Stand Structure and Composition 32 Years after Precommercial Thinning Treatments in a Mixed Northern Conifer Stand in Central Maine

Aaron R. Weiskittel, Laura S. Kenefic, Rongxia Li, and John Brissette

ABSTRACT

The effects of four precommercial thinning (PCT) treatments on an even-aged northern conifer stand in Maine were investigated by examining stand structure and composition 32 years after treatment. Replicated treatments applied in 1976 included: (1) control (no PCT), (2) row thinning (rowthin; 5-ft-wide row removal with 3-ft-wide residual strips), (3) row thinning with crop tree release (rowthin+CTR; 5-ft-wide row removal with crop tree release at 8-ft intervals in 3-ft-wide residual strips), and (4) crop tree release (CTR; release of selected crop trees at 8×8-ft intervals). PCT plots had more large trees and fewer small trees than the control in 2008. There were no other significant differences between the rowthin and control. The rowthin+CTR and CTR treatments had lower total and hardwood basal area (BA) and higher merchantable conifer BA than the control. CTR also resulted in more red spruce (*Picea rubens* [Sarg.]) and less balsam fir (*Abies balsamea* [L.]) than the other treatments. Although stand structures for rowthin+CTR and CTR were similar, the percentage of spruce in CTR was greater. Although the less-intensive rowthin+CTR treatment may provide many of the same benefits as CTR, the latter would be the preferred treatment if increasing the spruce component of a stand is an objective. Overall, early thinning treatments were found to have long-term effects on key stand attributes, even more than 30 years after treatment in areas with mixed species composition and moderate site potential.

Keywords: balsam fir, red spruce, crop tree release, Acadian Forest, Penobscot Experimental Forest

Throughout the Acadian region, widespread spruce budworm (*Choristoneura fumiferana* [Clemens]) infestations during the 1970s and 1980s and subsequent salvage logging resulted in densely stocked immature spruce-balsam fir (*Picea* spp.: *Abies balsamea* [L.]) stands. Similar conditions have also resulted from more recent logging; 51% of harvests in Maine in 2008 were reported as shelterwood cuts (Maine Forest Service 2009). Currently, almost 40% of the spruce-fir forest type in Maine is in the sapling stage of development, and this proportion is expected to increase during the next decade (McWilliams et al. 2003). Because balsam fir seeds quite prolifically and grows more rapidly than its conifer associates, this species often dominates young softwood stands (Bakuzis and Hansen 1965). Growth of dense stands such as these is relatively slow and can be further depressed by hardwood competition (Newton et al. 1992).

Precommercial thinning (PCT) is an effective means of reducing stand density, accelerating crop tree growth, enhancing understory structural development, and maintaining desired species composition of northern conifer stands (Brissette et al. 1999, Pothier 2002, Pitt and Lanteigne 2008). Such treatments can increase windthrow resistance (Achim et al. 2005), wood uniformity (Shinya et al. 2002), nutrient availability (Thibodeau et al. 2000), spruce budworm resistance (Lamontagne et al. 2002), wildlife habitat availability (Homyack et al. 2004), and commercial operability (Piene 1982). PCT can also have a positive long-term impact on revenues; the simulated internal rate of return at peak net present value for PCT in a typical spruce-fir stand in Maine has been estimated to be between 7 and 14% (Saunders et al. 2007). Consequently, a significant number of acres are treated each year with PCT, particularly in the spruce-fir forest cover type.

Based on simulations with a regional growth-and-yield model, Saunders et al. (2007) suggested that 8 × 8-ft PCT spacings (i.e., ~680 stems ac^{-1}) are favorable in very productive areas (site index >70 ft at breast-height age 50) and where balsam fir composition is high (>80% of initial basal area [BA]). Numerous PCT trials have been established in the Acadian region, but very few have been maintained for the long term. An exception is the Green River thinning trial in northwestern New Brunswick that was installed between 1959 and 1961 and recently remeasured (Pitt and Lanteigne 2008). However, the site index of the Green River stand is quite high for the region (i.e., ~66 ft at breast height age 50), it was heavily dominated by balsam fir (>90% of initial BA), and ingrowth was removed for 11–13 years after PCT treatment. Additional information is needed on the range of long-term stand response to PCT in the Acadian region, particularly in areas of moderate productivity and mixed species composition, given the relative predominance of this stand condition in the region.

