Growth and Injury Patterns of Eastern White Pine (*Pinus strobus* L.) Seedlings as Affected by Hardwood Overstory Density and Weeding Treatments

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ABSTRACT: *White pine seedlings were underplanted under a range of overstory densities in a hardwood stand in northern Minnesota. Vegetation surrounding seedlings was left untreated (control), weeded annually, or completely removed through monthly weeding. After 4 years, the benefit of weeding woody competition for diameter growth of seedlings was limited to areas with relatively open overstory conditions. Seedling height growth was reduced in areas with higher overstory density, but improved through weeding treatments that removed woody vegetation. The removal of herbaceous vegetation did not improve growth of seedlings in any conditions. Open growing conditions created by overstory removal and weed control resulted in higher incidences of seedling injuries, e.g., through infection by white pine blister rust. Conditions for pine bark adelgids also were enhanced in areas with low overstory densities and weeding treatments. The incidence for white pine weevil seems to follow a similar pattern, although the number of trees infected was minimal. Results show that improving growing conditions through management of the overstory and understory vegetation improves seedling growth rates, but must be balanced with potentially higher incidences of seedling injuries under more open conditions. North. J. Appl. For. 21(2):61–68.*

Key Words: White pine, overstory density, understory vegetation management, competition, injury agents.

Over the last decade, harvesting operations in Minnesota, much like in other parts of the United States and Canada, exhibited a trend toward the increased retention of residual trees (green tree retention) (Puettmann and Ek 1999). Typically, this practice is not aimed at providing optimal conditions for regeneration, but to fulfill other objectives, like riparian protection, wildlife habitat, or visual quality. Thus, green tree retention results in residual stands unique from those subject to the practice of clearcut and shelterwood systems or those affected by natural disturbance (Franklin et al. 1997, Halpern et al. 1999). The implications of this practice, especially related to regeneration and younger cohorts, are as yet uncertain (Acker et al. 1998). These remnant vertical structures influence the regeneration process, thus increasing the need for understanding how understory vegetation, including tree regeneration, responds to conditions created by different overstory and understory conditions. Gaining an improved understanding of stand dynamics under these conditions may provide insight to silvicultural treatments that optimize the benefits of green tree retention while minimizing the negative effects of interspecific competition (Palik et al. 1997).

A number of studies have documented white pine seedling response to ranges of light conditions (Shirley 1945, Logan 1966, Messier et al. 1999) and to vegetation management (Freeman and Van Lear 1977, Brand and Janas 1988, Cornett et al. 1998). Few studies have documented the integrated effect of over- and understory vegetation management on subsequent white pine seedling growth (Smidt

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and Puettmann 1998, Wetzel and Burgess 2001). The objective of this study was to gain insight into the role that harvesting intensity and vegetation management play in early growth response of underplanted white pine. The specific objectives included (1) quantification of the growth response of planted white pine to a range of overstory hardwood densities, (2) evaluation of the impact of understory vegetation management practices on early seedling growth, (3) examination of the influence of different vegetation components (overstory, shrub, and herbaceous vegetation) in terms of their influence on seedling growth during years 2 and 4 after planting, and (4) documentation of how white pine seedling injury patterns are influenced by overstory and understory conditions.

Study Area

The study site was located 12 km northwest of Two Harbors, Minnesota, in southern St. Louis County (approximately 47°04′ N, 91°51′ W: altitude = 420 m above sea level). The 5.4-ha site lies on flat terrain with a few scattered shallow depressions. Soils are an outwash-derived, well-drained medium/sandy loam in the Normanna-Canosia soil series (57% sand, 33% silt, 10% clay). A soil macronutrient analysis was conducted at a central location at 0–15 cm and 16–30 cm depth (Table 1). Due to the relatively low relief across the site and the consistency of the soil series and cover types, it is unlikely that nutrient conditions varied substantially across the site. The climate is considered to be mid-continental, with mean Jan. temperatures of –11° C and a mean July temperature of 18° C. Mean cumulative growing season (Apr. to Aug.) precipitation is 42 cm of rain (Two Harbors meteorological station, MN State Climatology Service).

