Precommercial thinning in a northern conifer stand: 18-year results

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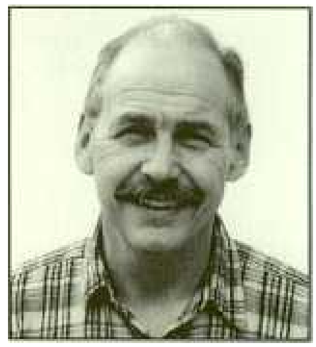
Four levels of precommercial thinning were applied with and without fertilization in a young, even-aged stand of northern conifers in east-central Maine. After 18 years, precommercial thinning resulted in longer and wider crowns and greater survival, growth, and yield of selected crop trees compared to untreated controls. Growth and yield were greater with uniform spacing at approximately 2.4 × 2.4 m and 1.5-m row thinning with crop-tree release in residual strips than with row thinning without crop-tree release. Control of stand species composition was greatest with uniform spacing. Fertilization had no significant effect.

Quatre niveaux d'éclaircie précommerciale ont été appliqués avec et sans fertilisants dans un jeune peuplement équienne de conifères nordiques du centre-est du Maine. Après 18 ans, l'éclaircie précommerciale a permis d'obtenir des cimes plus longues et plus larges et un taux de survie, une croissance et un rendement plus élevés parmi les arbres destinés à la récolte par rapport aux témoins non traités. La croissance et le rendement étaient plus importants lors d'un espacement uniforme approximatif de 2,4 × 2,4 m et d'un dégagement d'une rangée de 1,5 m où les arbres d'avenir se retrouvent dans les rangées résiduelles, que selon une éclaircie par rangée sans dégagement des arbres d'avenir. Le contrôle de la composition en espèces du peuplement était plus important suite au dégagement uniforme. La fertilisation n'a eu aucun effet significatif.

Introduction

Much of Maine and the Maritime Provinces are covered with a mixed-species forest that marks a transition from broadleaf forest to the south and boreal forest farther north. This territory is known as the Acadian Forest Region (Rowe 1972) and many of the tree species here are near their range limit, either south or north. The Acadian Forest Region is dominated by conifers, including boreal species such as balsam fir (*Abies balsamea* (L.) Mill.) and a number of spruces (*Picea* spp. A. Dietr.), and more southern species; e.g., eastern hemlock (*Tsuga canadensis* (L.) Carr.) and pines (*Pinus* spp. L.). Common hardwoods include red maple (*Acer rubrum* L.), paper birch (*Betula papyrifera* Marsh.), and aspen (*Populus* spp. L.). Stand-replacing fires are less frequent in the Acadian Forest than in other boreal or temperate forests (Wein and Moore 1977, 1979). More common natural disturbances are insect epidemics and windstorms that often cause sporadic, partial mortality.

Selective logging for high-value products was common during the 18th and 19th centuries. The rate of harvesting accelerated in the early 20th century as the pulp and paper industry expanded in the region. Following a severe outbreak of spruce budworm (*Choristoneura fumiferana* Clemens) that began in the mid-1970s, even-age management has become common (Seymour 1992). To ensure timely stand establishment following harvesting, advance regeneration is essential (Seymour 1995). Fortunately, natural reproduction is prolific in the Acadian Forest (Smith 1991), though not always of the species most desired by managers. Young conifer stands in the Acadian Forest can be very dense, i.e., as many as 60 000 seedlings per hectare (ha) (Baldwin 1977, Piene and Anderson 1987, Brissette 1996, Swift 1997). Severe competition among trees inhibits both individual tree and stand growth and development. Precommercial thinning (PCT) can reduce early competition and thereby increase growth on the remaining trees. PCT has been shown to increase the diameter growth of northern conifer species (Ker 1987, Barbour *et al.* 1992, Briggs and Lemin 1994, Burns *et al.* 1996). Further, depending on the method of PCT used, species composition of the stand can be altered.



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Fertilizers sometimes are applied to forest soils to offset deficiencies and increase tree growth (Pritchett 1979). However, faster growth of young trees can result in poorer wood quality by reducing relative density (basic specific gravity) and strength, and by prolonging production of low-quality juvenile wood (Panshin and de Zeeuw 1970). While Barbour *et al.* (1992) found that the relative density of red spruce (*P. rubens*

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Sarg.) wood was not adversely affected by PCT, Shepard and Shottafer (1990) found that the opposite was true for black spruce (*P. mariana* (Mill.) B.S.P.), a closely related species.

