maintained and future publications will document the effects of the 10-year delayed treatments.

INTRODUCTION

The Cooperative Forestry Research Unit

The Cooperative Forestry Research Unit (CFRU) is a partnership between Maine forest landowners and managers and the University of Maine. The purpose of the CFRU is to help member organizations advance forest management practices in Maine through applied scientific research. Member organizations contribute annual dues to support research projects that are guided by an advisory committee. In 2013, the CFRU had 31 members (representing approximately 8 million acres), including private industrial, private nonindustrial, and public forest landowners; wood processors; and other private contributors.

The Commercial Thinning Research Network

The Commercial Thinning Research Network (CTRN) is a statewide system of study sites created with substantial funding from the CFRU to study questions surrounding commercial thinning of Maine's spruce-fir resource. The CTRN was installed in 2000-2001 and consists of two experiments, each replicated at six sites (Fig. 1). The research questions for the two experiments are:

1. For naturally regenerated spruce-fir stands that have never received precommercial thinning (PCT), what is the influence of (a) method of commercial thinning and (b) residual density on subsequent stand response?
2. For naturally regenerated spruce-fir stands that have received PCT, what is the influence of (a) timing of first commercial thinning entry and (b) residual density on subsequent stand response?

The Penobscot Experimental Forest (PEF) study site hosts one replicate of the second experiment type, hereafter referred to as the "PCT Study."

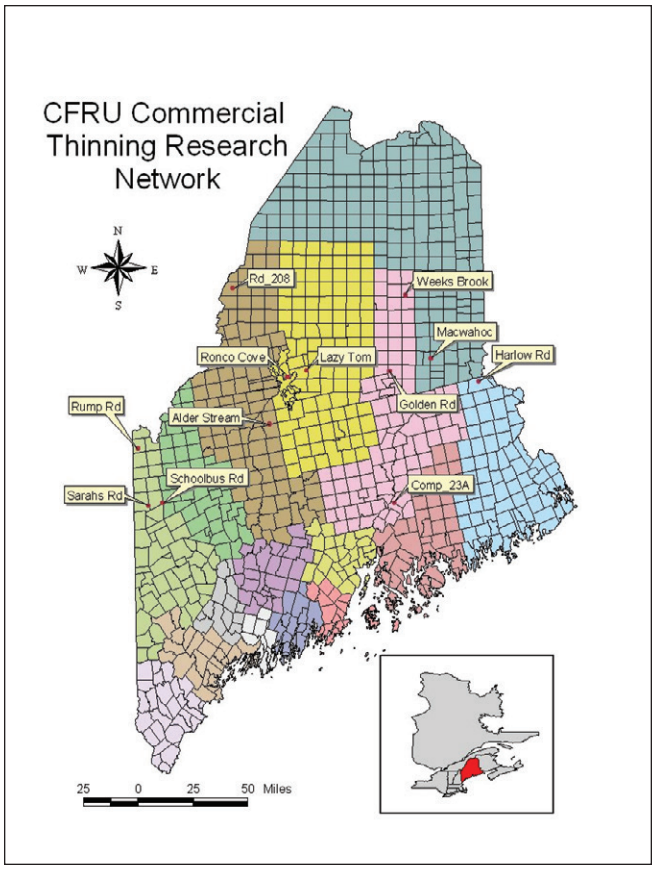


Figure 1.—Location of the 12 original CFRU Commercial Thinning Research Network study sites in Maine.

METHODS

Treatment Prescriptions

In the PCT-origin stands of the CTRN, treatments were designed to answer two important questions regarding the (a) timing and (b) intensity of first commercial thinning entry (Table 1).

The "immediate" treatment should be interpreted as implementing a commercial thinning as soon as the stand is commercially harvestable, typically when the average height of all trees is about 35 feet if it has been precommercially thinned.

Treatments were 33 percent and 50 percent removal based on the original relative density, calculated from the diagram of Wilson et al. (1999). Relative density is the ratio of the current density (trees per acre) to the maximum number of trees possible based on the current average tree volume. Trees to be cut were marked with paint for the harvester operators. Marking generally favored the largest, most vigorous crop trees, while attempting to maintain fairly uniform spacing of residuals and discriminating against smaller merchantable firs. One exception is that balsam fir (*Abies balsamea*) over 9 inches in diameter at breast height (d.b.h.) were generally removed, based on the increasing likelihood of heart rots and susceptibility to the balsam woolly adelgid (*Adelges piceae*).

Treatment plots are nominally 1.0 acres with a 0.2-acre measurement plot in the center (Fig. 2). Forwarder trails are spaced 100 feet apart with only one forwarder trail running through the sample plot. In the first two entries, small, single-grip processors used "ghost trails" spaced between forwarder trails to conduct thinnings.

Table 1.—Treatment prescriptions used in the PCT-origin stands. (Codes used in the subsequent text and analysis begin with the relative density reduction followed by the timing. For example, the 33 percent relative density removal waiting 5 years is coded "LT5.")