In the summer of 1994, a diameter-limited thinning operation was conducted across the site using a mechanical harvester and full tree skidding to a central landing. The thinning created a range of residual overstory conditions that allowed the establishment of this experiment. The resulting residual overstory basal areas (BA) ranged from relatively open (4 m^2/ha) to relatively dense (22 m^2/ha).

The postthinning stand was comprised of an approximately 70-year-old overstory dominated by sugar maple (*Acer saccharum* Marsh.) (45% of BA) and paper birch (*Betula papyrifera* Marsh.) (29% of BA) and with scattered basswood (*Tilia americana* L.), yellow birch (*Betula alleghaniensis* Britton), aspen (*Populus tremuloides* Michx.), ash (*Fraxinus* sp.), white spruce (*Picea glauca* (Moench) Voss), and balsam fir (*Abies balsamea* (L.) Mill). Average tree height was 17 m, average diameter was 23 cm, and total overstory BA averaged 11 m^2/ha. The understory consisted of dense patches of regenerating hardwood stems, especially sugar maple, raspberry (*Rubus* spp.), blackberry (*Rubus* spp.), and beaked hazel (*Corylus cornuta* Marsh.). Common herbaceous species included big leaf aster (*Aster macrophyllus* L.), braken fern (*Pteridium aquillinum* (L.) Kuhn.), bunchberry (*Cornus canadensis* L.), and sweet scented bedstraw (*Galium triflorum* Michx.).

Table 1. Soil nutrient analysis of study area.

Depth	pH	Bray-P	K	Ca	Mg	Na	NO-3-N
0–15 cm	5.6	10	77	1,314	142	32	2
16–30 cm	5.8	6	51	947	94	35	0.6

Experimental Design

In Apr. 1996, 24 rectangular plots (approximately 8.5 m × 10 m) were established across the site. We surveyed the stands to ensure that an approximately equal number of plots would be allocated to areas that have BA in the upper, middle, and lower third of the density range. Within this constraint, plots were located randomly and cleared of existing woody and herbaceous vegetation. The plots were placed a minimum of 14 m apart and skid trails were avoided. Thirty-six bare root seedlings (3–0) were planted in each plot (6 rows × 6 seedlings/row, 867 total, 3 rows received one extra tree). Seedling spacing was 1 m within rows and 1.5 m between rows. In an attempt to mitigate the impact from herbivory, seedlings were grown in plastic mesh cages through Apr. 1998 (Ward et al. 2000). Following the removal of the mesh cages, paper bud caps were used during the following two winters.

Weeding treatments were randomly assigned to rows of seedlings. The weeding treatments were (1) control (no removal of competing vegetation), (2) annual (single removal of understory vegetation in early June), or (3) monthly weeding (understory vegetation was removed monthly during the growing season). Based on the assumption that the majority of competitive influences from understory vegetation were resulting from direct neighbors during the first few years, weeding treatments were applied in a 1-m swath centered on the rows during all 4 years (Wagner et al. 1989). Weeding treatments were accomplished using a nylon-line-equipped gas-powered weed trimmer accompanied by hand removal of plants when needed.

