# Early Growth Responses of Naturally Regenerated Eastern White Pine (*Pinus strobus* L.) to Partial Release from Juvenile Aspen and Pathological Pruning

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**ABSTRACT:** *Height, breast height diameter, and basal diameter growth responses of 7- to 12-year-old naturally regenerated eastern white pine (*Pinus strobus *L.) to partial release from juvenile (15-year-old) trembling and bigtooth aspen (*Populus tremuloides *Michx. and* Populus grandidentata *Michx.) and pathological pruning were monitored over four growing seasons. Pathological pruning is the removal of disease-infected branches before the disease can reach the stem or the removal of lower branches that are most susceptible to infection. Results indicated that seedling growth responses to release and pruning depended strongly on the height stratum to which a seedling belonged. Whereas growth rates of small white pine up to 190 cm tall were significantly reduced by increasing aspen densities and by pruning, growth rates of white pine taller than 190 cm were not significantly affected by either aspen density or pruning. Effects of pruning on small white pine were restricted to the first 2 years after release, after which growth rates were similar between pruned and unpruned individuals. This likely was due to natural crown recession of unpruned white pine, which brought crown lengths and crown ratios closer to those of pruned individuals. Besides affecting natural crown recession rates and growth of small unpruned white pines, release intensity also affected upper stratum aspen, which responded vigorously to release. Findings of this study suggest that early release from upper stratum juvenile aspen should enable the conversion of an aspen cover type to a mixture of aspen and white pine, but may have to be followed up by repeated interventions into the upper canopy stratum. It is, however, questionable if the expense of pruning to prevent blister-rust infections under a partial canopy is warranted. North. J. Appl. For. 22(1):27–34.*

**Key Words:** Aspen, growth, pathological pruning, release, white pine.

Eastern white pine (*Pinus strobus* L.) was once a dominant tree species in much of the Lake States forests. In northern Minnesota, after the intensive white pine harvests in the late 1800s and early 1900s, much of the forest has succeeded to an aspen (*Populus* spp.) cover type. Recently, landowners throughout the western Lake States have begun to convert aspen/northern hardwood cover types to conifer cover types, with a special interest in white pine (WPRSWG 1996, Burgess et al. 1999).

Historical site conversion prescriptions from aspen to conifers call for clearcut, chemical, or mechanical site preparation by shearing, roller chopping, or barrel scarifying, followed by planting of conifers (Perala 1977). Successfully converting a site to white pine after clearcutting, however, has been difficult. In the absence of intensive site preparation, white pine often is outcompeted in highly productive mixed-hardwood stands, where early height growth of hardwoods typically exceeds that of white pine (Lancaster and Leak 1978). Moreover, unsuccessful regeneration efforts

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Table 1. Density and characteristics (mean and standard error by plot) of the aspen overstory on the research plots in 1998 (post-cut) and in 2000.

| Plot No. | 1998 | | | 2000 | | | |
|---|---|---|---|---|---|---|---|
| | Stems/ha | Avg. dbh (cm) | Basal area ($m^2$/ha) | Stems/ha | Avg. dbh (cm) | Avg. ht (m) | Basal area ($m^2$/ha) |
| 5 | 1,486 ± 633 | 4.7 ± 0.5 | 2.8 ± 1.5 | 2,193 ± 462 | 6.1 ± 0.6 | 7.2 ± 0.5 | 6.7 ± 2.4 |
| 3[a] | 1,769 | 3.2 | 2.4 | 1,022 | 8.0 | 9.6 | 5.2 |
| 8[a] | 2,162 | 2.1 | 1.4 | 1,257 | 5.3 | 7.6 | 3.1 |
| 1 | 2,706 ± 1,832 | 4.3 ± 1.7 | 4.2 ± 2.6 | 3,024 ± 1,308 | 5.6 ± 1.7 | 7.5 ± 1.8 | 6.7 ± 0.9 |
| 9 | 2,954 ± 664 | 4.6 ± 0.7 | 5.6 ± 1.7 | 2,343 ± 683 | 6.5 ± 0.7 | 8.3 ± 0.3 | 8.3 ± 3.3 |
| 6 | 3,565 ± 509 | 4.0 ± 1.6 | 5.9 ± 3.6 | 2,343 ± 279 | 6.4 ± 1.1 | 7.9 ± 1.1 | 7.9 ± 2.6 |
| 4 | 4,389 ± 2,259 | 3.6 ± 1.4 | 6.2 ± 3.9 | 2,264 ± 592 | 6.3 ± 2.0 | 7.3 ± 1.5 | 8.3 ± 4.0 |
| 2 | 9,904 ± 4,901 | 3.5 ± 1.9 | 9.2 ± 4.9 | 5,659 ± 2,647 | 3.5 ± 1.0 | 5.1 ± 1.2 | 6.8 ± 4.2 |
| 7 | 11,884 ± 6,529 | 4.4 ± 1.8 | 18.0 ± 8.1 | 7,924 ± 2,934 | 5.5 ± 1.6 | 8.5 ± 1.5 | 19.6 ± 5.8 |