	Relative density (RD) reduction (code)	
Timing (code)	33% (LT)	50% (HT)
Immediate (0)	Evenly space residual stand and reduce RD by 33% in 2001-2002	Evenly space residual stand and reduce RD by 50% in 2001-2002
Wait 5 years (5)	Evenly space residual stand and reduce RD by 33% in 2006-2007	Evenly space residual stand and reduce RD by 50% in 2006-2007
Wait 10 years (10)	Evenly space residual stand and reduce RD by 33% in 2011-2012	Evenly space residual stand and reduce RD by 50% in 2011-2012
Never	Untreated control (NT)	

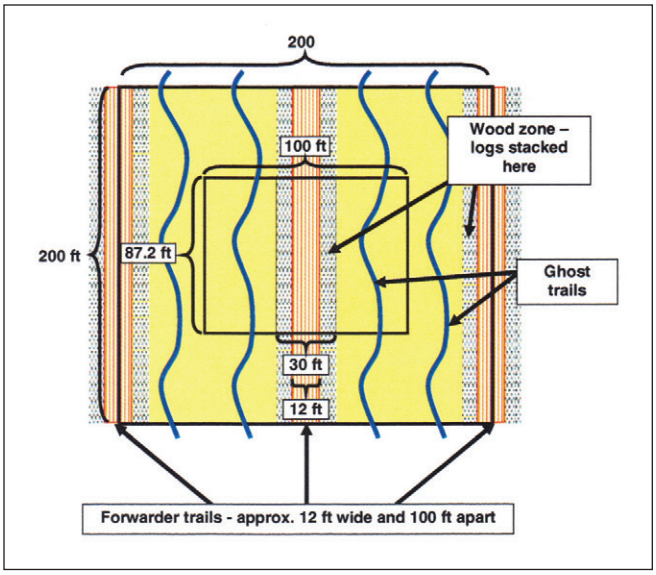


Figure 2.—Treatment and sample plot design for CFRU Commercial Thinning Research Network study sites.

Measurement Protocol

All trees ≥4.6 inches in d.b.h. have been measured annually since the study's inception on seven 0.20-acre (87.2 feet by 100 feet) sample plots per site that are centered within the 0.92-acre (200 feet by 200 feet) treatment plots. Measurements are status (live or dead, with apparent cause of mortality), d.b.h., total height, and crown height of every tree. All logs removed from the plots during thinning were measured for length, diameter, and species.

Initial Stand Conditions

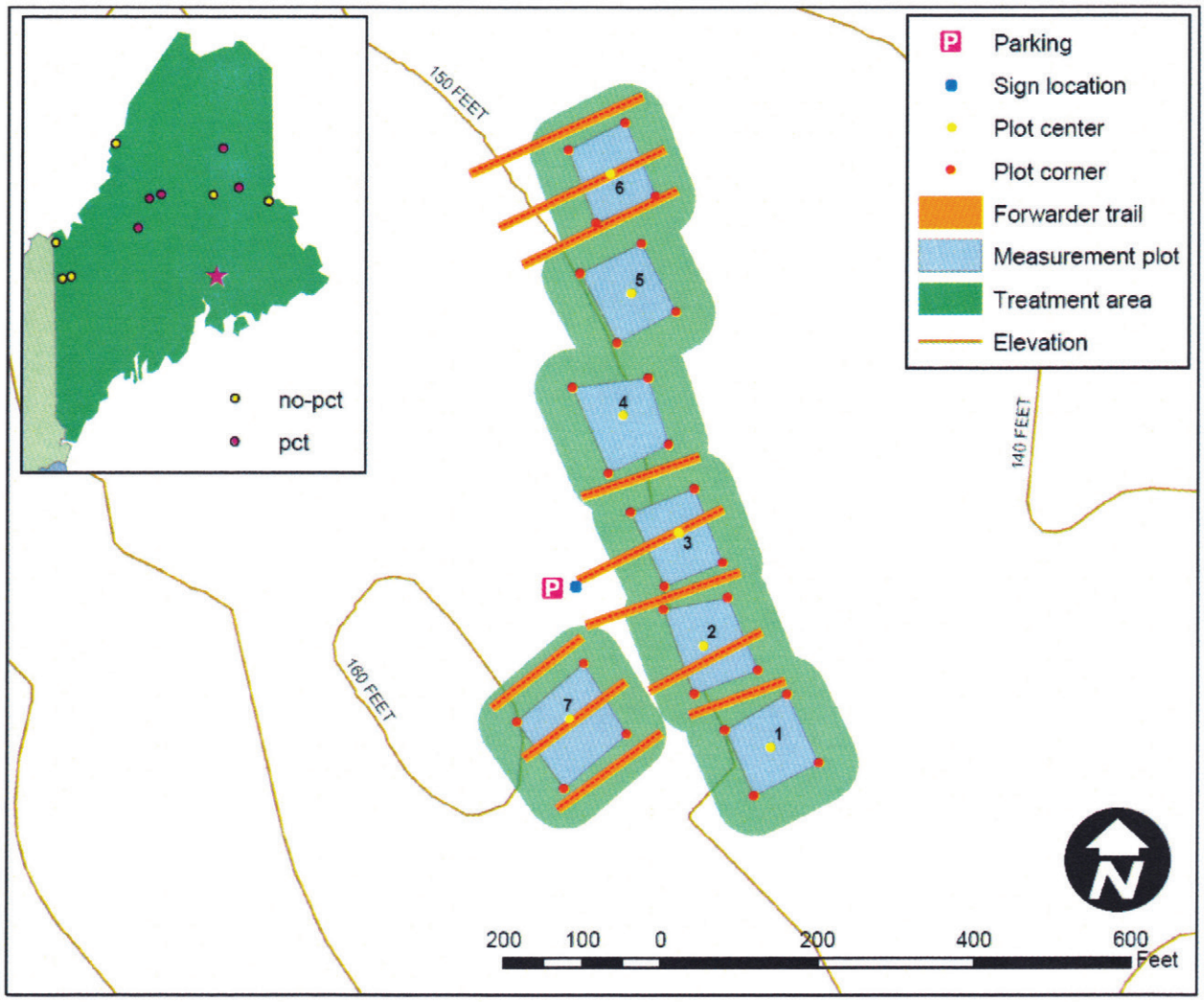
All stands were originally precommercially thinned during the 1980s to a spacing of about 8 feet by 8 feet (600-800 trees per acre). Stand age at the time of our first commercial thinning in 2001 ranged from 23 to 40 years; site index is high, ranging from 60 to 80 (height in feet at a breast-height [bh] age of 50). All sites are dominated by balsam fir, some more than others (Table 2). The remaining stocking is mostly red spruce (*Picea rubens*), with occasional white spruce (*Picea glauca*) and other conifers such as eastern white pine (*Pinus strobus*) and eastern hemlock (*Tsuga canadensis*).