Measurements

Percent cover of shrubs and herbs that were taller than half the seedling height within 1 m of each target tree were estimated visually in the second and fourth growing season following planting (1997 and 1999). Estimates in each year were conducted by the same observer to ensure consistency in the estimations. Light extinction by the overstory was quantified using the LICOR LAI2000 in summer 1997. Light readings were taken directly above the terminal leader for each seedling on an overcast day following the method proposed by Saunders and Puettmann (1999a). The LICOR LAI2000 calculates diffuse noninterceptance (DIFN), an indicator of "canopy structure or openness" (*sensu* Saunders and Puettmann 1999a) and an unbiased predictor of average growing season transmittance (Comeau et al. 1998, Gendron et al. 1998). As a means to characterize growing conditions as modified by overstory BA trees in weeded rows (i.e., with no overtopping herbs and shrubs), DIFN was measured at each tree and averaged by treatment for each plot. To isolate the influence of overstory BA from the influence of overtopping shrub cover for seedlings growing in control rows, we averaged the DIFN values for weeded seedlings by plot and subtracted the individual control tree DIFN value. This value was used to calculate a control treatment mean DIFN value to represent the influence of shrub cover by plot. Overstory BA was measured by a prism count (1 m^2 BA factor) in the center of each plot and used as a second metric for overstory canopy density. There is a close correlation between the DIFN and plot level BA values (Comeau 2001, Lieffers et al. 2002, Puettmann and D'Amato 2003), with BA being a commonly used metric to characterize stand density for management purposes, while DIFN represents a more physiological approach related to light availability, as it also quantifies factors associated with crown fullness (Comeau 2001).

Tree seedlings were measured in the fall of 1994 and every fall thereafter until 1999. During this time, measurements included total height and basal diameter (at 5 cm, hereafter referred to as diameter). At the same time we noted the source (where identifiable) of any damage or reason for mortality. While seedlings were not measured at the time of planting, they were selected for homogenous size and planting sequence was random. Thus, we assumed that seedling size was not different at the time of planting and subsequent size differences were due to growth differences after outplanting. Height and diameter values were averaged by row. The size after four growing seasons was used as an indicator of early seedling growth.

The incidence of herbivory, insect, and disease were assessed though the fifth year following planting. Animal damage, mainly rabbit and deer browsing, during the 1999/2000 winter reduced the sample size, and in the fall of 2000 measurements were limited to identifying damage agents and the cause of seedling mortality.

Data Analysis

SAS Version 8 (SAS Institute Inc., Cary, NC) was used to construct and test statistical models. All tests were considered marginally significant if $P < 0.10$, significant if $P < 0.05$, and highly significant if $P < 0.01$. Model construction was accomplished under the direction of C. Davey (University of Minnesota Biostatistics Laboratory, Minneapolis, MN).

Analysis of covariance (ANCOVA) was used to test objectives 1 and 2 for the effect of an overstory density gradient (overstory BA), categorical weeding treatments (WEED), and their interactions on total height and diameter in year 4. The least squares means test (LS Means) was used to correct for unbalanced data parameters. The Bonferroni (Dunn) *t*-test approach for multiple comparisons was used to prevent the inclusion of any false significant differences related to weeding treatments (Rosner 1982).

Multiple linear regression was used to test objective 3. The model tested the effect of herbaceous and shrub cover and DIFN (as influenced only by the overstory) and all possible interactions on seedling growth during years 2 and 4. Because the assumption of similar seedling size at the beginning of the growing seasons was not valid after the first year, initial size (height after 1 or 3 years, diameter after 3 years) and possible interactions were included into the models. Residual analysis was used to determine whether model forms were appropriate. No transformation of the variables was warranted (C. Davey, University of Minnesota Biostatistics Laboratory, Dec. 7, 2001).

Logistic regression was used to investigate the general relationship between BA and WEED on the incidence of three common diseases/pests: white pine blister rust (*Cronartium ribicola* J.C. Fisch.), pine bark adelgids (*Pineus strobi* Hartig), and white pine weevil (*Pissodes strobi* Peck). Due to the limitations of the data set for determining incidence rates, inference on specific relationships is limited.

Results

Effect of Overstory Density and Weeding Treatments on 4-year Height and Diameter Growth

ANCOVA identified overstory density (BA) and weeding treatments (WEED) as significantly influencing 4-year height and diameter growth of white pine seedlings (Table 2). In general, seedlings responded to decreasing overstory

Table 2. Results of the ANCOVA investigating the influence of canopy density and weeding treatment on total height and basal diameter 4 years after planting.