[a] In plots 3 and 8, only one large central plot was established, precluding calculations of standard errors. In all other plots, five measurement plots were established.

are often attributed to biological agents that include white pine blister rust (*Cronartium ribicola* Fisher), white pine weevil (*Pissodes strobi* Peck), and deer herbivory (Sauerman 1992, Saunders and Puettmann 1999a, 1999b, Puettmann and Saunders 2001). To reduce white pine weevil infestations and to control rust damage and infection that are particularly aggressive in full sunlight, pathological pruning and retention of a partial residual overstory have been recommended (Lancaster and Leak 1978, Katovich and Morse 1992, Krueger and Puettmann, 2004). Pathological pruning removes infected branches before the disease can reach the stem and removes lower branches that are most susceptible to infection (Van Arsdel 1961, Hunt 1991, Hagle and Grasham 1988). Although retention of a partial residual overstory may greatly reduce weevil infestations, light conditions under aspen can be very low due to the high stem density of young aspen trees, and white pine seedlings may be light-limited when overtopped by aspen regeneration (Wendel and Smith 1990, Pinno et al. 2001, Lieffers et al. 2002). To counter this, silvicultural prescriptions often call for a release of overtopped white pine seedlings.

Release operations have positive effects on understory seedlings by altering microclimate and increasing above- and below-ground resources (Wetzel and Burgess 2001). A number of studies report positive effects on white pine seedling growth from release operations that removed the entire overstory (Logan and Farrar 1953, Berry 1982, Helms and Standiford 1985). On the other hand, Puettmann and Saunders (2000) observed a rapid response in height and diameter growth after only a partial hardwood overstory removal. Less is known about the growth response when partial release is done in young, vigorously growing stands less than 20 years of age. Furthermore, little is known about the growth effects of pruning on white pine seedlings, particularly when combined with only a partial release. If early pruning largely prevents infection from blister rust, but also extends the time that white pine seedlings remain within the reach of deer (Saunders and Puettmann 1999a), then pruning may not enhance white pine regeneration. Understanding the implications of such operations is essential to wise decisions by land managers, particularly since interest in precommercial thinning in juvenile aspen is rapidly gaining popularity as a means to increase crop tree growth (David et al. 2001, Rice et al. 2001) or to potentially speed the development of a two-storied stand. The purpose of this experiment was to document growth responses of naturally regenerated white pine growing under varying densities of juvenile aspen, and to quantify the impact of pruning on these responses.

## Site Description

The roughly 7-ha research site is located 32 km north of Duluth, MN near the north shore of Island Lake Reservoir in southern Saint Louis County (47°03′ N, 92°05′ W, altitude 410 m) on gently rolling terrain. Soils are an outwash-derived, well-drained, medium/sandy-loam in the Pequaywan and Alden Lake soil series (60% sand, 35% silt, 5% clay). The climate is mid-continental, with mean temperatures of –14° C in Jan. and 19° C in July, and mean growing season (Apr. to Aug.) precipitation of 42 cm (Duluth Airport Meteorological Station, MN State Climatology Service).

The previous stand of white pine with northern hardwoods dominated by aspen was clearcut in the summer of 1983. Immediately after the clearcut, aspen regenerated through suckering. White pine seeded in within a few years from neighboring stands. In 1998, the stand was composed of an upper height stratum of trembling (*Populus tremuloides* Michx.) and bigtooth (*Populus grandidentata* Michx.) aspen at densities of 7,000 to 12,000 trees/ha and a range of dbh from 1 to 7 cm. The lower height stratum had an irregular distribution of naturally regenerated white pine, 0.5 to 6 m tall. A sample of selected white pine trees was aged using the whorl count method and found to be between 7 and 12 years old.

## Experimental Design

In 1998, nine plots were established across the site. Circular 9-m diameter plots were placed a minimum of 27 m apart, avoiding skid trails or landings. Various release intensities and two control (no release) treatments were randomly assigned to the plots. A chemical release using a low-volume stem-bark Garlon 4 band application in the spring of 1998 left 1,500 to 12,000 aspen trees/ha (Table 1). Aspen basal area was measured by a prism count at the center of each plot, and the edge of the plot at the four cardinal directions. The five readings were averaged for each plot. Aspen height and dbh were measured on a random subsample of trees found across the plots in 1998 and