An experiment combining PCT and fertilization was initiated in 1976 on the Penobscot Experimental Forest (PEF) in east-central Maine. The objective of the study was to determine the degree to which cultural treatments such as selective and non-selective (mechanical) cleaning and thinning, applied independently or in combination with fertilization, affect species composition and the growth and yield of individual crop trees.

Materials and Methods

The PEF is located in the towns of Bradley and Eddington in Penobscot County. The centre of the 1 550 ha site is at approximately 44°52′N, 68°38′W. Glacial till is the principal soil parent material and soil types range from well-drained loams and sandy loams on glacial till ridges to poorly and very poorly drained loams and silt loams in flat areas between these low-profile ridges. The forest canopy is dominated by a mixture of species. Conifers include eastern hemlock; spruce, mostly red with some white (*P. glauca* (Moench) Voss); balsam fir; northern white-cedar (*Thuja occidentalis* L.); eastern white pine (*Pinus strobus* L.); and, infrequently, tamarack (*Larix laricina* (Du Roi) K. Koch) or red pine (*P. resinosa* Ait.). The most common hardwoods are red maple, paper and gray birch (*Betula populifolia* Marsh.) and aspen, both quaking (*Populus tremuloides* Michx.) and bigtooth (*P. grandidentata* Michx.). An array of silvicultural treatments was implemented on the PEF between 1952 and 1957 in a replicated experiment of both even-age and uneven-age management. The PCT and fertilizer study was installed in one of the even-aged stands that were regenerated by a two-stage shelterwood harvest. During the preparatory harvest of July 1957, 46 percent of the overstory stand volume was removed. The remaining overstory was harvested in October 1967.

For the PCT and fertilizer study, the experimental design is a factorial arrangement of four methods of PCT and two levels of fertilization. The eight treatment combinations, with four replications of each, were assigned completely at random to experimental units approximately 24 × 24 m. Soils within the study area differ only slightly; there are no very poorly drained loams. All submerchantable trees from the previous stand that remained in the experimental units were cut. These "holdover trees" were defined as larger than 12.7 cm in diameter at breast height (dbh) or estimated to be older than 20 years. Following removal of the holdover trees, densities of the 32 plots ranged from 27 540 to 79 783 trees per ha, with an overall mean of 42 736 trees per ha. To determine fertilizer application rates, 12 soil samples were collected at random from among the experimental units that were to be fertilized.

The PCT treatments, applied between April and August 1976, included: (1) Control – no PCT; (2) Row-No Release – 1.5-m mechanical row thinning with no crop tree release in 0.9-m residual strip; (3) Row-Release – 1.5-m mechanical row thinning with crop-tree release at intervals of about 2.4 m in the residual strip; and (4) Spacing—selected crop trees spaced at intervals of about 2.4 × 2.4 m. In the Row-Release and Spacing treatments, all woody vegetation was removed from around the crop trees, i.e., only crop trees remained. In the Spacing treatment, a minimum of 0.6 m separated the crowns of adjacent crop trees at the time of their selection. Crop-tree selection favoured red or white spruce. Where spruce was absent at the desired location, balsam fir, pine, quality hardwoods, hemlock, or other species were selected in that order. Selected crop trees were at least 0.3 m tall; their crowns had a full or nearly full compliment of foliage on at least three sides.

Table 1. Species and characteristics of selected crop trees when treatments were initiated

Species	N	Dbh Mean	Dbh Max.	Height Mean	Height Max.
		(cm)		(m)	
Balsam fir	908	1.5	5.6	1.95	4.32
Red spruce	641	0.8	8.1	1.59	5.10
White spruce	388	1.0	6.4	1.53	4.44
Paper birch	23	0.3	2.8	1.35	3.48
Red maple	15	1.0	7.4	1.83	7.35
Eastern hemlock	7	0.5	1.3	1.32	1.98
Eastern white pine	6	1.5	3.6	1.44	2.88
Other hardwoods	6	1.0	3.0	2.07	4.56
Overall [1]	1994	1.3	8.1	1.74	7.35

[1] Equivalent to 1638 trees per ha.

Fertilizer treatments included a control (no fertilizer) and fertilization with granulated limestone (spring of 1977) and urea (spring of 1978). The limestone provided about 2100 kg Ca and about 45 kg Mg per ha. The urea provided about 250 kg N per ha.