Source	Coefficient	*df*	*MS*	*F*	*Pr > F*
Mean height year 4					
Model		3	13,402	31.24	<0.0001
BA	–2.3	1	18,903	44.06	<0.0001
WEED		2	10,496	24.46	<0.0001
Error		133	429		
WEED-Annual	–2.76				
WEED-Monthly	0				
WEED-Control	–27.63				
Mean diameter year 4					
BA	–0.53	1	551	54.09	<0.0001
WEED		2	287	28.15	<0.0001
BA*WEED		2	57	5.59	0.0047
Error		131	10		
WEED-Annual	–1.21				
WEED-Monthly	0				
WEED-Control	–11				
BA*WEED-A	0.1				
BA*WEED-M	0				
BA*WEED-C	0.38				

density and the removal of competing vegetation with increased growth, both in height and diameter (Figure 1, a and b). There was no interaction between BA and WEED for 4-year height growth, but a significant interaction between BA and WEED existed for diameter growth (Table 2). Vegetation removal resulted in trees that were significantly taller across the range of BA examined (Figure 1a). Mean height was 93.4 cm ± 3.1 for trees receiving annual weeding and 96.1 cm ± 3.1 for trees receiving monthly weeding. This differs significantly from control trees, which averaged 68.5 cm ± 3.1. Seedling diameter growth benefited from weeding under open overstory, but not under dense overstory canopies where DIFN values were appreciably lower (Figure 1b). Overall, diameter for annual and monthly weeded trees averaged 13.19 mm ± 0.47 and 14.26 mm ± 0.47, respectively, while control tree diameter averaged 7.55 mm ± 0.48. Bonferroni (Dunn) and LS Means tests revealed that the height growth response to annual and monthly weeding treatments were significantly different from seedlings in the control rows, but not significantly different from one another. A visual analysis of Figure 1b suggests that diameter growth patterns also follow this trend.

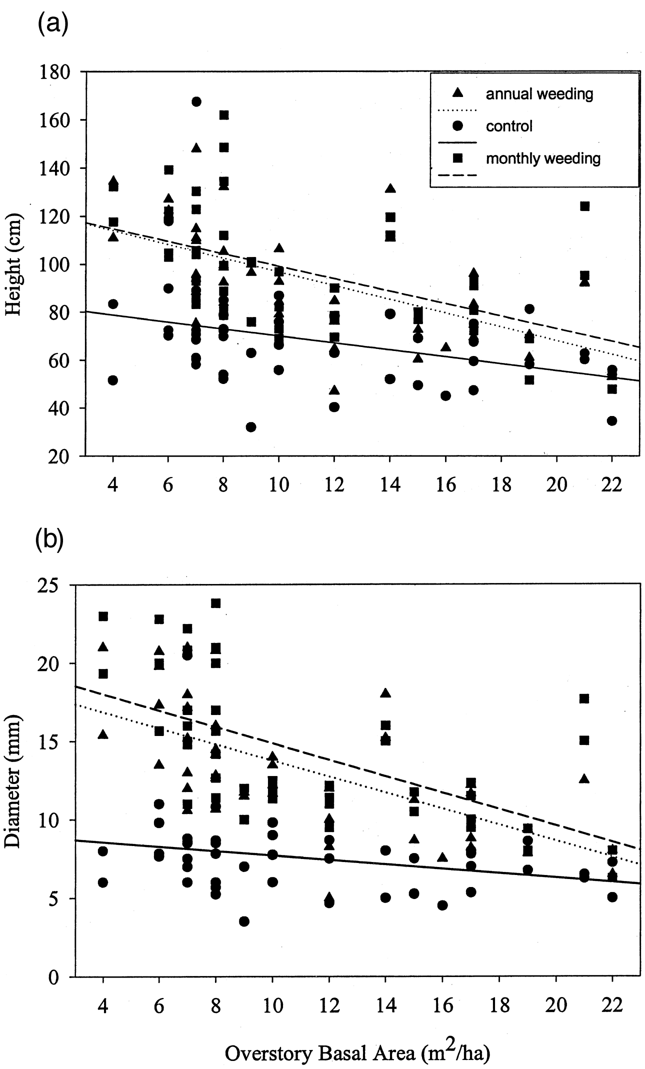

Figure 1. Height (a) and basal diameter (b) after four growing seasons as influenced by overstory BA and weeding treatments.