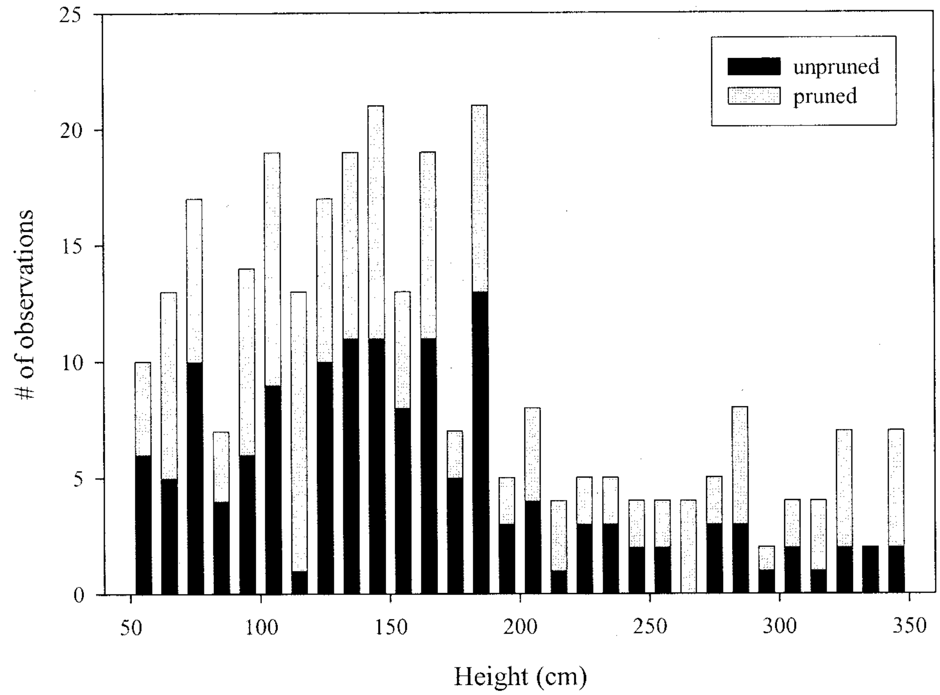


**Figure 1. Height distribution in 1998 of all 288 advance white pine regeneration combined.**

2000 (Table 1). Aspen were defoliated heavily by forest tent caterpillars (*Lymenistria dentar* L.) (>75%, J.A. Krueger personal observation) in June of 2001.

In each plot, 32 white pine seedlings (288 trees total) were randomly selected across the full range of heights present on the site (Figure 1). Half of the seedlings in each plot were randomly selected for pruning. Between 20 and 45% of the live crown was removed with pruning shears. White pine blister rust was present, although rates of infection were low. Four years after release, 8 of 288 permanently tagged white pine died from blister rust; of these, 3 were pruned, and 5 were not. However, 4 years are insufficient to quantify the actual benefit of pruning in terms of controlling blister rust infection rates at this site.

Total height, basal diameter (at 5 cm), diameter at breast height (dbh at 137 cm), and live crown length were measured each fall through 2001. To minimize the impact of herbivory by deer, paper bud caps were applied each fall to terminal leaders of trees shorter than 2 m in height.

### Statistical Analysis

After inspecting the height distribution and finding a natural break point in white pine heights at 190 cm (Figure 1), we grouped seedlings in two height classes, i.e., seedlings shorter than 190 cm ("small," $n = 210$) and seedlings equal to or taller than 190 cm ("tall," $n = 78$), as measured in 1998 (Figure 1). All statistical analyses included height class as an indicator variable to test for differences in growth dynamics between small and tall white pines.

SAS Version 8 (SAS Institute Inc., Cary, NC) was used to construct and test all statistical models. Multiple linear regression analysis was used to examine the effects of different upper stratum aspen densities and pruning on growth of advance white pine regeneration and used a measure of a tree's initial size as a covariate and an indicator of release potential (Table 2). Models of dbh growth were restricted to trees that were at least 1.37 m tall at the time of release. All tests were considered significant if $P \leq 0.05$. Least squares means (due to unequal group sizes) and preplanned multiple comparison tests (Tukey-Kramer HSD test) were used to compare effects of pruning in each height class on growth. To test for a temporal effect of release and pruning on growth, growth differences were investigated separately for the first and second 2 years after release.

## Results

### Initial Crown and Tree Sizes

There were no significant differences in initial crown lengths, crown ratios, heights, diameters, and basal diameters of white pines not selected and selected for pruning for either height class (Figure 2). Initial crown lengths and tree sizes were not significantly smaller in plots with higher upper stratum aspen densities; however, initial crown ratios of small white pine were significantly lower under denser aspen canopies (Table 3).

### Crown Dynamics

Crown dynamics between unpruned and pruned and between small and tall white pines differed significantly and were shaped by pruning and natural crown recession.

*Pruning*

Pruning caused a significant reduction in crown lengths of 35.7 (32.1 to 39.2) cm and 78.8 (73.5 to 84.2) cm and crown ratios of 35.6 (34.0 to 37.2) and 31.8 (29.4 to 34.2)% of both small and tall white pines, respectively (Figure 2).