PEF Study Site Description

The study stand, compartment 23A, is one of two replicates of the three-stage shelterwood treatment in the U.S. Department of Agriculture, Forest Service's long-term experiment on the PEF (Fig. 3). It originated after a shelterwood removal cutting that released small-sapling-size regeneration in 1972 (see Brissette and Kenefic, this volume). After the removal cutting, all stems >2.5 inches in d.b.h. were felled, resulting in a very uniform even-aged condition. Precommercial thinning was done in 1981 to a 2 m by 3 m spacing (slightly lower density than 8 feet by 8 feet). The first commercial thinnings were done in the winter of 2001-2002, the second treatments were completed

Table 2.—Preharvest stand metrics for the PCT-origin sites, averages or totals of all trees with d.b.h. ≥4.6 inches. (Site Index is the height of the tallest 40 trees per acre at a bh age of 50, from the equations in the appendix of Wilson et al. [1999]. QMD is the quadratic mean d.b.h.; volumes are from Honer's [1967] equations; merchantable limits are 4.6 inches d.b.h. to a 3.0-inch top diameter inside bark; relative density is from the equations in Wilson et al. [1999]; balsam fir percentage is based on the relative basal areas.) Site abbreviations from Figure 1 are Alder Stream (AS), Lake Macwahoc (LM), Lazy Tom (LT), the Penobscot Experimental Forest (PEF), Ronco Cove (RC), and Weeks Brook (WB).

Site	Age at bh (yr)	Site index	Basal area (ft^2 per acre)	Density (trees per acre)	QMD (inches)	Height (ft)	Total stemwood volume (ft^3)	Merchantable stemwood volume (ft^3)	Relative density	Balsam fir
AS	28	74	109	539	6.1	33	1,926	1,454	0.29	82%
LM	40	60	125	656	6.0	39	2,427	1,774	0.36	100%
LT	28	70	122	778	5.4	34	2,154	1,406	0.34	73%
PEF	29	67	101	606	5.5	35	1,854	1,254	0.29	69%
RC	23	80	113	736	5.3	31	1,802	1,169	0.29	97%
WB	29	67	124	831	5.3	35	2,273	1,477	0.36	92%



Penobscot Exp. For. Site Information		Plot Information		
Site name	PEF, Penobscot Exp. For., Compartment 23A Site	Plot	TrtmntDate	Treatment
Township	Bradley	1		Control
County	Penobscot	2	2001-2002	33%
Landowner	University of Maine	3	2001-2002	50%
History	PCT - 1983	4	2011-2012	33%
Plots established	August 2001	5	2011-2012	50%
Commercial Thinning(s)	February 2002, February 2007	6	2006-2007	50%
Location	45-51'-17" N, 68-38'-07" W	7	2006-2007	33%
For more information contact the Cooperative Forestry Research Unit at (207) 581-2893				

CFRU

Cartographer: Benjamin Gannon
Date: August 16, 2007
Projection: UTM Zone 19 North
Datum: NAD 1983

Figure 3.—Treatment map for the CFRU Commercial Thinning Study installation in compartment 23A of the PEF.

in the winter of 2006-2007, and the final (10-year) treatment was completed during the winter of 2011-2012.

Analysis

All data are contained in a master Microsoft Office Access database which is updated annually. Data included here include the preharvest measurements from 2001, along with the annual measurements from 2002 through 2011. Because trees are generally measured early in the growing season, this analysis thus includes nine growing seasons, broken into two periods corresponding to the timing of the 5-year treatments: 2002 through 2006, and 2007 through 2010. Data from the 5- and 10-year treatments were treated as unthinned controls during the years prior to thinning. The 10-year treatments were treated after the last measurement used here, so these plots are effectively the same as the controls during this period. Accretion is the volume increment on trees that are merchantable at the beginning of the growth period. Ingrowth is the ending-period volume of trees that grew across the 4.6-inch d.b.h. threshold. All volumes are merchantable, inside-bark cubic feet, from Honer's (1967) equations; merchantable limits include trees ≥4.6 inches in d.b.h. to a 3.0-inch top diameter inside bark. Statistical analyses were done with Systat's version 12 General Linear Model procedure (Systat Software Inc., San Jose, CA).

RESULTS AND DISCUSSION

Commercial Harvests

The first harvests (the "immediate" treatment, done in 2001-2002) yielded significant volumes of commercial products, ranging in value from about $500 to nearly $1,200 per acre on a mill-delivered basis (Fig. 4).

Over all sites, volume removals averaged between 8 and 10 cords per acre in the first entries in 2001. The year-5 entries removed 26 percent more volume than the first, undoubtedly owing to the higher stocking levels and taller trees removed with essentially the same prescription (Table 3).