Separating the Effects of Overstory, Shrub, and Herbaceous Cover on Seedling Growth in the Second and Fourth Year

This analysis is aimed at exploring the results from the previous section in greater depth by utilizing detailed assessments of understory vegetation cover taken in the summer of 1997 and in 1999, i.e., 2 and 4 years after outplanting. The response variable examined is the annual growth (diameter and height) as influenced by four factors (initial height or diameter, herb cover, shrub cover, and DIFN). Initial height is a highly significant predictor of height growth in year 2 ($P < 0.0001$). However, the interaction between initial height and DIFN was not statistically significant ($P = 0.78$). Thus, in year two, a 10% increase in the DIFN level (i.e., a tree grown under more open conditions) results in an increased height growth of 1.1 cm while holding other model values constant. By the fourth year, significant interactions had developed between DIFN and the seedling initial diameter and height (Table 3). Overstory conditions strongly influenced seedling growth during the first 3 years, and consequently seedlings under higher overstory densities were smaller in the beginning of year 4.

A second, highly significant interaction developed between shrub cover and DIFN for year 4 diameter growth. This suggests that plots with lower overstory densities have both higher initial diameters and a greater abundance of competing woody vegetation, which in turn is correlated with the growth of the seedlings in year 4 (Figure 2). Under open overstory conditions (high DIFN values), increasing shrub cover will lead to reduced seedling growth, while under dense overstory conditions, the seedling growth response to increasing shrub cover is essentially flat (Figure 2). In general, however, increasing DIFN levels results in increased seedling growth, with the amount of growth increase higher in areas with low shrub densities (Figure 2).

Herb cover was marginally significant as a predictor of height growth in year 2, but by the fourth year was not statistically significant for height or diameter growth (Table 3). Even in year 2, the practical importance of herb cover is minimal. For example, in the second year a 10% increase of herb cover results in a 2-mm decrease in height growth. By year 4, a similar increase in herb cover results in a decrease of diameter growth of 0.4 mm.

Injury Patterns: Herbivory, Disease, and Insects

Herbivory was the major reason for the termination of the experiment. Over the 5 years, 377 (43%) of seedlings were subject to terminal browse and 728 (84%) had some lateral browse. In the final year, the number of viable seedlings dropped from $n = 556$ to $n = 262$, with 5 of 24 plots no longer having viable seedlings. This reduction was primarily a function of herbivory by deer and rabbits.

During the study period, white pine blister rust was not a major source of mortality. Cankers on stems or lateral branches were observed on 102 trees (12%). Nearly twice

Table 3. Regression results and coefficient estimates quantifying the influence of initial height, herbaceous cover, shrub cover, and DIFN on height and diameter growth in years 2 and 4.

Source	Coefficient	*df*	*MS*	*F*	*Pr > F*
Height growth (year 2)					
Model		4	276	43.89	<0.0001
Initial height	0.22	1	84	13.32	0.0004
Herb cover	–0.02	1	16	2.6	0.1094
Shrub cover	–0.04	1	174	27.67	<0.0001
DIFN	11.4	1	681	108.43	<0.0001
Error		139	6		
Height Growth (year 4)					
Model		5	1,255	38.43	<0.0001
Initial height	0.58	1	1,129	34.6	<0.0001
Herb cover	–0.01	1	5	0.15	0.7034
Shrub cover	–0.1	1	439	13.45	0.0004
DIFN	23.12	1	123	3.77	0.0554
Initial height*DIFN	–0.33	1	107	3.27	0.0737
Error		90	33		
Diameter growth (year 4)					
Model		6	40	33.81	<0.0001
Initial diameter	0.57	1	20	16.54	0.0001
Herb cover	–0.01	1	2	1.28	0.2617
Shrub cover	0.01	1	0.5	0.38	0.5398
DIFN	11.21	1	17	14.16	0.0003
Initial diameter*DIFN	–0.67	90	9	7.82	0.0063
Shrub cover*DIFN	–0.08		13	10.67	0.0015
Error		90	1		

