Eastern White Pine (*Pinus strobus*) Growth Response to Partial Hardwood Overstory Release

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ABSTRACT: *We measured the response of white pine (*Pinus strobus *L.) saplings after partial release of a hardwood overstory on three sites in central Minnesota. Both height and diameter growth increased quickly after release compared to prerelease growth. Diameter growth response was related to prerelease diameter growth, but not to initial size of the sapling (diameter at time of release). On the other hand, height growth response was strongly influenced by the initial height of all trees, but not related to prerelease height growth in the largest saplings (initial heights > 8.76 m). Increased release intensity (i.e., difference between prerelease and postrelease overstory densities) resulted in higher diameter and height growth responses. The height/diameter ratios decreased after release, indicating that stability as well as growth increased after the release. North. J. Appl. For. 17(3):89–94.*

Over the last decade, land managers in the Lake States have increasingly emphasized retention of residuals after harvesting to maintain more forest structure and diversity across the landscape (Puettmann and Ek 1999). On many sites, the structure and density of residual overstory is not necessarily determined by the regeneration ecology of the desired species [e.g., for frost or sun protection (Buckley et al. 1998, Valigura and Messina 1994)], but more and more by other objectives, like visual quality, wildlife habitat, or pest management concerns (Puettmann and Ek 1999). One result of this trend is that regeneration may have to be attempted under conditions that are not optimal for a species. This requires understanding how seedlings and saplings respond under a wide range of competitive environments, especially in regard to optimal intensity and timing of overstory removal (i.e., liberation or overstory release) above advanced regeneration.

While many studies have investigated growth responses to reduced competition when the competing trees are approximately of the same size, as in a thinning (e.g., Oliver 1985, Gillespie and Hocker 1986), few studies have documented the effects of liberation or overstory release on seedlings or saplings. Unfortunately, most of these only investigated seedlings' responses to *total* removal of the overstory (e.g., Seidel 1980, Ferguson and Adams 1980, Helms and Standiford 1985). These studies, while providing information about responses to removal cuts in traditional shelterwood systems, are not applicable to conditions with partial overstory retention for many years after the initial release (Carlson and Schmidt 1989).

The optimal regeneration conditions for eastern white pine (*Pinus strobus* L.) in Minnesota are determined by a combination of climate and soil conditions, competing vegetation, and pest management concerns. For example, retention of at least 20–50% overstory cover discourages attacks by white pine weevil (*Pissoides strobi* Peck) and reduces infection rates by white pine blister rust (*Cronartium ribicola* Fisher) (Lancaster and Leak 1978, Katovich and Morse 1992). Since land managers have targeted white pine for restoration throughout its range in Minnesota (WPRSWG 1996), successful regeneration is often attempted on sites where overstory residuals remain for a variety of reasons. However, the best timing and intensity of subsequent liberation cuts to promote understory white pine growth is relatively unknown. With these issues in mind, this study's objectives were to: (1) determine if there was a growth response of understory white pine to partial overstory release; and (2) determine how release timing (as represented by sapling size at the time of the release) and release intensity (i.e., percent trees removed) influences postrelease growth response patterns.

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Table 1. Current overstory basal area (1997) and a summary of release treatment effects on species composition. Standard errors are given in parentheses except where noted.

Stand	1997 overstory basal area (m^2/ha)	Time of release	% trees removed (range)	Species composition: Species*	Prerelease density (trees/ha)	Postrelease density (trees/ha)
1	20.9	1991	36	*Acer* spp.	30	0
	(1.3)		(6–72)	*Betula* spp.	120	40
				Populus spp.	450	90
				Quercus spp.	80	70
				Other species	150	130
				Total	830 (90)	330 (70)
2	16.2	1991	48	*Acer* spp.	200	70
	(1.2)		(10–82)	*Betula* spp.	140	0
				Populus spp.	460	20
				Quercus spp.	100	100
				Other species	150	110
				Total	1,050 (90)	310 (60)
3	16.6	1992	44	*Acer* spp.	330	130
	(1.5)		(13–77)	*Betula* spp.	390	130
				Populus spp.	380	0
				Quercus spp.	170	170
				Other species	300	280
				Total	1,560 (230)	720 (230)

* The "Other species" category is primarily *Ostrya virginiana*, but also may include *Picea abies*, *Pinus resinosa*, and *Ulmus* spp.