Following PCT treatment, a 19.5 × 19.5-m measurement plot was established in each experimental unit. On these plots, residual trees in the Row-Release and Spacing treatments were labelled, and potential crop trees were selected and labelled in the Control and Row-No Release treatments, at about 2.4 × 2.4-m spacing. In Control and Row-No Release, the order of species to favour as crop trees was the same as in the more selective treatments.

At a spacing of 2.4 × 2.4 m, 2048 crop trees were possible in the study. In all, 1994 crop trees were selected and identified, that is, a suitable potential crop tree was located at the desired spacing more than 97 percent of the time. Although red and white spruces were favoured for selection, together they accounted for only 52 percent of the crop trees; 46 percent were balsam fir. Less than 3 percent were other species, mostly paper birch and red maple. The initial dbh and height of the selected crop trees were measured (Table 1).

The identified crop trees were measured periodically. Analyses of variance for a completely random design was used to test for an interactive effect between PCT and fertilization, and for independent effects of fertilization and PCT for various response variables (Table 2). For individual crop trees, variables included diameter growth at breast height (1.37 m) and height growth, and crown width and percent live crown of balsam fir and red and white spruces. On a stand basis, variables included survival, basal area of all crop trees, and total volume of fir and spruce crop trees. Total tree volume (outside bark) was calculated using an equation by Lemin and Briggs (1993) for young precommercially thinned fir and spruce trees. In addition to the individual crop tree measurements, on 25 percent of the measurement area of each Control plot, the species of each tree was recorded and its diameter measured to the nearest 1.3 cm class.

Besides testing for an interaction and for main treatment effects, we were interested in all pairwise comparisons among PCT

Table 2. Analysis of variance for fertilization and precommercial thinning treatments in a completely randomized design with four replications

Source	Degrees of freedom	Mean square	F-test
Fertilization (F)			
Precommercial thinning (T)			
F × T			
Error			
Total			

treatments when the analysis of variance was significant ($p \le 0.05$). Those tests were made using the Tukey method of multiple comparisons (Neter *et al.* 1985), defining differences between means as significant when $p \le 0.05$.

Results and Discussion

After 18 years, neither the interaction between PCT and fertilization nor the main effect of fertilization had a significant effect on the crop-tree responses measured (probability values ranged from 0.2 to 0.9). Thus, there were no statistically detectable effects of fertilization on growth or yield in this experiment. By contrast, PCT had a marked effect on all measured variables.

The effect of fertilization on growth of spruce and fir following PCT is not clear. In a study in Newfoundland, Lavigne and Donnelly (1989) found that fertilizing with N did not increase growth of precommercially thinned balsam fir. However, based on results reported by Briggs *et al.* (1999), fertilization following PCT may increase growth of spruce and fir, if the fertilizer application is timed properly. They applied N one year after PCT, two years after that, both foliar concentration of N and current-year needle mass were significantly greater than in non-fertilized controls; N fertilization did not increase growth, however. The authors recommend waiting at least two years after PCT, and perhaps longer, before applying fertilizer.

Survival

On measurement plots, survival of crop trees ranged from 64 to 100 percent; overall survival was 90 percent. Together, the experimental treatments (fertilization, PCT, and their interaction) accounted for 69 percent of the variation in survival. The main effect of PCT alone explained 68 percent of the variation. Among pairwise comparisons of the PCT treatment means, differences ≥ 8.2 percent were significant. Consequently, all PCT treatments differed from the control, but not from each other (Table 3). Average survival of crop trees in the thinned treatments was 17 percent greater than in the control, or 294 more crop trees per ha in thinned than in unthinned stands. However, in Control plots, an undetermined number of trees not originally selected as crop trees developed into suitable crop trees. Most of these were balsam fir that replaced dead or suppressed spruce trees. These replacement crop trees did not become part of the experiment and were not measured. Compared to the initial densities of the eight Control plots, survival of all trees (not just crop trees) ranged from 25.3 to 70.6 percent (overall average of 39.3 percent), i.e., a rate about one-half that of the selected crop trees in those plots.

Dbh Growth

When this study was initiated in 1976, the average dbh of crop trees was 1.3 cm (Table 1). Over 18 years mean plot diameter growth ranged from 3.8 to 11.9 cm (overall average of 8.4 cm). The PCT treatments explained nearly all of the 94 percent of the variation accounted for by the ANOVA model. Together, the PCT × fertilizer interaction and the main effect of fertilizer explained less than 1 percent. PCT treatment means differed significantly when diameter growth differed by ≥ 1.0 cm. Thus, all PCT treatments exceeded the Control, and Row-Release and Spacing treatments had significantly more growth than the Row-No Release treatment (Table 3). However, there was no significant difference between Row-Release and Spacing.