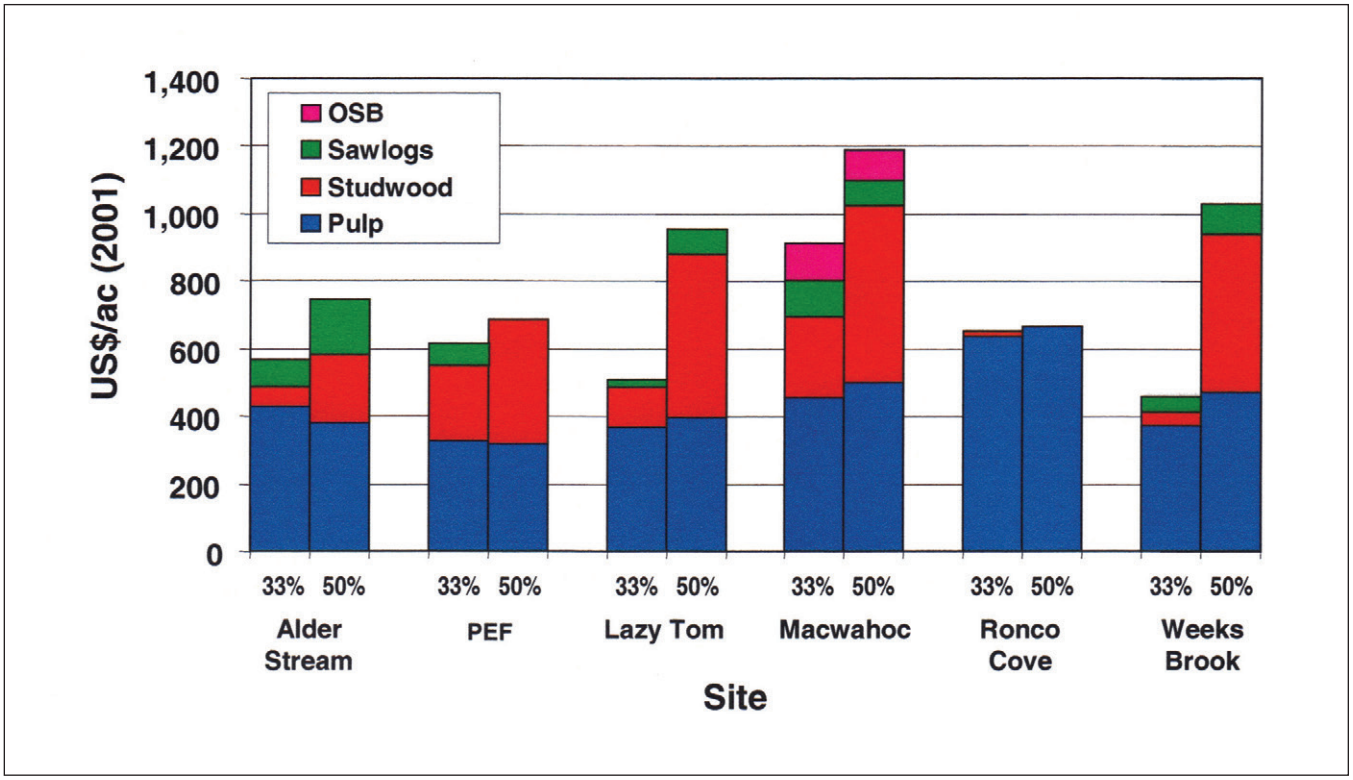


Figure 4.—Mill-delivered value by product class from thinning each of the six sites at 33 percent and 50 percent relative density reductions from first thinning (2001).

Table 3.—Merchantable harvests (cubic feet per acre, cords in parentheses) from the commercial thinning treatments averaged over all six sites, by timing and removal rate

Timing	LT (33%)	HT (50%)
Immediate	673 (7.9)	890 (10.5)
Year 5	934 (11.0)	1039 (12.2)

Nine-Year Stand Development and Growth Responses

Over all sites, yields increased from 1,694 ft^3 (19.9 cords) per acre in 2002 to 2,934 ft^3 (34.5 cords) in 2011, a 73 percent increase (Fig. 5). Net periodic annual increment (PAI) averaged 128 ft^3 (1.5 cords) per acre during the first 5 years, increasing to 143 ft^3 (1.7 cords) during the next 4 years. Over the 9-year period, yields of many plots more than doubled. These stands are exceptionally productive by any relevant standard. The only exception is the LM site, where the 5-year treatments suffered post-thinning mortality losses, as evidenced by the level or declining yields in two plots in the oldest site (>age 40, Fig. 5).

The overall analyses of variance (Table 4) revealed significant effects of treatment on the positive growth components, although this effect is due entirely to the lower growth of the "heavy thinning, wait 5 years" (HT5) treatment (Fig. 6). When each growth period was analyzed separately, accretion was not different among treatments during the first 5 years, averaging 116 ft^3 (1.4 cords) per acre per year. During this period, but not the second, there was a significant difference in ingrowth, with the unthinned controls exceeding the treated plots. Evidently, many small (<4.6 inches d.b.h.) trees were harvested in the early treatments, thus preempting their subsequent ingrowth.