Methods

Site Description and Experimental Design

Three stands in which white pine saplings were partially released from overstory competition were surveyed in this study. These stands occurred in the Camp Ripley Military Reservation in Crow Wing County, MN (94°27'W, 46°13'N) on Menahga loamy sand soils. The three stands were similar in age and structure (Table 1); each had a moderately dense approximately 65-yr-old mixed aspen (*Populus* spp.) and northern hardwood overstory (basal area = 26 m^2/ha; height = 15–20 m) with an understory/midstory consisting of 250–750 stems/ha of white pine natural regeneration (3.7–18.0 m in height). In 1991 (Stands 1 and 2) or 1992 (Stand 3), all white pine trees greater than 0.7 m in height were released from overtopping competition. All aspen and hardwood stems greater than 7.6 cm diameter at breast height (dbh), and within 6.1 m of each white pine tree were girdled (Table 1).

In September 1997, we selected 23, 30, and 19 target trees on Stands 1, 2, and 3, respectively, to assess white pine growth response to the 1991–1992 overstory release. Target trees were systematically located by overlaying an evenly spaced set of parallel transects across each site. Target white pine were then selected along each transect if they were free of recent damage (e.g., breakage, insect, disease, herbivory, etc.) and were overtopped prior to release treatment (i.e., not open-grown, as determined by the presence of stumps and/or trees within 6 m of the target tree). To reduce spatial autocorrelation, we maintained a spacing of 12 m between each target tree along transects. If the transect intersected a clump of white pine regeneration, the tallest, undamaged crop tree within the clump was selected as a target tree.

For each target tree, diameter at breast height (dbh), total height, height of lowest live branch, and crown width was measured. Heights of the last 15 yr of internodes (or as many as were apparent) were measured with a clinometer or height pole, and increment cores were collected from target trees to reconstruct tree height and diameter during the years before and after overstory release and to determine breast height age. However, since several cores did not include the pith, breast height age could only be estimated for 66 of the 72 trees.

Basal areas of the overstory trees around target trees were measured using a 2 m^2 basal area factor (BAF) prism, and the number of all residual, dead, or removed overstory trees within 6 m of each target tree were also recorded. A summary of the average sizes of the white pine trees at time of release and in fall 1997 is presented in Table 2.

Table 2. Current (1997) breast height age and average size (standard error) of white pine target trees at time of release (REL) and in fall 1997.

Stand	*N*	Age in 1997 (yr)	Height (m) Rel	Height (m) 1997	Dbh (cm) Rel	Dbh (cm) 1997	H/D Ratio Rel	H/D Ratio 1997	1997 crown diameter (m)
1	23	40.6	13.2	16.6	17.7	21.9	77.8	77.9	6.46
		(1.2)	(0.6)	(0.6)	(1.1)	(1.2)	(3.3)	(2.3)	(0.36)
2	30	34.2	7.8	10.4	10.3	14.1	80.7	77.4	5.10
		(1.1)	(0.4)	(0.5)	(0.8)	(1.0)	(3.0)	(2.4)	(0.28)
3	19	33.9	7.0	9.1	7.6	10.6	95.6	87.1	3.87
		(1.1)	(0.5)	(0.5)	(0.6)	(0.8)	(3.2)	(2.0)	(0.20)

Statistical Analysis

After yearly tree heights and diameters were reconstructed, growth data for the target white pine trees were summarized into two measures: (1) average annual prerelease diameter or height growth for the 5 yr prior to overstory release; and (2) average annual postrelease diameter growth or height growth for the 5 yr following overstory release. Growth that occurred during the year of release (i.e., "Year 0") was not included. Trees that did not have complete reconstructions and two extreme outliers were discarded from the height growth analysis. This resulted in sample sizes of $n = 65$ and $n = 72$ for height and diameter growth analyses, respectively.

To reduce the influence of prerelease growth conditions in the analysis, the difference between average annual growth before and after release was calculated and used as a measure to determine if the white pine saplings showed a growth response to overstory release. This allowed use of the Student's t-test to determine if there was a growth response for either diameter or height growth (i.e., H_o: postrelease growth – prerelease growth = 0).

Initial size was used as an indicator for release timing for several reasons. First, age estimation was limited to a subsample, and inclusion of age in the model would have limited the sample size. Consequently, when included in growth response models, age was not significant ($P \geq 0.12$). Second, estimated age was correlated with initial height and diameter ($n = 60$, $r = 0.694$, and $r = 0.627$, respectively). Third, in many instances, foresters may not know the age of white pine regeneration, but they can always determine size.