For the PCT treatments combined, 18-year growth in dbh was double that of the control. When crop trees were fully released (Row-Release and Spacing) their growth was about 60 percent greater than if they had been released on only two sides (Row-No Release). Differences among treatments clearly show the impact of stand density on the diameter growth of individual trees. As shown in similar studies with northern conifers (Ker 1987, Burns *et al.* 1996), the diameter of crop trees increases when they are given additional room to grow.

Mean dbh of the sample of all trees in the Control plots ranged from 4.7 to 6.6 cm (overall average 5.6 cm). Because the best trees were selected as crop trees at the start of the experiment, it is reasonable to assume that the overall average dbh was less than the initial average crop tree mean of 1.3 cm. Nevertheless, in the control plots, average stand diameter growth was probably somewhat less than that of the crop trees.

Height Growth

Average crop-tree height was 1.74 m when the study began (Table 1). Average height growth on measurement plots was 4.9 to 8.0 m (overall average of 6.2 m). Treatments accounted for 87 percent of the variation in average plot height growth, with PCT treatments alone accounting for 85 percent. PCT treatment means that differed by ≥ 0.5 m were significant. All PCT treatments grew significantly taller than the Control, and Row-Release and Spacing had significantly more height growth than Row-No Release (Table 3). The difference between Row-Release and Spacing was not significant. On average, crop trees from PCT plots grew 32 percent taller than crop trees in the control plots, and Row-Release and Spacing crop trees grew at least 15 percent taller than Row-No Release crop trees.

Height was not measured on the sample of all trees in the Control plots. Because mortality among crop trees was greatest in the Control plots, it is also likely that some crop trees in that treatment became suppressed during the 18 years following their selection. However, at 18 years, the average dbh of the surviving crop trees in the Control was greater than the mean dbh of the treatment as a whole, i.e., the initially selected crop trees grew to be larger than the stand overall. Because the crop trees were, on average, larger in diameter, it is also probable that their mean height was at least than that of the stand. Thus, the mean height for the crop trees in the Control plots is a reasonable estimate of the mean height of the treatment. Because the crop trees in the Control treatment were shorter than the crop trees in the PCT treatments, it is most likely that the treatment as a whole was shorter as well.

Generally, height growth is considered independent of stand density; that relationship is the basis for site index.

Table 3. Effects of precommercial thinning on growth and yield of selected crop trees 18 years after treatment

Response Variable	Units	Control	Row-No Release	Row-Release	Spacing	MSD[1]
				93.8b		
				10.7c		
				7.1c		
				2.9c		
				70.5c		
				18.3c		
				85.7c		

[1] MSD = Minimal significant difference by Tukey method of multiple comparisons at $p \leq 0.05$; i.e., within each response variable, means followed by different letters are significantly different.

However, our results show that the height growth of crop trees can benefit from reducing stand density with PCT. Results elsewhere are inconsistent. Initially following PCT, the height growth of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) on a relatively poor site was reduced (Harrington and Reukema 1983). However, 10 to 20 years after thinning, height-growth increment of PCT treatments were significantly greater than that of the control. Ker (1987) found no significant difference in the height of balsam fir between PCT and control plots for any five-year period up to age 25, but Piene and Anderson (1987) reported 27 percent greater height growth after 10 years in spaced stands than in unspaced controls. Burns *et al.* (1996) concluded that for black spruce growing on three sites in northern Minnesota, spacing at 2.7 × 2.7 m increased site index by about 30 percent. Whether height growth increases following PCT probably depends largely on site factors.

Crown Width and Percent Live Crown

Crown dimensions are important because they provide an indication of past competition and potential for future growth. Competition reduces crown size, especially width. On a given site, trees with larger crowns should grow more than trees with smaller crowns. However, percent live crown is an indicator of the amount of the bole that can produce knot-free wood (more live crown results in knottier wood).

In this study, the average crown width of balsam fir and spruce trees on measurement plots was 1.4 to 3.4 m (overall average of 2.4 m). Treatments explained 94 percent of the variation. Of the response variables, crown width was most affected by the fertilizer × PCT interaction. Nevertheless, that relationship was not statistically significant ($p = 0.17$) and the interaction and fertilizer effects together explained only 1.6 percent of the variation in crown width.