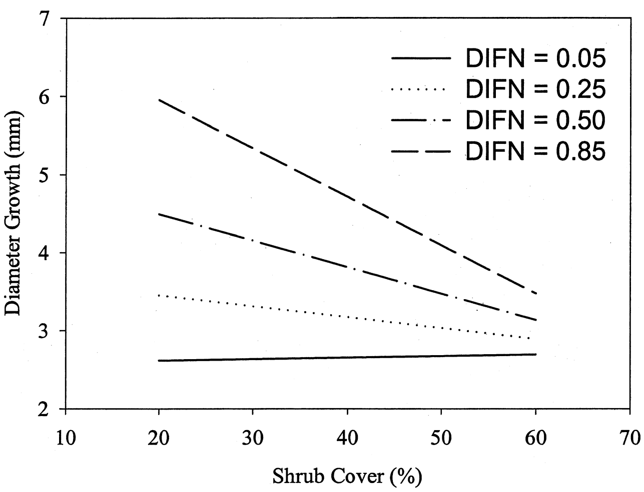

Figure 2. Basal diameter growth in year 4 as influenced by shrub cover and light availability (DIFN).

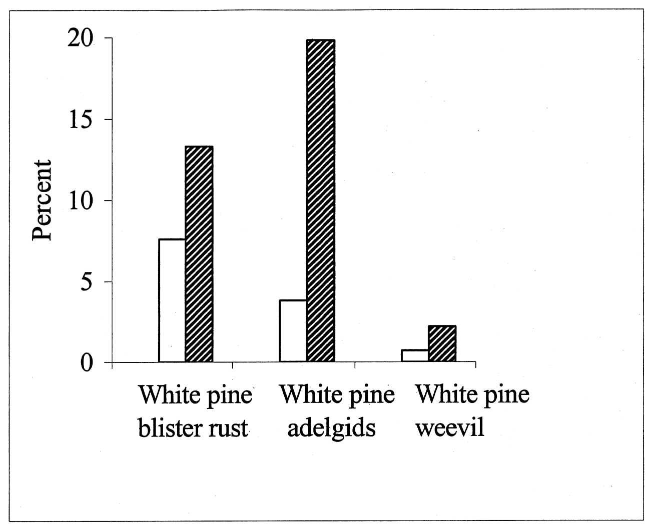

Figure 3. Percentages of seedlings in weeded and unweeded rows that were affected by white pine blister rust, white pine adelgid, and white pine weevils.

the proportion of trees (13.3%) were infected in weeded rows compared to those in control rows (7.6%) (Figure 3). The logistic regression model indicated that BA and WEED are significant predictors of rust infection at this site.

Pine bark adelgids were present to some degree across the entire site. A total of 127 trees (15%) were observed to have some level of infestation. Almost all (91%) occurred in rows with active vegetation removal. Trees in weeded rows had an infestation rate nearly five times higher than trees in control rows, 19.8% versus 3.8% (Figure 3). Using logistic regression, both BA and WEED were significant in predicting the probability for adelgid infestation. As the level of BA decreased and vegetation removal occurred, the probability for infestation increased. No specific instances of dieback or loss of growth or vigor were observed as a result of adelgid presence on seedlings.