Within the analysis, release intensity was quantified relatively as the percentage of trees removed during the release (i.e., number of trees removed in release divided by the initial prerelease tree density). Although both initial tree size and prerelease growth were negatively related to initial overstory density ($–0.253 \leq r \leq -0.416$, $P \leq 0.042$), they were not correlated with percentage of trees removed in release ($–0.196 \leq r \leq 0.007$, $P \geq 0.119$). This suggested that treatments were unbiased in regard to prerelease white pine size or growth and a relative measure, like the percentage of overstory trees removed, would better separate (although not isolate) prerelease growth patterns from postrelease growth patterns within the analysis.

The influence of release timing (i.e., initial tree size) and release intensity on postrelease growth was analyzed using blocked analysis of covariance (ANCOVA) models. Main effects in these models included: (1) stand as a block, (2) prerelease diameter or height growth, (3) initial tree size at release [diameter (cm); height(m)], and (4) release intensity.

All tests were considered significant if $P \leq 0.05$ and marginally significant if $P \leq 0.10$. All statistical analyses were done with JMP® 3.2.2 (SAS Institute Inc. 1996).

Results and Discussion

Postrelease Growth Responses

White pine in all three stands responded similarly and showed a significant difference in diameter ($t = 13.21$, $P < 0.001$) and height growth ($t = 6.57$, $P < 0.001$) before and after overstory release. On average, diameter growth increased 115%, from 2.7 ± 0.2 mm/yr (mean ± SE) before release to 5.8 ± 0.3 mm/yr after release. Likewise, average height growth increased 42%, from 29.0 ± 2.2 cm/yr before release to 41.3 ± 1.5 cm/yr. Although an increase in growth after release was expected (Katovich and Morse 1992, Helms and Standiford 1985, Seidel 1977), it was surprising how quickly it occurred, particularly for diameter growth. Other species have shown time lags in growth response after thinning or release, with older, larger trees showing delays as they more fully develop their crowns (Ferguson and Adams 1980, Heath and Alfaro 1990). In this study, white pine of all sizes showed immediate increases in growth even during the first year after release (Figure 1). This agreed with other studies that have reported that white pine advanced regeneration can quickly respond to release even in individuals up to 38 yr old (Kelty and Entcheva 1993, Berry 1982).

Although average height growth increased, 15% of trees had decreased height growth in response to release. In general, these trees were significantly taller at the time of release ($t = 4.03$, $P < 0.001$) and growing in height more quickly ($t = 6.13$, $P < 0.001$) (Table 3). Since they were already growing rapidly and in or slightly below the overstory canopy, overstory release would have less of a relative impact on these trees than on smaller trees that were not growing as rapidly (Figure 1). In addition, normal year-to-year variation in height growth rates likely lead to some of the larger trees to have slower growth after release, whereas the normal annual variation in height growth was overwhelmed in the smaller trees by their relatively much stronger response to release.

Release effects on the height-to-diameter ratios of white pine were significant ($t = 2.83$, $P = 0.006$), but weak. By 1997, some 5–6 yr after release, the average height/diameter ratio had only decreased 3.27 ± 1.16 from a prerelease average of 83.45 ± 2.03. However, the percentage of trees with height-diameter ratios greater than 100, generally thought to be a threshold for "instability" and increased risk of windthrow or snow breakage (Mård 1997, Petty and Worrell 1981), declined dramatically after release (Figure 2).

Initial Size and Release Intensity Effects

The timing of the release operation, i.e., the initial size of the released trees, had significant effects on growth response (Table 4). Postrelease height growth increases were positively related to not only prerelease height growth, but also to initial height. However, there was a strong indication that prerelease height growth was only slightly influencing postrelease height growth; when the significant interaction between prerelease height growth and initial height was removed from the ANOVA model, prerelease height growth was no longer significant ($F = 0.02$, $P = 0.887$). This suggested that the effects of prerelease height growth depended on initial tree size. For example, postrelease height growth was not correlated with prerelease height growth ($r = 0.027$, $P = 0.886$) for the tallest 50% of trees at time of release (initial height ≥ 8.76 m), but was positively correlated for the shortest 50% of trees ($r = 0.349$, $P = 0.047$). In general, trees that were growing quickly before release were often larger, in