The goal of this study was to evaluate the influence of PCT on key attributes of a northern conifer stand in central Maine 32 years after treatment. Specific objectives were to evaluate the influence of the PCT

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treatments on stand structure (BA, merchantable BA, quadratic mean diameter [QMD], and diameter distribution) and species composition.

Methods

Study Area

The Penobscot Experimental Forest (PEF) is located in the towns of Bradley and Eddington in Penobscot County in central Maine (44°52′N, 68°38′W). The PEF is in the Acadian Forest (Braun 1950), which is a transition zone between boreal forests to the north and broadleaf forests to the south. Conifers with an admixture of hardwoods dominate the study area and include balsam fir, red spruce (*Picea rubens* [Sarg.]), white spruce (*Picea glauca* [Moench] Voss.), eastern hemlock (*Tsuga canadensis* [L.] Carr.), eastern white pine (*Pinus strobus* L.), and northern white-cedar (*Thuja occidentalis* L.). Hardwoods commonly found in the study area include red maple (*Acer rubrum* L.), paper birch (*Betula papyrifera* Marsh.), gray birch (*Betula populifolia* Marsh.), yellow birch (*Betula alleghaniensis* Britt.), quaking aspen (*Populus tremuloides* Michx.), and bigtooth aspen (*Populus grandidentata* Michx). A more complete description of the study area is found in Sendak et al. (2003).

The study site used for this analysis is located on a Monarda-Burnham stony fine sandy loam, which is relatively poorly drained and developed in a deep till parent material. The area is generally flat with slopes between 0 and 8%. Based on the last remeasurement, the balsam fir site index (base age of 50 years at breast height; Griffin and Johnson 1980) was estimated to be 46.8 ± 1.7 ft.

Experimental Design

The US Forest Service, Northeastern Forest Experiment Station (now the Northern Research Station) established a PCT study (Study 58) on the PEF in 1976. The purpose of this study was to investigate the long-term effects of different PCT regimes and fertilizer applications on species composition and the growth and yield of crop trees selected at the time of treatment. The PCT study was installed in a 10-year-old even-aged stand regenerated by a two-stage shelterwood sequence between 1957 and 1967. In 1957, 46% of the overstory was removed in the establishment cut, and the remaining merchantable overstory was harvested in the removal cut in 1967. In 1976, all residual trees of >5 in. diameter at breast height (dbh 4.5 ft) or estimated to be >20 years old were removed from the stand.

The experimental design was a completely random factorial arrangement with four different PCT treatments and two levels of fertilization, each replicated four times. The PCT treatments were applied with brushsaws between April and August of 1976 and included (1) control (no PCT); (2) row thinning (rowthin; 5-ft-wide row removal with 3-ft-wide residual strips); (3) row thinning with crop tree release (rowthin+CTR; 5-ft-wide row removal with crop tree release at 8-ft intervals in 3-ft-wide residual strips); and (4) crop tree release (CTR; release of selected crop trees at 8 × 8-ft intervals). Treatments were applied randomly to 80 × 80-ft experimental units, and 64 × 64-ft measurement plots were established within each experimental unit (Brissette et al. 1999). At the time of treatment, crop trees were selected from the largest and fastest-growing stems >4.5 ft tall, favoring (in order of priority) spruce species, balsam fir, eastern white pine, quality hardwoods, and eastern hemlock, with a minimum of 2 ft separating the crowns of adjacent crop trees. All woody and competing vegetation within 4 ft of each crop tree was mechanically removed both at the time of the initial treatment and 3 years later. Full tallies of trees by species and 1-in. dbh class (i.e., ≥0.5 in. dbh) on the plots were done in 1976 (pretreatment) and in 2008.