**Table 2. Analysis of variance for the effects of aspen density (trees/ha), pruning, and initial crown and tree size parameters on crown recession and post-release growth. Significant effects are in bold type. Ht0 and ht2, dbh0 and dbh2, bdia0 and bdia2, and cl0 and cl2 refer to heights, diameters, basal diameters, and crown lengths, at the time of release and 2 years after release, respectively.**

| Model[a] | Covariates | Aspen trees/ha *P*-value | Pruning *P*-value | *N* | $R^2$ |
|---|---|---|---|---|---|
| Crown recession first 2 years (ln)[b] | Ln(cl0) | 0.069 | **<0.001** | 287 | 0.623 |
| Crown recession second 2 years (ln) | Ln(cl2) | **<0.001** | **<0.001** | 285 | 0.468 |
| Height growth first 2 years (ln) | Ln(ht0) | **0.046** | **<0.001** | 285 | 0.568 |
| Height growth second 2 years (ln) | Ln(ht2) | **<0.001** | 0.302 | 266 | 0.430 |
| Diameter growth first 2 years (ln) | Ln(dbh0) | **0.015** | **0.038** | 149 | 0.453 |
| Diameter growth second 2 years (ln) | Ln(dbh2) | **0.051** | 0.404 | 144 | 0.305 |
| Basal diameter growth first 2 years (ln) | Ln(bdia0) | **<0.001** | **0.018** | 284 | 0.646 |
| Basal diameter growth second 2 years (ln) | Ln(bdia2) | **0.001** | 0.127 | 267 | 0.333 |

[a] Both aspen density and pruning reflect interactions with height classes, significant *P*-values indicate that at least one of the height classes has an effect size different from zero. Interactions of aspen density and pruning were nonsignificant and thus removed from the models.
[b] Ln indicates natural logarithmic transformation.

After pruning, crown lengths and crown ratios were significantly different between unpruned and pruned white pines (Figure 2) and crown ratios of small white pines were not significantly associated with aspen density any more (Table 3).

*Crown Recession*

Crowns of pruned white pines did not recede further beyond that caused by pruning during the first and only slightly during the second 2 years after release (Figure 3). During the second 2 years after release, crowns of small pruned white pines receded significantly more than those of tall pruned white pines [2.3 (1.4 to 3.7) times as much, $P \leq 0.001$]. Compared to the first 2 years, crown recession of unpruned white pines almost doubled during the second 2 years (Figure 3).

Crown recession rates of both small and tall white pines were not related to the density of the upper aspen canopy during the first 2 years (both $P > 0.1$). During the second 2 years, crown recession rates of small white pines significantly increased under a denser aspen stratum [7.7 (3.5 to 12.0)% for an additional 1,000 upper canopy aspen, $P \leq 0.001$]; those of tall white pines were not significantly increased by a denser aspen stratum [5.0 (–3.0 to 13.7)% for an additional 1,000 upper canopy aspen, $P > 0.1$]. Crowns of unpruned small and tall white pines receded 3.7 (2.5 to 5.5) and 13.5 (7.4 to 24.4) times the amount of pruned small and tall white pines, respectively ($P \leq 0.001$).

Four growing seasons after pruning, crown lengths and crown ratios of pruned small white pines were significantly lower than those of unpruned small white pines; this was not the case for pruned tall white pines (Figure 2). Crown ratios of small white pines were lower than those of tall white pines, whether pruned ($P \leq 0.003$) or not ($P \leq 0.007$).

### Temporal Effects of Upper Stratum Aspen Density and Pruning

Regression analyses indicated a strong relation of height, diameter, and basal diameter growth to a white pine's initial size (Table 2). Trees of larger sizes generally grew more than smaller trees.

*Small White Pines*

Increasing densities of upper stratum aspen resulted in significant reductions in height, diameter, and basal diameter growth during both 2-year periods after release (Figure 4). After four growing seasons, heights and basal diameters were significantly lower, and diameters of small white pines were marginally smaller under denser upper canopy aspen (Table 3, Figure 2).

Pruning significantly reduced height and basal diameter growth of small white pines only during the first 2 years after release (Figures 3 and 4). Four growing seasons after pruning, only heights were significantly different between pruned and unpruned small white pines, but there were no significant differences in diameter and basal diameter (Figure 2).

*Tall White Pines*

Neither increasing densities of upper stratum aspen nor pruning significantly affected height, diameter, and basal diameter growth during either two-year period after release (Figures 3 and 4). Four years after release, there were no differences in height, diameter, and basal diameter between pruned and unpruned tall white pines (Figure 2) nor significantly reduced heights, diameters, and basal diameters under denser aspen canopies (Table 3).

### Response of Upper Stratum Aspen to Release

Upper stratum aspen sustained high mortality rates (Table 1) that substantially lowered the stem density per hectare and led to an increase in average aspen diameter. Aspen basal area 2 years after release was a function of the remaining aspen stems per hectare ($P \leq 0.02$, $n = 9$, $R^2 = 0.56$), with more stems per hectare leading to higher aspen basal areas 2 years after release. However, growth of aspen basal area was negatively related to the density of aspen stems after release ($P \leq 0.03$, $n = 9$, $R^2 = 0.53$), indicating that more basal area was added in plots that had fewer aspen remaining after release.