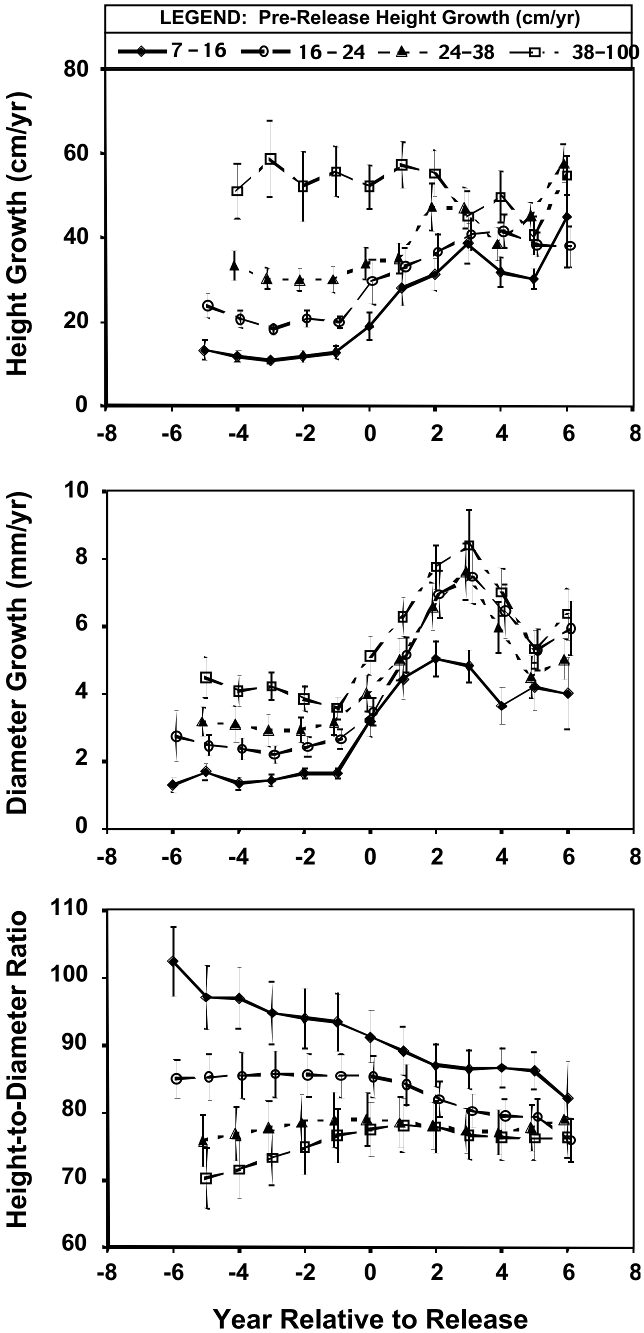

Figure 1. Mean height (A) and diameter (B) growth for white pine trees relative to release date. Trees are separated into quartiles based on average prerelease height growth. Overstory release occurred in the winter prior to Year 0. Error bars indicate ± 1 standard error.

slightly better growing conditions to begin with, and probably close to the maximum height growth rate for the site, since height growth is relatively insensitive to competition as compared to diameter growth (Brand 1990, Saunders and Puettmann 1999). Therefore, these trees were less likely to see marked improvements in height growth after release. On the other hand, trees growing slowly before release were often smaller; these individuals responded relatively more vigorously to release (Figure 1). Although this seems somewhat counterintuitive, this response has been documented in grand fir, where postrelease height growth was greatest in the

Table 3. Average height and prerelease height growth of trees that had a positive (i.e., average height growth after > height growth before) or negative response to release. Standard errors are given in parentheses.

Release response	N	Ave height at release (m)	Ave prerelease height growth (cm/yr)
+	55	8.72 (0.44)	23.2 (1.4)
−	10	13.25 (1.04)	47.3 (4.5)

smallest trees, except during the first year after release (Ferguson and Adams 1980). This was attributed to the smaller trees' ability to increase relative photosynthetic area much more quickly and attain a much more balanced root-to-shoot ratio. However, it is important to note that this difference in height growth response is only on a relative basis (when compared to prerelease growth). In absolute terms, the trees that were growing faster before the release operation were not falling behind, but maintained their growth rates and, thus their height advantage, in the first 5 yr after release (Figure 1).

Postrelease diameter growth increases were not related to by prerelease tree diameter, but were positively related to prerelease diameter growth. This was expected as prerelease diameter growth is more of a reflection of prerelease live crown ratio (Helms and Standiford 1985, Ginn et. al 1991), which should better predict postrelease diameter growth. Prerelease diameter, on the other hand, is a reflection of the competitive conditions summed over the entire life of the tree and may or may not reflect prerelease crown size. For example, an individual tree may experience very rapid diameter growth early in its life cycle, then be overtopped and lose both diameter growth and live crown. It may still be a large diameter tree, but it will not respond to release as a smaller tree with higher diameter growth and, consequently, larger live crown.