Data Analysis

A linear mixed model analysis of covariance was used to evaluate the data (Pinheiro and Bates 2000). Preliminary analysis indicated that pretreatment plot BA and species composition were significantly different. Consequently, the pretreatment value was used as a covariate in the analysis. A random effect for each plot was also estimated to account for unidentified factors that might influence the dependent variable. Pairwise comparisons among PCT treatments were made using Tukey's method of multiple comparisons, and statistical significance was deemed when $P < 0.05$. Preliminary analysis also indicated that fertilization did not have statistically detectable effects on any of the dependent variables and was consequently not used as a main treatment effect in the analysis, which is similar to the results of Brissette et al. (1999).

We used stand BA (ft^2 ac^{-1}) of trees ≥1 in. dbh as a measure of yield because regional volume equations were biased and confounded with treatment at this site (Weiskittel et al. 2009). Merchantable BA was calculated as the sum of individual BAs for trees ≥4.5 in. dbh. Species composition was analyzed by dividing the BA of species or species groups by total BA. Because species composition was a percentage, it was analyzed using a logit transformation. Finally, a three-parameter Weibull function was used to model the dbh distribution:

$$f(D) = \frac{c}{b}\left(\frac{D-a}{b}\right)^{1/c} e^{-[(D-a)/b]^c}, \quad (1)$$

where $f(D)$ is the probability density, a is the location parameter (assumed to be 0.5 in this analysis), b and c are scale and shape parameters, and D is diameter class. Parameters b and c were estimated for each plot using maximum likelihood. The Weibull function has been one of the most commonly used functions for modeling dbh distributions because it is flexible and produces probabilities without numerical integration (Cao 2004).

Results

Stand Structure

In 1976 (pretreatment), mean plot BA ranged from 13.9 to 19.3 ft^2 ac^{-1}, and there were an average of 1,829 to 2,560 trees ac^{-1} (Table 1). In 2008, mean BA ranged from 167.4 to 224.4 ft^2 ac^{-1}, and the mean number of trees per acre varied from 1,698 to 2,961 (Table 1). Mean BA and tree density differed significantly by treatment in 2008 ($P < 0.001$; Table 2). Pairwise comparisons indicated that rowthin+CTR and CTR treatments had significantly lower tree density and total BA in 2008 than the control, whereas the rowthin BA was not significantly different from the control (Table 2). Pairwise comparisons also suggested no statistically significant differences among the treatments in terms of merchantable BA (Table 2). However, the rowthin+CTR and CTR had significantly higher merchantable conifer BA by 56.5 ± 12.5 ft^2 ac^{-1} (mean ± SE) and 47.5 ± 12.8 ft^2 ac^{-1}, respectively, compared with the control for a given initial BA ($P < 0.001$; Table 2).

In 2008, the CTR treatment had the highest QMD (4.5 ± 0.1 in.), and the control had the lowest (3.8 ± 0.1 in.; Table 1). The PCT treatments had significantly higher QMD than the control but were not statistically different from one another ($P < 0.05$; Table 2). The differences in QMD were more evident when only conifer

Table 1. Mean attributes (standard error in parentheses) of the plots in 1976 (pretreatment) and 2008 (32 years posttreatment) by species group and treatment. The hardwood species included red maple, paper birch, gray birch, and quaking aspen, and the conifers were primarily red spruce and balsam fir.