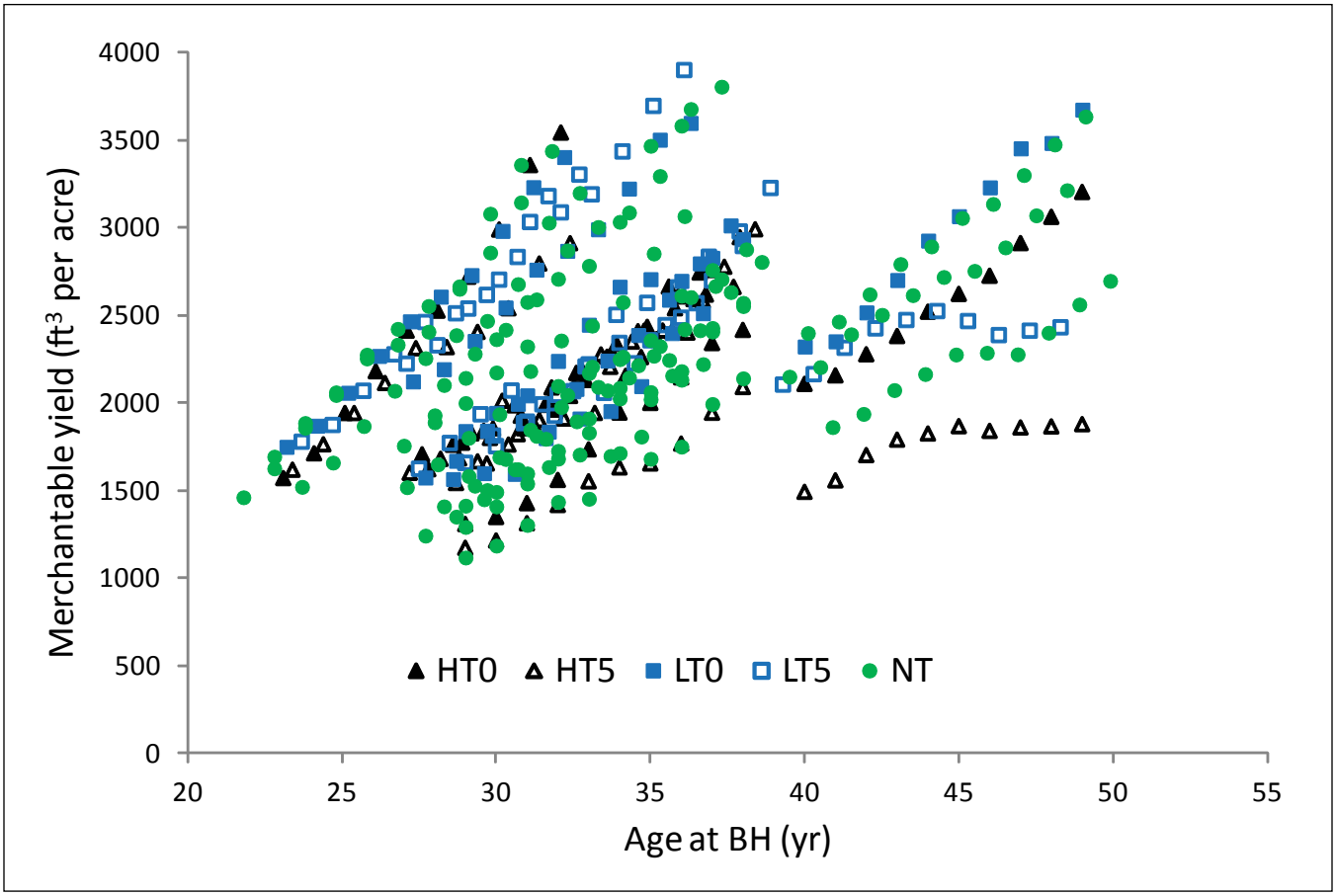


Figure 5.—Nine-year stand development of all 42 plots in the CTRN PCT study, grouped by thinning treatment. Yields include standing volumes plus removals in prior thinnings, if any.

Table 4.—Analyses of variance of four growth components using treatment and growth period as main effects and site as a blocking factor. P-values in italics are the probability of no differences in each growth component (columns) resulting from each factor. Data are least-squares means (in ft³ per acre per year); means followed by the same letter do not differ at p = 0.10 using Tukey's Honestly-Significant-Difference test.

Factor		Accretion	Ingrowth	Mortality	Net PAI
Treatment	*p-value*	*0.002*	*0.001*	*0.097*	*0.003*
LT0		153.5 b	8.6 a	15.6 a	162.1 a
HT0		133.4 b	6.1 a	5.9 a	139.5 ab
LT5		137.6 b	11.6 ab	22.3 a	149.3 a
HT5		99.7 a	12.7 ab	17.7 a	112.4 b
NT (control)		137.6 b	14.3 b	6.8 a	152.5 a
Growth period	*p-value*	*<0.001*	*<0.001*	*0.959*	*<0.001*
2002-2006		116.0 a	15.0 a	13.5 a	131.0 a
2007-2010		148.9 b	6.4 b	13.7 a	155.3 b
Site	*p-value*	*<0.001*	*<0.001*	*0.001*	*<0.001*
Ronco Cove (RC)		176.8 a	14.1 bc	6.8 a	190.9 a
Alder Stream (AS)		156.1 ab	8.3 b	5.0 a	164.4 b
Weeks Brook (WB)		136.6 bc	18.1c	11.0 ab	154.7 b
Lake Macwahoc (LM)		114.2 cd	1.6 a	23.6 b	115.8 c
Lazy Tom (LT)		107.5 d	8.9 b	26.3 b	116.4 c
PEF		103.4 d	13.3 bc	8.8 a	116.8 c