## Discussion

Our study supports the hypotheses that pruning leads to at least temporary growth reductions, that competition from

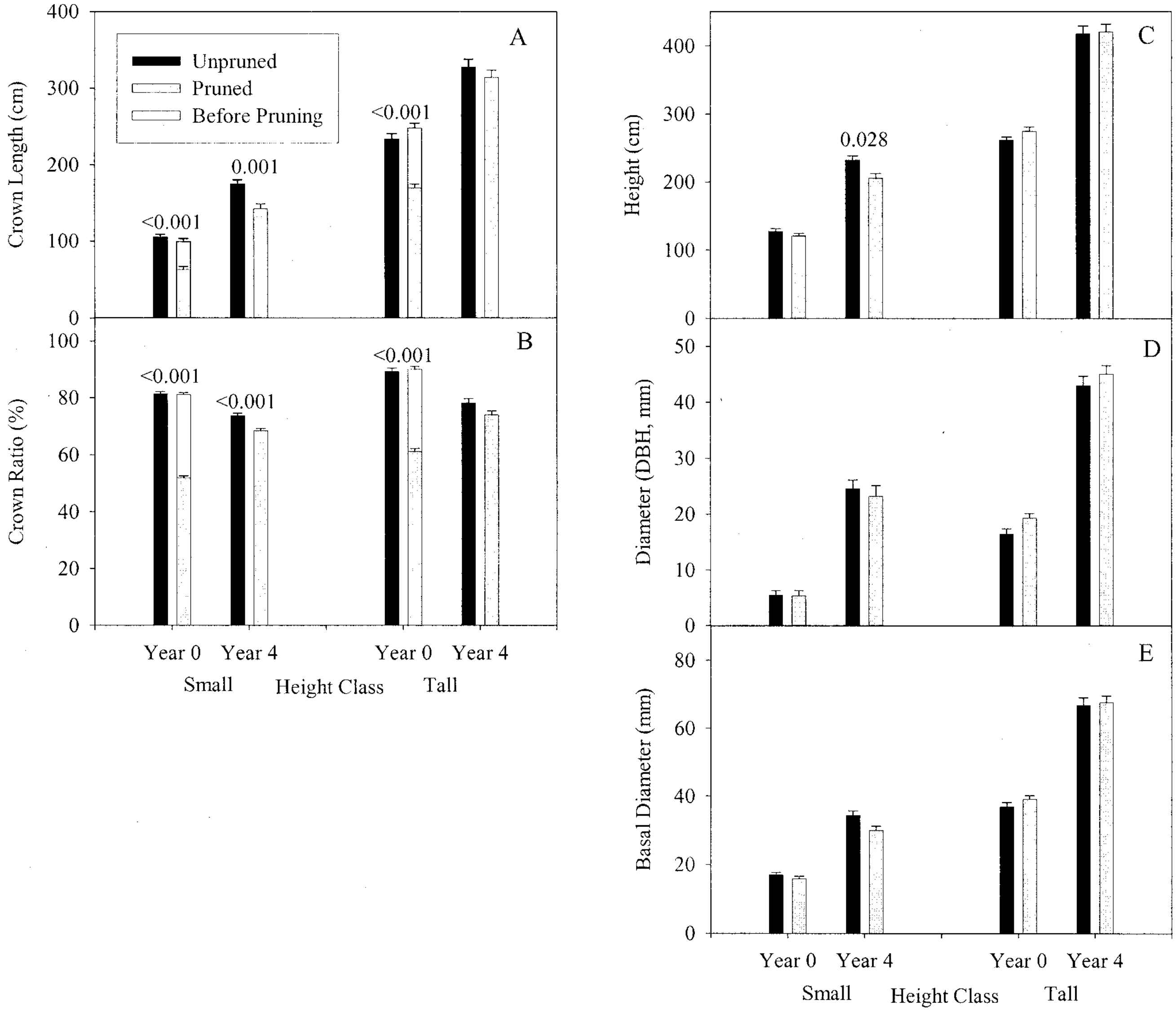


**Figure 2. Crown length (A), crown ratio (B), height (C), breast height diameter (D), and basal diameter (E) of unpruned and pruned white pine advance regeneration before and four growing seasons after release. Significant *P* values for differences between unpruned and pruned white pine are given in the figure.**

upper stratum trees leads to significant growth reductions of lower stratum white pine seedlings (Saunders and Puettmann 1999a, Krueger and Puettmann, 2004), and that even partial removal of the upper stratum improves seedling growth (Puettmann and Saunders 2000). Pruning and release effects on individual white pine growth, however, are strongly dependent on the height stratum to which a seedling belongs. Height stratum is a surrogate for a seedling's crown size, competitive status, and access to direct sunlight (Helms and Standiford 1985).