Treatment	1976 Total basal area (ft^2 ac^{-1})	1976 Merchantable basal area (ft^2 ac^{-1})	1976 Tree density (trees ac^{-1})	1976 Quadratic mean diameter (in.)	2008 Total basal area (ft^2 ac^{-1})	2008 Merchantable basal area (ft^2 ac^{-1})	2008 Tree density (trees ac^{-1})	2008 Quadratic mean diameter (in.)
Hardwoods								
Control	7.3 (1.4)	0.7 (0.4)	760 (111)	1.3 (0.06)	54.5 (10.8)	40.0 (10.4)	460 (50)	4.5 (0.3)
Row thin	8.0 (1.3)	0.2 (0.2)	810 (121)	1.3 (0.03)	33.9 (4.6)	23.4 (4.3)	366 (48)	4.1 (0.1)
Row thin + crop tree release	5.1 (1.0)	0.0 (0.0)	468 (67)	1.4 (0.12)	6.2 (1.2)	1.4 (0.8)	179 (28)	2.5 (0.2)
Crop tree release	8.7 (1.3)	0.4 (0.2)	741 (98)	1.4 (0.06)	10.7 (1.9)	1.8 (0.8)	300 (43)	2.5 (0.1)
Conifer								
Control	11.9 (2.9)	0.0 (0.0)	1799 (375)	1.1 (0.02)	169.9 (14.9)	90.5 (12.5)	2502 (216)	3.5 (0.1)
Row thin	10.2 (2.2)	0.2 (0.2)	1476 (250)	1.1 (0.03)	169.3 (10.7)	113.0 (10.6)	1913 (137)	4.1 (0.2)
Row thin + crop tree release	8.8 (2.2)	0.0 (0.0)	1361 (305)	1.1 (0.04)	161.2 (4.6)	133.8 (6.3)	1538 (92)	4.4 (0.2)
Crop tree release	9.1 (2.5)	0.0 (0.0)	1321 (320)	1.1 (0.02)	174.1 (4.2)	145.8 (4.3)	1398 (44)	4.8 (0.1)
All								
Control	19.3 (4.1)	0.7 (0.4)	2560 (443)	1.2 (0.03)	224.4 (6.5)	130.5 (6.9)	2961 (184)	3.8 (0.1)
Row thin	18.2 (3.2)	0.3 (0.2)	2285 (338)	1.2 (0.02)	203.2 (8.7)	136.5 (9.4)	2279 (112)	4.1 (0.1)
Row thin + crop tree release	13.9 (2.3)	0.4 (0.2)	1829 (266)	1.2 (0.05)	167.4 (4.8)	135.2 (6.1)	1716 (97)	4.3 (0.2)
Crop tree release	17.7 (3.4)	0.4 (0.2)	2062 (367)	1.2 (0.02)	184.8 (3.6)	147.7 (4.7)	1698 (70)	4.5 (0.1)

Table 2. Multiple pairwise comparisons and adjusted 2008 means (standard error in parentheses) of the variables examined in this analysis among treatments obtained from the mixed-effects analysis of covariance using the initial plot pretreatment condition in 1976 as the continuous covariate.

Attribute	Treatment: Control	Row thin	Row thin + crop tree release	Crop tree release
Tree density (trees ac^{-1})	2962 (184)^{a}	2279 (113)^{b}	1716 (97)^{c}	1699 (70)^{c}
Total BA (ft^2 ac^{-1})	228.6 (7.7)^{a}	205.6 (6.7)^{a,b}	172.7 (8.6)^{c}	187.9 (7.1)^{b,c}
Merchantable BA (ft^2 ac^{-1})	147.4 (9.2)^{a}	135.8 (7.7)^{a}	137.6 (10.5)^{a}	147.4 (8.3)^{a}
Conifer merchantable BA (ft^2 ac^{-1})	88.9 (8.8)^{b}	112.3 (8.8)^{a,b}	136.4 (9.0)^{a}	145.5 (9.3)^{a}
Balsam fir merchantable BA (ft^2 ac^{-1})	36.2 (6.9)^{b}	62.1 (7.0)^{a,b}	79.1 (7.0)^{a}	47.1 (6.9)^{b}
Spruce merchantable BA (ft^2 ac^{-1})	7.7 (3.5)^{c}	15.8 (6.9)^{c}	43.2 (5.7)^{b}	91.9 (5.9)^{a}
QMD (in.)	3.8 (0.15)^{b}	4.1 (0.14)^{a,b}	4.3 (0.17)^{a}	4.5 (0.14)^{a}
Conifer QMD (in.)	3.8 (0.19)^{c}	4.2 (0.16)^{b,c}	4.7 (0.22)^{a,b}	4.9 (0.17)^{a}
Weibull scale parameter (b)	3.1 (0.3)^{a}	3.3 (0.3)^{a}	3.4 (0.8)^{a}	3.7 (0.7)^{a}
Weibull shape parameter (c)	1.7 (0.2)^{a}	1.6 (0.4)^{a}	0.9 (0.1)^{b}	1.2 (0.3)^{b}
Conifer BA (%)	78.1 (3.9)^{b}	84.7 (3.3)^{b}	98.4 (4.4)^{a}	96.4 (3.5)^{a}
Spruce BA (%)	5.6 (1.7)^{c}	11.6 (3.4)^{c}	30.3 (3.7)^{b}	54.9 (2.8)^{a}
Balsam fir BA (%)	38.2 (5.4)^{b,c}	50.5 (3.6)^{a,b}	58.3 (2.7)^{a}	34.5 (2.4)^{c}