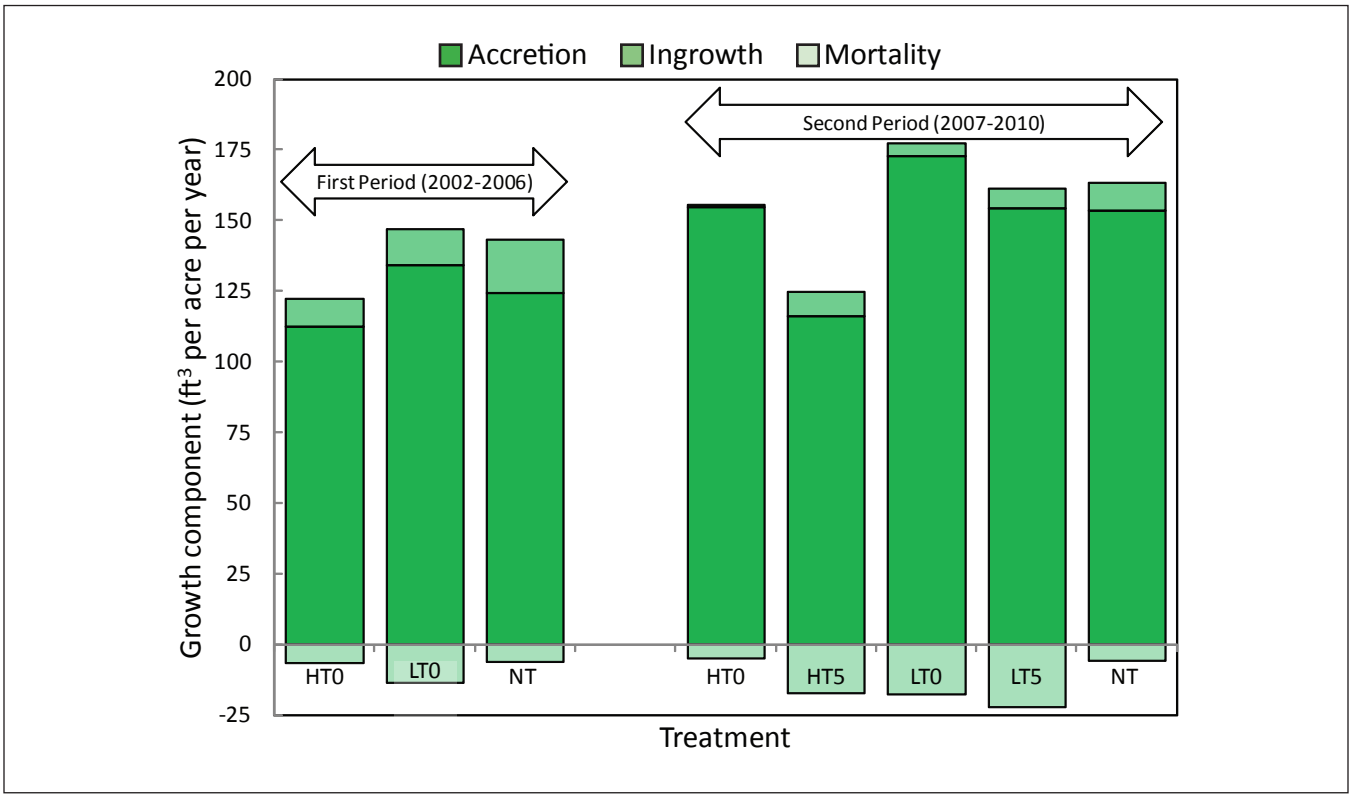


Figure 6.—Growth components (merchantable ft³ per acre per year) by thinning treatment and growth period, averaged over the six PCT sites. The positive height of the bars (accretion plus ingrowth) is the gross growth; gross growth minus the negative bars (mortality) is net growth.

Except with the HT5 treatment, growth increased significantly over the course of the study. Net PAI was 24 ft^3 greater during the second period than the first (Table 4). The treatment effect on mortality was marginally significant overall, yet no mean separations reached this significance threshold. Note that mortality was very low on the unthinned controls during both periods (Fig. 6), suggesting that these stands are not yet self-thinning.

Growth was quite different among the six sites (Table 4), reflecting differences in their site indices (Table 2). The extraordinary growth (>2 cords per acre per year) and high site index (80 feet) of the Ronco Cove site are especially noteworthy. The net PAIs of the top three sites (Table 4) exceed the highest PAIs reported in the Green River spacing study (Pitt and Lanteigne 2008), and the Ronco Cove site approaches the highest PAIs reported by Pelletier and Pitt (2008) for white spruce plantations with a high site index in northwestern New Brunswick.

When relative density at the midpoint of the growth period was added to the analysis of variance model (Table 4) as a covariate, treatment effects became highly significant (Fig. 7). This difference is due entirely to the relatively lower growth of the unthinned control plots at a given relative density. The different slopes fitted to each treatment separately suggest an interaction between treatment and relative density, but this interaction was significant only at $p = 0.29$. Clearly the thinned treatments are more growth-efficient at a given density, likely owing to their improved light environment. The pattern illustrated in Figure 7 is the main reason that Saunders et al. (2008) needed to perform extensive treatment-related growth calibrations to the Forest Vegetation Simulator for analyzing various commercial thinning regimes.