Another pest of white pine in Minnesota, white pine weevil, appeared to have little impact at this site. We did not specifically check for the presence of weevils, but we associated the terminal leader dieback that is typical for white pine weevil attacks as an indication of infestation (Drooz 1985). This condition was observed only on 15 seedlings (2%) in 5 years. Due to the small number of trees infected, we could not test statistically whether terminal dieback occurred on plots that were more open. However, only 1 of 15 (7%) proposed weevil attacks occurred in control rows with denser cover over seedlings. Proportionally, 0.7% of control trees exhibited weevil symptoms versus 2.3% of those in weeded rows (Figure 3).

Other factors, such as windthrow, which may have occurred after opening up the stand, apparently were not influencing seedling vigor and survival. While a number of overstory trees did subsequently blow down, no widespread windthrow occurred. A single seedling was killed due to an overstory tree falling on it.

Discussion

Our results support the hypothesis that there is a significant, quantifiable relationship between overstory density, understory competition, and the growth response of white pine seedlings. A negative relationship existed between overstory density and seedling diameter and height growth for the range of overstory densities present in our study site. This is very similar to results reported by Smidt and Puettmann (1998), who studied the growth response of white pine up to 10 years after planting in stands with varying vertical structure, composition, and vegetation management in northern Minnesota. Our study supports their findings that under relatively open overstory conditions, the understory cover represented the dominant competition for white pine seedlings. On the other hand, where dense overstory conditions exist, there is a discernible dampening effect, as understory is less competitive. Consequently, under denser canopy conditions, weeding treatments have a smaller effect, most likely due to the suppression effect that canopy closure has on both the competing species and the seedlings (Riegel et al. 1992, Smidt and Puettmann 1998). Wetzel and Burgess (2001) reported similar results for early growth in white pine if brush control was combined with overstory thinning (1–2 crown spacing) and blade scarification.

Shrub cover response following the harvest appeared uniformly aggressive across the site, irrespective of overstory BA coverage (data not presented). In areas where weeding occurred (which included removal of woody materials), the impact of shrubs on white pine growth was greatest where overstory densities were lowest. In those conditions, we found that seedling height and diameter growth were negatively correlated with shrub cover. Conversely, Saunders and Puettmann (1999a) found that brush control treatments strongly affected seedling diameter, but not their height growth. This difference may be due to the fact that they applied only a single understory weed control treatment, used older seedlings, and may also be due to different site and climate conditions.

Conversely, the presence of dense understory vegetation may support favorable outcomes. Retention of competing shrub cover and higher levels of overstory densities seemed to provide protection from blister rust as reported by several authors (Van Arsdel 1972, Lancaster and Leak 1978, Katovich and Morse 1992). We observed a similar response with the incidence of pine bark adelgids, which were nearly absent under the heaviest competition levels in control rows. In addition, shrub cover provides hiding cover for juvenile white pine that once exposed as a result of vegetation removal may be subject to severe browse (Saunders and Puettmann 1999b).

Herbaceous competition did not exhibit a significant influence on seedling growth patterns (height or diameter growth) through the fourth year. This is likely due to the manual weeding treatment, which set back any herbaceous vegetation. While herbs recovered quickly, they may not be as competitive as undisturbed herbaceous vegetation (with the same percent cover). The competitive impact in year 2 is statistically significant. However, because of the small absolute impact, it is of low practical importance. Harrington et al. (1995) also point out the ability of herbs to expand when shrubs and tree cover were reduced by release treatments. Various authors (e.g., Wagner et al. 1996, 1999, Bell et al. 2000, Zutter et al. 1998) reported that herbaceous competition significantly impacts height and diameter growth of seedlings for up to 5 years. For example, Wagner et al. (1996 and 1999) reported a decrease in stem growth rate of 20% after a single year of exposure to herbaceous competition. The discrepancy in the importance of herbaceous competition and these studies may be due to difference in study setup and location. For example, the cited studies occurred in clearcuts rather than understory settings. Herbaceous vegetation was only impacted as part of the site preparation treatments; in our study we deliberately controlled any herbaceous vegetation in the annual weeding treatment. The significance of herbaceous competition in this study may also be tied to the species mix, gradient of herbaceous competition studied, and differences related to the influence of environmental factors on the nature of competition on site.