^{a,b,c} Row values followed by the same letter were not significantly different. $P < 0.05$ using Tukey's multiple comparison test.
BA, basal area; QMD, quadratic mean diameter; b, Weibull scale parameter; c, Weibull shape parameter.

species were examined. Compared with the control, the QMD was greater by 1.1 ± 0.2 and 0.9 ± 0.2 for the CTR and rowthin+CTR, treatments, respectively (Table 2). Based on the current stocking and the Wilson et al. (1999) density management diagram, the control plots exceed the zone of competition-induced mortality (relative density > 0.67), whereas the PCT plots are rapidly approaching this value.

PCT also had a significant impact on the dbh distribution ($P <$ 0.001; Table 2). Pairwise comparisons for the shape parameter show that CTR and rowthin+CTR treatments were statistically different from the control and rowthin ($P < 0.05$; Table 2). The largest difference existed between the CTR treatment and the control (Figure 1). On average, the distribution was shifted toward the larger diameter trees following PCT. The CTR and rowthin+CTR treatments had relatively similar dbh distributions (Figure 1).

Species Composition

Prior to treatment in 1976, the mean percentage of BA composed of balsam fir ranged from 34 to 50%, whereas mean percentage of spruce was between 3 and 8% (Table 3). Red maple was the predominant hardwood in the stand, making up 26 to 38% of the initial BA (Table 3). PCT significantly shifted the species composition toward conifers ($P < 0.001$; Table 2). Conifer BA in the control was 78% on average, whereas the rowthin+CTR and CTR had means of 98 and 96%, respectively (Table 2). Although balsam fir composition was statistically influenced by PCT, red spruce was much more responsive (Table 2). Spruce BA was nearly 6% of the total BA in the control, but over 30% in the rowthin+CTR and nearly 55% in the CTR (Table 2). These increases were even greater for composition of merchantable BA (Table 3). Despite being a small component of the initial BA (9.1 ± 6.7%), other conifer species (eastern hemlock, eastern white pine, northern white-cedar) have increased in importance (16.2 ± 15.8%), particularly in the control plots.

Discussion

PCT has long been used to reduce competition and improve the growth of desirable trees and species in densely stocked mixed-species northern conifer stands in the Acadian region. PCT has been shown in several studies to have a positive impact on selected crop

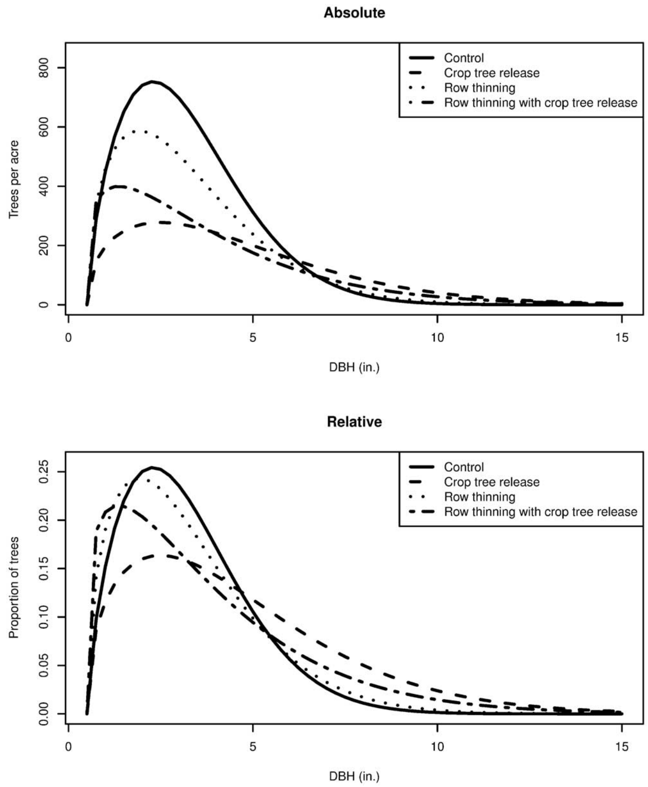

Figure 1. Absolute and relative predicted Weibull curves of 1-in. diameter classes by treatment.