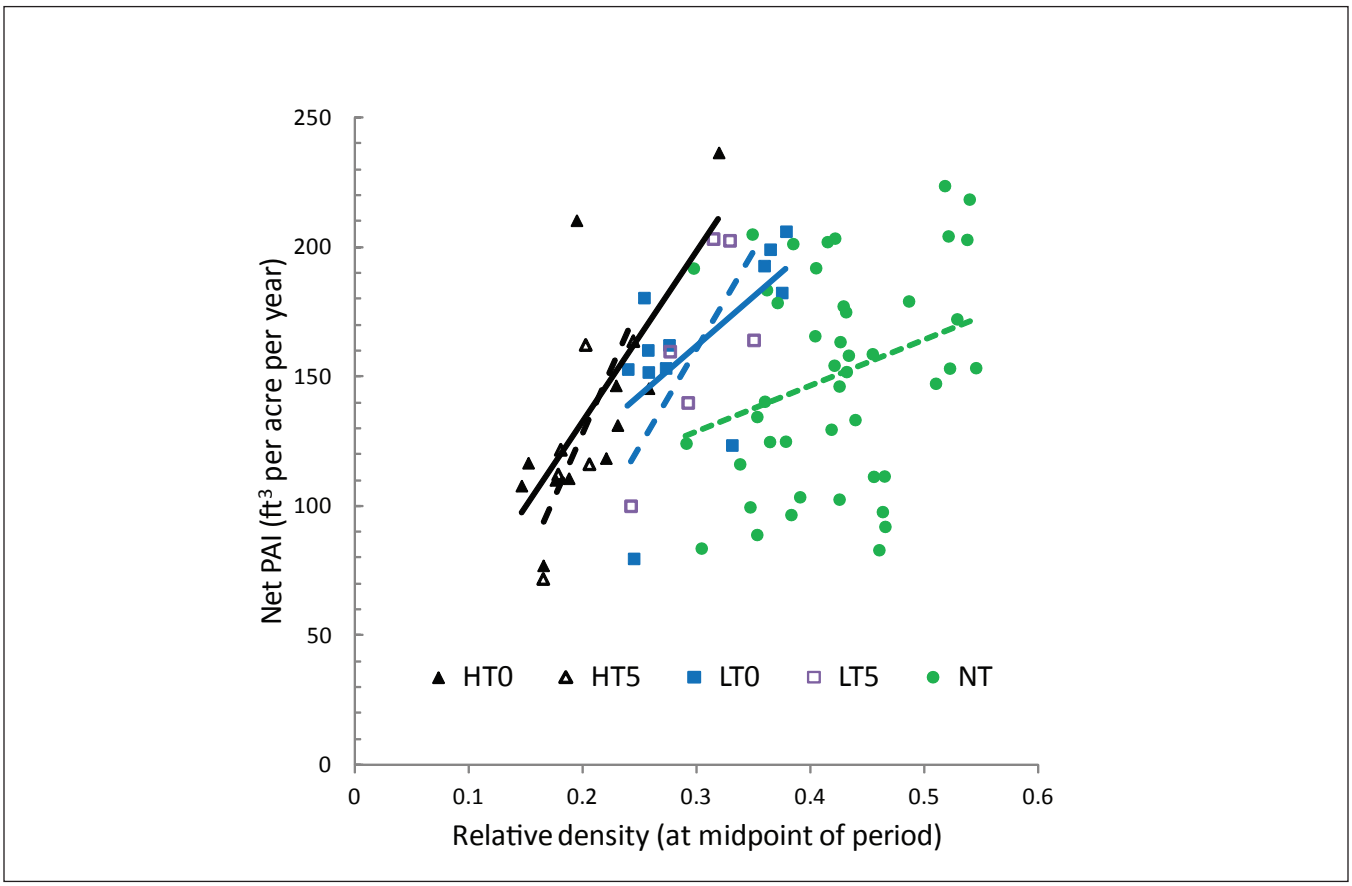


Figure 7.—Net PAI over relative density at the midpoint of the growth period, by treatment. Lines represent separate least-squares regressions fitted to each treatment.

Stand Development of the PEF Site in Compartment 23A

When the PEF plots are graphed on the Wilson et al. (1999) density management diagram (Fig. 8), we see that the 50 percent removal (H) treatments left residual stands at a density of 240-260 trees per acre, or a spacing of about 13 feet between crop trees. The 33 percent (L) treatments left about 100 more trees per acre (340-355), a spacing of 11 feet. Plots 1 (the control) and 4 (unthinned until 2012) began the study at a relative density of about 0.3 and have grown to nearly 0.5 over the 9-year period. No evidence of self-thinning or density-dependent mortality is yet apparent.

Growth components by treatment (Fig. 9) are somewhat lower than the overall study averages. During the first growth period, the L0 treatment grew much more than its heavier counterpart (H0), but during the second period, three large (8 inches, 12 inches, and 13 inches d.b.h.) balsam firs died standing on this plot. We suspect they were attacked by the balsam woolly adelgid, which has not been observed on the other five installations.

FUTURE WORK

Although these results are interesting, conclusive findings must await future measurements and include the outcome of the 10-year delayed treatments implemented during the winter of 2012-2013. We hope to maintain this study until stands reach rotation age. Mean annual increments are still much lower than periodic growth, suggesting the culmination is at least 10-20 years in the future. The CTRN was also expanded in 2009-2010 to include three more stands of PCT origin with lower site indices and more spruce stocking, and thus more representative of the entire spruce-fir region than the six fir-dominated stands with high site indices reported here.