Pruning was an important factor shaping the crown dynamics of white pine and hence its growth responses. White pine growth reductions due to pruning were expected given that growth of individual trees is correlated with the size of the living crown (Maguire and Hann 1990). Although growth reductions were observed on all white pine, they were significant only for small trees and only for a very short period. Furthermore, the effect was highly variable and not consistent across all growth parameters (e.g., diameter growth was not significantly affected). During the second 2-year period after release, diameter and basal diameter growth of pruned white pine even exceeded growth of unpruned individuals slightly (Figure 4).

The reason for the short-lived impact of pruning on growth of small white pine seems to be in the natural crown recession dynamics. Natural crown recession during the first 2 years after pruning was between one-quarter and one-third the magnitude of the pruning effect. Natural crown recession on pruned trees halted during the first 2 years after release and was small even during the second 2 years after release, leading to an increase in crown ratios of pruned white pine. In contrast, natural crown recession on unpruned white pine doubled during the second 2 years after release and greatly reduced crown ratios and crown size

**Table 3. Relationship between post-release upper stratum aspen densities and initial crown and tree sizes (year 0) and sizes after four growing seasons (year 4) of advance white pine regeneration. Significant *P*-values are in bold.**

| | Small white pine | Tall white pine |
|---|---|---|
| Crown length (cm, year 0)[a] | 0.083 | 0.087 |
| Crown length (cm, year 0) | 0.071 | 0.128 |
| Crown length (cm, year 4) | **<0.001** | 0.240 |
| Crown ratio (%, year 0)[a] | **0.006** | 0.972 |
| Crown ratio (%, year 0) | 0.063 | 0.742 |
| Crown ratio (%, year 4) | **<0.001** | 0.878 |
| Height (cm, year 0) | 0.114 | 0.102 |
| Height (cm, year 4) | **0.001** | 0.119 |
| Diameter (mm, year 0) | 0.955 | 0.148 |
| Diameter (mm, year 4) | 0.070 | 0.077 |
| Basal diameter (mm, year 0) | 0.397 | 0.286 |
| Basal diameter (mm, year 4) | **<0.001** | 0.146 |

[a] Before pruning.

differences between pruned and unpruned small white pine over 4 years. It thus appears that pruning merely preempted natural branch mortality and natural crown recession by a few years. It is questionable whether pruning is an effective tool to guard against white pine blister rust infections and whether the expense of pruning is economically justified, particularly given the low infection rates of the white pine growing in partial shade of aspen. Apart from considerations about the efficacy of pruning to prevent blister rust infections, pruning does not seem to cause long-term growth losses, although small pruned white pine still had significantly smaller ending heights after 4 years. However, these differences will probably disappear in the near future as crown ratios and crown lengths of pruned white pine have recovered or are recovering to levels observed in unpruned individuals.

Crown recession of small white pine was also accelerated by a denser upper aspen stratum. However, lessening the intensity of release to accomplish the levels of crown recession induced by pruning is not recommended. First, natural crown recession nearly caught up with artificial pruning after only a few years. Second, a denser upper stratum canopy results in substantial and long-lasting growth reductions particularly of the small advance white pine regeneration. Conversely, heavier release results in improved growth of the small white pine component. This result further extends findings by Puettmann and Saunders (2000) that growth of white pine responds very quickly following partial release to very young (7- to 12-year-old) white pines. This response contrasts with more shade-tolerant species such as white fir (*Abies concolor* (Gord. & Glend.) Lindl.), red fir (*Abies magnifica* (A. Murr), Pacific silver fir (*Abies amabilis* (Dougl.) Forbes), and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) (e.g., Gordon 1973, Herring and Etheridge 1976, Herring 1977, Helms and Standiford 1985), which can show a delayed growth response of several years due to slow crown expansion rates.

In contrast to growth responses of small white pine that were significantly higher in plots that were more heavily released, growth of tall white pine seedlings in this study