tree growth and quality (Brissette et al. 1999). Weiskittel et al. (2009) found that the individual crop trees in the CTR treatment on the PEF had a 25-year diameter growth rate that was 136.1% higher than the crop trees in the control. At the stand level, PCT often increases stand value, enhances structure, and improves species composition (e.g., Pitt and Lanteigne 2008). However, long-term observations on the influence of PCT in the Acadian region are relatively few. Studies by Pothier (2002) as well as Pitt and Lanteigne (2008) have provided insights into the long-term response to PCT in stands predominated by balsam fir, whereas Brissette et al. (1999) and Weiskittel et al. (2009) examined changes in individual crop tree attributes only. The current study highlights the long-term stand-level response to PCT in conifer-dominated mixedwood stand with moderate site potential, which is relatively quite common in the Acadian region.

Since treatment over 32 years ago, stand structure and species composition have been greatly altered. There was originally a nearly even distribution of conifers and hardwoods, whereas the rowthin+CTR and CTR treatments now have over 90% of their BA in conifers. Although total stand BA and density were lower in the PCT treatments in 2008 than the control, the mean tree size and merchantable BA of conifer species were significantly higher. Given the significant increase in crop tree height growth reported by Brissette et al. (1999) 18 years after treatment and still evident more than 30 years after PCT (Weiskittel et al. 2009), the relative increase in merchantable stand volume is likely greater than that found for merchantable BA. Pitt and Lanteigne (2008) observed that merchantable BA in the thinned, conifer-dominated Green River plots was 12% higher than the unthinned plots, whereas gross merchantable volume (to a 3.1-in. top diameter) was 21% greater. Although total merchantable BA in the present study was not statistically different among treatments, conifer merchantable BA increased by 26 to 64% compared with the control (Table 2). Similar to the results of Pitt and Lanteigne (2008), this suggests that PCT can significantly increase growth and improve composition, even in areas not initially dominated by conifers and with a moderate site potential.

The residual target spacing used for PCT on the PEF ranged from ~5 × 3 to 8 × 8 ft; minimum intertree distances in 2008 ranged from 4.4 to 5.1 ft (based on stem density). These densities are much higher than those observed at Green River, where the mean minimum intertree distance ranged from 7.3 to 9.4 ft at the last remeasurement (Pitt and Lanteigne 2008). These differences illustrate the variability that can occur in residual stem density because of natural regeneration despite similar initial target spacings. This might also be reflective of the intensive cleaning of volunteer growth for 11 to 13 years after PCT treatment at Green River (Pitt and Lanteigne 2008). There were numerous noncrop trees in the sapling classes of the CTR treatment on the PEF in 2008; a subsample of tree ages suggests that most of these recruited after the PCT treatment (US Forest Service, unpublished data).

Using a calibrated version of the Forest Vegetation Simulator Northeastern Variant (FVS-NE) growth-and-yield model, Saunders et al. (2007) recommended PCT thinning targets of 1,200 stems ac^{-1} for most sites in the Acadian region, except on high-quality sites (site index >70 ft) with a large component of balsam fir (>80%). In the present analysis, there were relatively small differences in merchantable BA, QMD, and diameter distribution between the rowthin+CTR and CTR treatments. For a stand age and site index similar to those of the stand in this present analysis, Saunders et al. (2007) projected the QMD to be 17 and 24% higher in 6 × 6- and 8 × 8-ft treatments, respectively, compared with an unthinned stand. Pitt and Lanteigne (2008) found the QMD to increase by 14 and 23% for the 6 × 6- and 8 × 8-ft spacing treatments, respectively, compared with the control. In this analysis, the QMD was found to be 14 and 19% higher in the rowthin+CTR and CTR treatments, respectively, than in the control (Table 2). Thus, the results of this analysis support the recommendations made by Saunders et al. (2007) for the use of a 6 × 6-ft PCT residual spacing target on most sites in the Acadian region.