PCT treatment means differed significantly when crown width differed by ≥ 0.2 m. Row-No Release (two sides) had significantly wider crowns than the Control, and Row-Release and Spacing (full release) crowns were wider than Row-No Release (Table 3). The crowns of balsam fir and spruce crop trees for all the PCT treatments combined were 46 percent wider than those in the Control, and Row-Release and Spacing crowns were 48 percent wider than Row-No Release crowns.

Average percent live crown of balsam fir and spruce crop trees was 37.7 to 73.4 (overall average of 59.2 percent). Treatments explained 92 percent of the variation, virtually all due to PCT alone. Among PCT treatments, differences ≥ 5.1 percent were significant. All PCT treatments had more live crown on average than the Control, and Row-Release and Spacing had more live crown than Row-No Release (Table 3). The difference between Row-Release and Spacing was not significant. On average, balsam fir and spruce crop trees in the PCT treatments had 21 percent more live crown than Control trees, and crop trees in Row-Release and Spacing had 14 percent more live crown than Row-No Release trees. Clearly, the wider, longer crowns in the PCT treatments reflect more open growing conditions from thinning and show that crowns develop in both width and length to occupy available space.

Crop-Tree Basal Area

After 18 years, plot basal area of crop trees ranged from 3.5 to 23.2 m^2/ha and averaged 13.2 m^2/ha; 94 percent of the variation in plot basal area was explained by treatments, all but 1 percent by PCT alone. Differences among PCT treatment means were significant when basal area differed by ≥ 2.6 m^2/ha. All PCT treatments had significantly more basal area than the Control; Row-Release and Spacing had more basal area than Row-No Release (Table 3). As with the other measures of growth, the difference between Row-Release and Control was not significant.

The Control crop trees had 60 percent of the basal area of Row-No Release crop trees but less than 30 percent of the basal area of the Row-Release and Spacing crop trees. The magnitude of the differences suggests that full release had twice the impact on basal area of crop trees as Row-No Release (two sides).

When all trees, not just crop trees, in the Control were included, basal area ranged from 23.0 to 49.1 m^2/ha. The overall mean of 41.9 m^2/ha was twice the average basal area of the Spacing treatment. However, in the Control there were eight times as many trees as in the Spacing treatment, and the mean dbh was only 45 percent of that in the spaced plots.

In our study, we had the same potential number of crop trees in each treatment (1682 trees/ha), whereas in the study by Burns *et al.* (1996) the number of crop trees varied by treatment. On a per-tree basis, their control treatment had 35 percent of the basal area of 2.7 × 2.7-m spacing 20 years after treatment. This was similar in magnitude to our results.

Balsam Fir and Spruce Volume

The total volume outside bark of balsam fir and spruce crop trees larger than 1.3 cm dbh ranged from 16.9 to 114.4 m^3/ha (overall mean of 62.2 m^3/ha). Treatments accounted for 90 percent of the variation in volume among plots, with PCT alone accounting for all but 1 percent. PCT treatment means were significantly different when they differed by ≥ 15.4 m^3/ha. Differences in volume among PCT treatments followed the same pattern as all the response variables except survival; that is each PCT treatment differed from Control and Row-Release and Spacing differed from Row-No Release but not from each other (Table 3). The magnitude of the differences for volume were

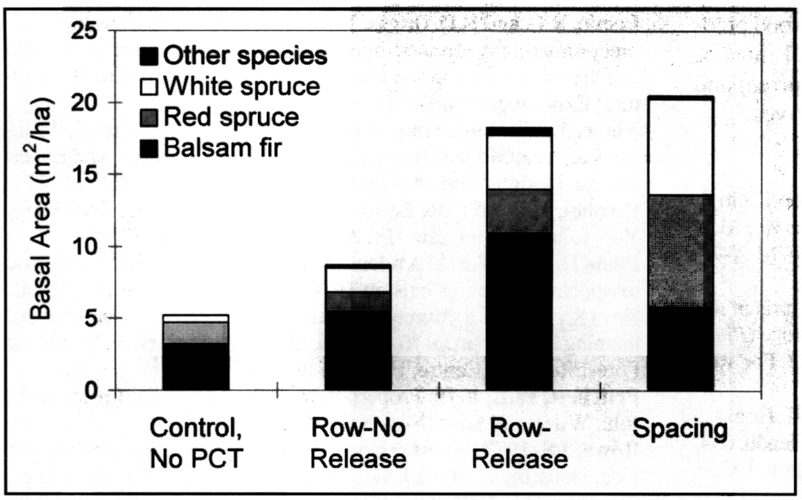

Fig. 1. Basal area by species of crop trees 18 years following precommercial thinning by four methods.

nearly identical to those for basal area. Crop trees in the control plots had about 60 percent the volume of Row-No Release but only 28 percent of the average volume of Row-Release and Spacing crop trees.