Release intensity had highly significant effects on postrelease diameter and height growth (Table 4). Not surprisingly, postrelease diameter and height growth were lowest among trees with the least relative change in tree density around them (i.e., a low release intensity) and greatest among trees with the greatest change. For example, ANCOVA models indicated that postrelease diam-

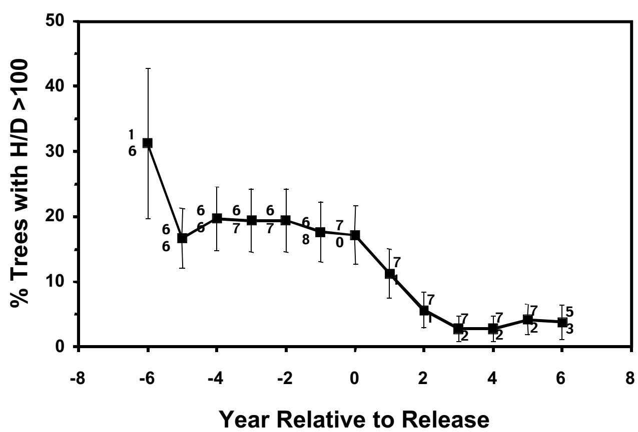

Figure 2. Percentage of trees with height to diameter ratio greater than 100 relative to release date. Overstory release occurred in the winter prior to Year 0. Error bars indicate ± 1 standard error. Since sample size varied by year, *n* is given for each data point.

Table 4. **Analysis of variance for the effects of stand, initial diameter or height, average annual prerelease diameter or height growth, and percent of overstory trees removed (i.e., release intensity) on average white pine postrelease diameter and height growth. Nonsignificant interactions have been removed from both models.**

Source	df	MS	*F*	*P*
Postrelease diameter growth (mm/yr)				
Stand	2	0.028	0.44	0.6490
Initial diameter	1	0.038	1.15	0.2877
Prerelease diameter growth	1	0.876	26.57	<0.0001
% trees removed	1	0.418	12.66	0.0007
Error	66	0.033		
Postrelease ht growth (cm/yr)				
Stand	2	0.000	0.02	0.9833
Initial ht	1	0.152	19.65	<0.0001
Prerelease ht growth	1	0.035	4.56	0.0368
Initial ht ¥ prerelease ht growth	1	0.050	6.47	0.0136
% trees removed	1	0.113	14.59	0.0003
Error	58	0.008		

eter and height growth increased by 0.4 ± 0.1 mm/yr and 2.3 ± 0.6 cm/yr, respectively, for every 10% increase in trees removed, holding all other factors constant (i.e., initial tree height, prerelease diameter growth, etc.). However, the univariate relationships between postrelease diameter and height growth increases, and percentage of trees removed were weak ($R^2 < 0.10$), indicating that other factors (e.g., genetic variation or initial overstory densities), contributed to the variation in growth response. It also may suggest that our simple derivation of release intensity may not have been the most appropriate. A measure that more directly represents the altered competitive conditions by incorporating the size of the competition, like relative change in basal area or overstory cover (i.e., light availability), may result in models with more predictive power. Nevertheless, our results agree with numerous studies that found initial size and release intensity to greatly affect growth of released stems (Carlson and Schmidt 1989, Gillespie and Hocker 1986, Ferguson and Adams 1980).

Management Implications

White pine is quite capable of replacing the overstory once it is established within the understory of a stand. As our results have shown, white pine of a wide variety of sizes can respond quickly to partial and nearly total overstory removal with increased height and diameter growth, reduced height-diameter ratios, and thereby, reduced risk of windthrow or snow breakage. Furthermore, white pine responded after years or even decades of suppression (see also Kelty and Entcheva 1993, Berry 1982). This provides managers with an attractive, low-cost opportunity for regenerating white pine in the Lake States. In these regards, managers should look for pockets of advanced white pine regeneration and promote them, being careful not to damage the regeneration while removing at least part of the overstory. This can be done using herbicides or through girdling in less valuable stands, as was done in this experiment, or using feller-buncher harvesting systems in more valuable timber. In either case, managers need to remain aware of the tradeoffs not only between residual overstory health and value, and advanced white pine regeneration growth and stability, but also among understory brush development (Smidt and Puettmann 1998), white pine blister rust infection rates, and white pine weevil attack incidence (Lancaster and Leak 1978, Katovich and Morse 1992), in determining the intensity of the release. Further research is ongoing to identify these tradeoffs and determine how they vary across sites.

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