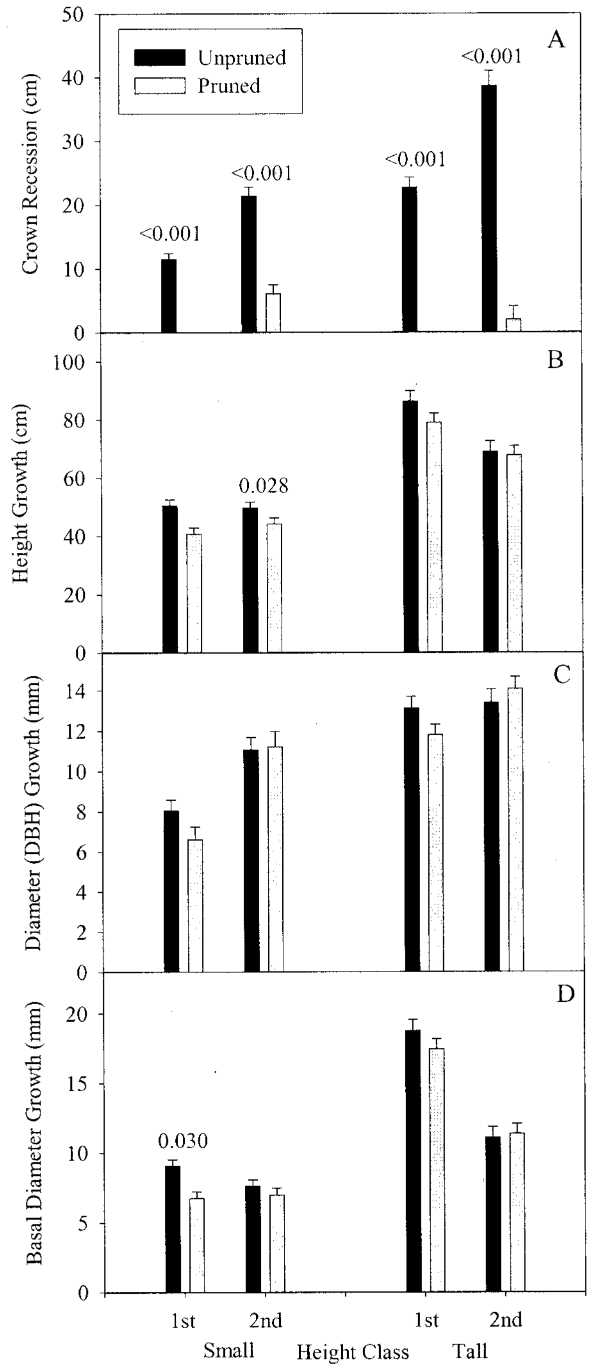


**Figure 3. Natural crown recession (A) and growth of height (B), breast height diameter (C), and basal diameter (D) of unpruned and pruned white pine advance regeneration during the first and second 2 years after release. Natural crown recession was significantly less in unpruned than pruned individuals ($P <$ 0.001). Other significant $P$ values for growth differences between unpruned and pruned white pine are given in the figure.**

was generally not affected by release. A reason for this nonresponse may be that tall white pine probably occupied sites that were less severely affected by the upper stratum aspen in the first place and that release intensities were too low to improve growing conditions of tall white pine enough to improve growth. This would explain why these individuals were taller, why they had very high live crown