Despite the initial prevalence of hardwoods in the study stand, PCT clearly shifted the composition toward balsam fir and spruce, particularly in the CTR treatment where spruce increased significantly. Using simulations with FVS-NE, Saunders et al. (2007) found that 20% of the initial density of hardwood BA was enough to significantly alter stand development in the Acadian region, and PCT can act as a weeding treatment in mixedwood stands. This combined with the improved spacing provided by PCT can drastically increase growth, as implied by the results of the present study. As noted by Saunders et al. (2007), the early removal of hardwood species also gives greater flexibility in implementing future commercial thinning regimes.

The interaction of PCT and commercial thinning needs further investigation in the Acadian region. Saunders et al. (2007) found that commercial thinning was beneficial for most stands, independent of whether PCT had been applied. Similarly, Meyer et al. (2007) found no drawbacks to early commercial thinning on moderate to high sites in Maine, even in stands that have received PCT. On a relatively moderate site, the PCT plots in the present study have reached an important merchantability threshold and provide an opportunity to explore the interaction of PCT and commercial

Table 3. Unadjusted mean attributes (standard error in parentheses) of the plots in 1976 (pretreatment) and 2008 (32 years posttreatment) by species and treatment.

Treatment	1976		2008	
	Total basal area (≥0.5 in. dbh)	Merchantable basal area (≥4.5 in. dbh)	Total basal area (≥0.5 in. dbh)	Merchantable basal area (≥4.5 in. dbh)
	(%)			
Balsam fir				
Control	49.6 (4.7)	6.3 (6.3)	38.2 (5.4)	28.6 (7.7)
Row thin	42.2 (3.3)	0.0 (0.0)	50.5 (3.6)	46.8 (4.7)
Row thin + crop tree release	44.4 (7.5)	12.5 (12.5)	58.3 (2.7)	58.1 (3.7)
Crop tree release	34.3 (3.0)	0.0 (0.0)	34.5 (2.4)	31.9 (3.0)
Red maple				
Control	26.9 (3.2)	37.5 (18.2)	8.9 (0.6)	9.1 (1.8)
Row thin	25.5 (4.4)	0.0 (0.0)	8.8 (1.6)	7.5 (1.7)
Row thin + crop tree release	28.9 (3.9)	12.5 (12.5)	2.5 (0.5)	0.2 (0.1)
Crop tree release	38.2 (4.4)	25.0 (16.3)	5.2 (1.1)	0.9 (0.4)
Spruce				
Control	2.6 (0.7)	0.0 (0.0)	5.6 (1.8)	5.5 (2.1)
Row thin	3.7 (0.8)	0.0 (0.0)	11.6 (3.4)	11.4 (3.4)
Row thin + crop tree release	3.7 (0.5)	0.0 (0.0)	30.3 (3.6)	33.5 (5.0)
Crop tree release	7.5 (2.0)	0.0 (0.0)	54.9 (2.8)	62.1 (3.2)

thinning. This illustrates and underscores the importance of long-term research installations like those on the PEF.

Conclusions

Measurement of all trees of ≥0.5 in. dbh more than three decades after PCT in a mixed-species, even-aged northern conifer stand of moderate site potential revealed important long-term differences in structure and composition. Rowthin+CTR and CTR resulted in similar stand-level conditions (e.g., reduced total and hardwood BA, increased merchantable conifer BA, and increased proportions of spruce), and both differed significantly from the control. The PCT plots had more large trees and fewer small trees; this is reflected in the QMD, which was almost 20% greater in the CTR treatment than in the control.

The results of this study suggest few benefits from row thinning of northern conifers, without release in the residual strips. However, managers applying CTR or less-intensive rowthin+CTR can expect improved stand structure and composition. Of these two treatments, CTR was more effective for species composition control (i.e., this treatment resulted in less balsam fir and more red spruce). Additional observations across a larger range of sites are warranted to confirm the broad applicability of these findings.

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