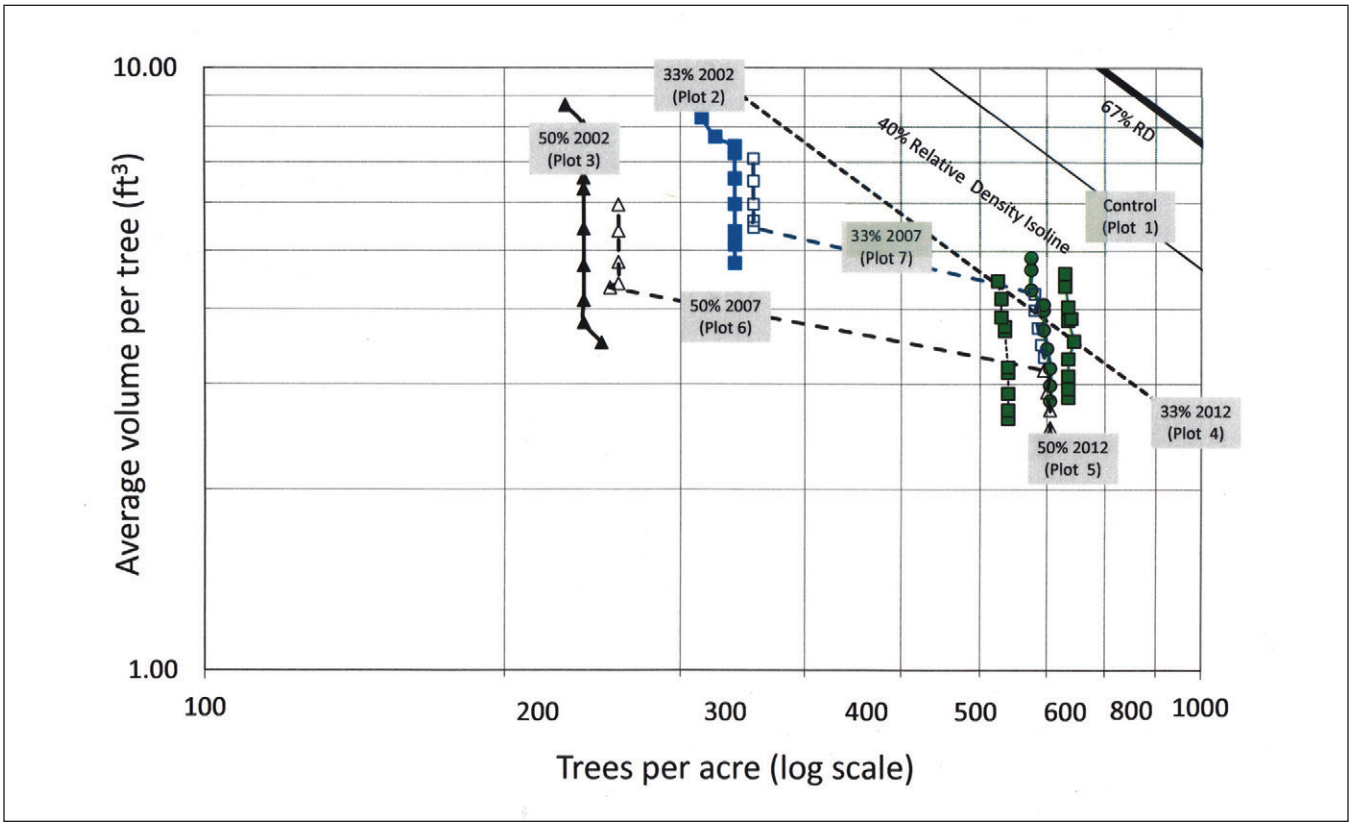


Figure 8.—Nine-year stand development of the PEF site plotted on the density management diagram of Wilson et al. (1999). Treatment symbols are identical to previous figures.

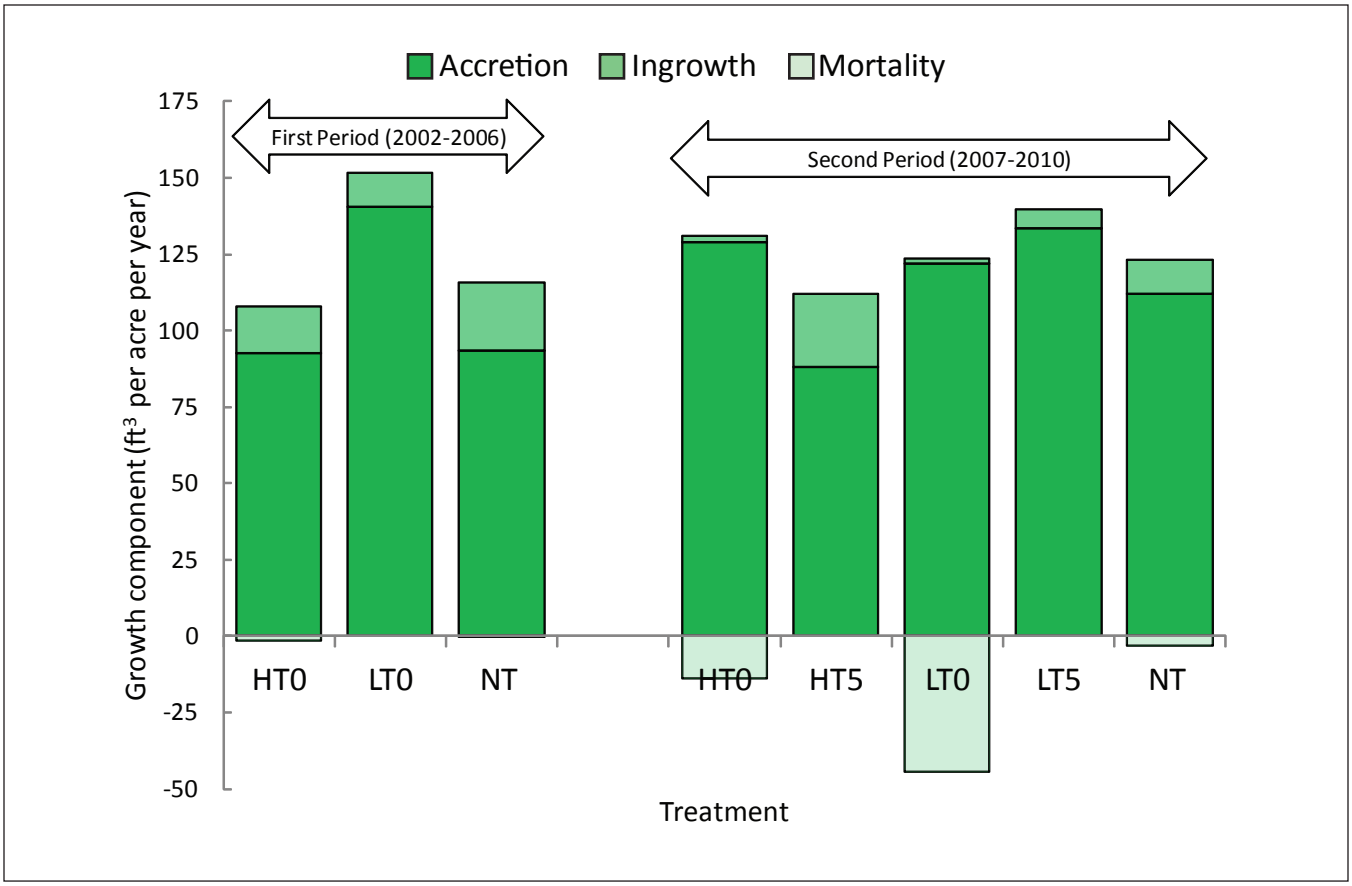


Figure 9.—Growth components (merchantable ft^3 per acre per year) by thinning treatment and growth period for the PEF site. The positive height of the bars (accretion plus ingrowth) is the gross growth; gross growth minus the negative bars (mortality) is net growth.

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