Among all trees in the control plots (not just crop trees), balsam fir and spruce accounted for 61 percent of the basal area and had 82 percent as much volume as the fir and spruce crop trees in the Spacing treatment. Although we only calculated volume of balsam fir and spruce trees, it is likely that the total volume of all species in the Control was greater than the total volume in Spacing, but in many more trees of much smaller size.

In the study by Burns *et al.* (1996), crop trees in the control plots had 37 percent of the volume of trees in 2.7 × 2.7-m spacing. Studying the effects of PCT on balsam fir in northern New Brunswick, Ker (1987) showed that for the total stand, spacing at 2.4 × 2.4 m resulted in 13 percent less volume than unthinned control plots 20 years after treatment. However, for trees > 9 cm dbh, spaced plots had 12 percent greater volume. In another study with balsam fir, Piene and Anderson (1987) showed that 10 years after spacing, volume increased by 36 to 135 percent over the control depending on initial density. Initial density was especially important in their study because the stands were not thinned until about 17 years after overstory removal.

Species Composition

In our experiment, PCT also had a marked impact on species composition. There was little control of species composition in Row-No Release and Row-Release because about 62 percent of the area in these treatments was removed in the rows. Spacing and Control had the least restriction on selecting individual crop trees. In Spacing, crop trees were selected from essentially the entire plot and released on all sides.

Consequently, in Control, Row-No Release, and Row-Release, red and white spruce make up 35 to 38 percent of the crop-tree basal area; in Spacing, spruces account for 70 percent (Fig. 1). Results are similar for fir and spruce volume. Thus, spruce is likely to be twice as dominant following standard 2.4 × 2.4-m spacing compared with mechanical row thinning when selection criteria as employed in this experiment are used.

Among all trees in the Control, red and white spruce accounted for only 6 percent of the basal area, balsam fir for 55 percent. Other dominant species were eastern white pine (14 percent) and eastern hemlock (10 percent). The most dominant hardwood was red maple (7 percent).

The ability to modify species composition in northern conifer stands is important because spruce is longer lived and more resistant to spruce budworm than balsam fir (Blum 1990, Frank 1990). If the goal is to maximize spruce fibre production or to maintain a mixed northern conifer stand beyond pulpwood rotation, more selective PCT treatments, such as spacing to favour spruce, should be preferred over row thinning.

Summary and Conclusions

In this study of the effects of fertilization and PCT on the survival, growth, yield, and species composition of northern conifers 18 years after treatment, PCT affected a number of individual tree and stand responses, but fertilization did not. Based on the results, we offer the following conclusions about PCT:

- Crop trees in the Control plots had smaller crowns and poorer survival, growth, and yield than crop trees in plots that received some form of PCT. However, when all trees were considered, the greatest basal area was in the Control, albeit in a large number of relatively small stems.
- Following PCT with rows, crop trees that were released in the residual strips developed larger crowns, had greater diameter and height growth, and yielded more wood than initially similar trees that were not released.
- Results of PCT with rows and release were similar statistically to those with conventional 2.4 × 2.4-m spacing.
- Whether PCT was done or not, the experimental plots were dominated by conifers; however, 2.4 × 2.4-m spacing controlled species composition better than no PCT or PCT with rows.

For individual crop trees, PCT can increase both diameter and height growth rates. On a stand basis, species composition can be altered but the impact on growth is not as dramatic as for individual trees. Nevertheless, numerous studies suggest that PCT will reduce the stand age at which commercial thinning can be contemplated. Furthermore, at that age, merchantable volume will be higher in a PCT-treated stand than in an unthinned stand. However, early thinning likely will prolong the period in which juvenile wood is formed and a larger number of larger branches will be retained. Thus, any gains in tree growth may be offset by poorer quality wood products. Consequently, decisions on whether to use PCT must be based on stand-level factors such as site quality, current and desired species composition, and long-term objectives.

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