The role and impact of deer and rabbit herbivory on this study was evident after removal of the protective mesh cages after the third growing season. We observed browse damage on most seedlings once exposed, which is typical throughout much of Minnesota (Sauerman 1992, Davis et al. 1998, Saunders and Puettmann 1999b). The actual intensity of browsing numbers may be artificially inflated, as we may have concentrated browsing by clearing experimental plots and planting in the midst of vigorous woody regeneration and shrubs. Saunders and Puettmann (1999b) suggest that removal of competing vegetation resulted in decreased hiding cover, exposing seedlings to an increased probability for browsing.

During our 5-year study, blister rust was not a major source of mortality even though this site is located in a high-risk zone (Zone 4) for the disease (Brown et al. 1999). The mortality rate of approximately 12% is consistent with those recently reported for pole and small timber size white pine in northern Wisconsin of 7.2–15.9% across a range of high-risk sites by (Dahir and Cummings Carlson 2001). Actual infection rates in our study are likely understated, as blister rust infections are not easily diagnosed for a few years after the disease enters the needles (Hunt 1997). In general, as the seedling cover (both overstory and understory vegetation) was reduced, the probability of blister rust infections increased. This is likely due to microclimatic conditions favorable for blister rust infection as predicted by Van Arsdel (1972) and Gross (1985). Anecdotal evidence indicates that rabbits prefer to browse on stem cankers, and the possibility exists that this herbivory may have removed part of the infected plants in the plots.

Pine bark adelgids were present across the entire site. As with weevil attacks, adelgids rarely cause seedling mortality in Minnesota, but may slow growth or effect seedling vigor (J. Krueger unpublished observation). Results indicate that adelgids, like weevils, may be found more often on faster growing trees that occur in relatively open growing conditions. White pine weevil also appeared to be of little importance at this site. Although weevil attack is not typically associated with seedling mortality, weevils set back height growth by killing terminal leaders. Due to the small number of trees affected, we cannot conclude that weevil attacks occurred more frequently on plots that were more open, the condition typically associated with increased incidence of weevil attack. Our visual analysis seems to agree with Stiell and Berry (1985) and Pubanz et al. (1999), who indicated that denser canopy cover typically resulted in small seedling terminal diameters, which do not favor weevil infestation (Katovich and Morse 1992).

Conclusion

Our study illustrates the complex interaction between factors and responses that need to be considered when manipulating residual stand structures and species composition. Opening up overstory canopies to improve growing conditions for seedlings resulted in increased height and diameter growth of underplanted seedlings. On the other hand, benefits of weeding treatments were consistent for height growth, but limited to areas with relatively open overstory conditions for diameter growth. This supports the recommendation by Smidt and Puettmann (1998) to focus white pine regeneration scenarios involving green tree retention or shelterwood treatments in a manner to take advantage of stand structures where the understory was suppressed. This seems especially important on mesic hardwood sites, where more vigorous understory vegetation can be expected. Particular attention should be paid to treating dense hardwood regeneration and shrubs to reduce competition for light, soil moisture, and nutrients. On this site, removing herbaceous vegetation provided little benefit to seedlings.

Silvicultural operations aimed at creating favorable growing conditions for seedlings may also have drawbacks. White pine seedlings growing in more open conditions are generally more susceptible to herbivory, white pine blister rust, white pine weevil, and pine bark adelgid infestations. Thus, for any site a balance must be struck between conditions that favor growth and incidences of injuries and mortality. The insect and disease incidence rates found on our study site would not be considered a serious problem in typical white pine plantation. Instead, impact from deer and rabbit herbivory while trees are small are more likely to lead to plantation failures. Of course, mortality agents act in an additive manner and any growth loss and mortality of planted seedlings is undesirable, especially in lower density or mixed species plantings. The ultimate significance of damage agents is not the influence on individual seedlings, but rather the impact on the overall recruitment process and subsequent stocking levels.

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