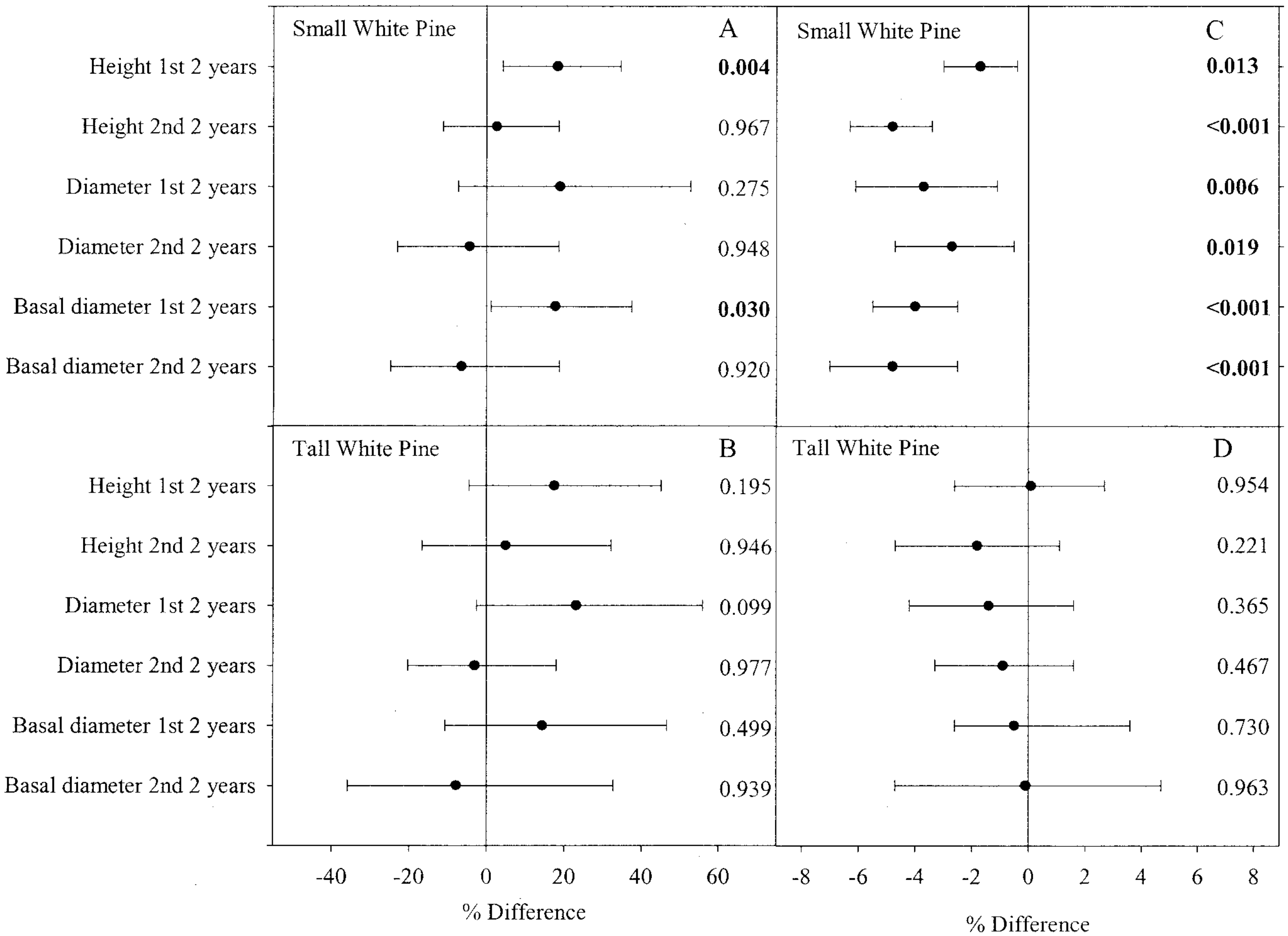


**Figure 4. Estimates (in %), confidence intervals, and *P* values for effects of pruning (A and B) and an additional 1,000 upper stratum aspen per hectare (C and D) on median growth (unpruned minus pruned) of small and tall advance white pine regeneration during the first and second 2 years after release.**

ratios of nearly 90% at the beginning of the study, and why crown recession rates of tall white pine were independent of upper stratum densities after release. The independence of growth of tall advance white pine and upper stratum aspen densities further indicates that light was probably not a limiting factor throughout the entire stand and that competition from upper-stratum aspen may have been spatially variable (Palik and Pregitzer 1995). Consequently, a plot-level estimate of the density of the upper aspen stratum may not adequately describe the competitive conditions of tall white pine, and local release intensities probably were too low to improve their growth, whereas average plot release intensities (i.e., a more open average upper aspen stratum than before release) greatly benefited small white pine.

Despite a heavy aspen defoliation in 2001, both height and basal diameter growth of tall white pine were substantially lower during the second 2 years compared to the first 2 years. Lower growth rates during the second 2 years combined with a substantial increase in crown recession may be due to increasing competition from an upper stratum aspen, which responded very vigorously to the release with increased average sizes and expanding basal area, thus quickly altering environmental conditions and resource availability for lower stratum white pine. This provides further evidence that the release intensities in this study may have been too low for a sustained improvement of growing conditions for white pine advance regeneration and that repeated thinnings may be necessary to keep white pine growing.

## Conclusions and Silvicultural Implications

Converting aspen-dominated sites to conifers has historically followed a paradigm of clearcutting the site, followed by chemical or mechanical site preparation and planting of conifers (Perala 1977). Due to the well-known perils of open-grown white pine to weevil and blister rust, as well as potential criticism of the clearcutting practice near highly visible recreation areas, new approaches are needed to successfully regenerate white pine. Our results indicate that it may be possible to successfully keep white pine growing under an aspen canopy. Early partial release improved growth of small advance white pine regeneration, but our release intensities did not sustain the white pine growth rates observed in the first 2 years after release. To do so, aspen may have to be managed closer to the lower end of the range created in this study. Managing aspen at lower densities (e.g., 1,360 trees/ha after a first thinning at age 10) would not compromise aspen yields at the end of a normal rotation period (Perala 1977).

Potentially reducing the risk of blister rust infections through pruning involves tradeoffs. Besides the additional cost, growth reductions will be more prevalent in the smaller trees, but likely limited to the first 2 years after release. However, Van Arsdel (1961) recommended pruning every 2 years beginning at ages 5–7 until there are no branches within approximately 250 cm of the ground. Our findings suggest that such an approach would be very aggressive and may not allow the quick recovery of height growth seen here, especially of the less vigorous seedlings. Furthermore, natural crown recession may accomplish the same goal in just a few years more. We conclude that aggressive pruning should be restricted to the most vigorous seedlings and to microsites favorable for blister rust. Growth of the seedlings should be monitored closely to avoid reductions due to competition by overstory trees or other competing vegetation.

If the long-term objective is to increase the presence of white pine in the landscape, our results indicate that a possible gradual conversion of an aspen-dominated stand to a mixed aspen-white pine cover type seems possible. As white pine seedlings grow and require more resources for survival and growth, repeated thinning of the upper aspen stratum to lower densities would be required to sustain future growth. This scenario, however, would allow managers to use more ecologically sound and socially acceptable management approaches to bring about gradual cover type changes. If kept alive and growing at least reasonably well in height, white pine may dominate the stand after the final harvest of the aspen at an age of 35–50 years. If few white pine are present at that time, the aspen may again regenerate successfully, resulting in a new aspen stand with a few superdominant white pines.

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