Forest Ecology and Management 105 (1998) 137–150

Overstory and understory competition affect underplanted eastern white pine

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Received 3 June 1997; accepted 4 September 1997

Abstract

The importance of canopy and understory competition on white pine (*Pinus strobus* L.) seedlings was evaluated in stands with shelterwood treatments. We sampled 20 stands in north-central Minnesota that were underplanted with white pine 3 to 10 years before sampling. We grouped the stands with various canopy and understory treatments into 6 stand types based on residual canopy composition. The effect of the shelterwood treatments, i.e., residual basal area and understory cover on white pine seedling growth varied significantly among the stand types. Lowering basal area had a greater positive impact on seedling growth when shade tolerant softwood species, especially balsam fir (*Abies balsamea* (L.) Mill.), were present in the canopy. Where shade tolerant softwood species were absent, the white pine seedling growth increased only slightly or not at all in the presence of lowered residual basal area. We hypothesize that the exclusion of the understory by a shade tolerant midstory, indicated by the presence of balsam fir, prior to shelterwood treatment created favorable conditions for white pine in the understory following the shelterwood treatment. The results suggest that shelterwood treatments on mesic, more productive hardwood sites should be linked to stand development stages where the understory is suppressed, e.g., following development of a shade tolerant midstory or during the stem exclusion phase. This method should complement present shelterwood prescriptions for drier, low quality hardwood sites. This research indicates the importance of evaluating both vertical structure and site quality prior to designing white pine shelterwood treatments. © 1998 Elsevier Science B.V.

Keywords: Silviculture; White pine; Regeneration; Shelterwood; Competition; Underplanting

1. Introduction

The interest in white pine (*Pinus strobus* L.) regeneration and management across the Lake States is high among the forest products industry, land managers, ecologists, and the general public (Stine and Baughman, 1992). Declines in the acreage of white pine cover type and in the abundance of white pine in other cover types resulted from the white pine logging and forest fires at the turn of the century, the lack of successful white pine regeneration, and losses from pests (white pine blister rust (*Cronartium ribicola* Fisher), white pine weevil (*Pissoides strobi* Peck), and deer browsing) (Jones, 1992). The economic, ecological, and aesthetic importance of white pine and the limited natural regeneration in Minnesota have increased local interest in silvicultural methods and systems for white pine.

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PII S0378-1127(98)00278-8

The moderate shade tolerance of white pine (Baker, 1949) allows regeneration in the understory. Understory regeneration also provides some protection from white pine blister rust (van Arsdel, 1961) and white pine weevil (Berry and Stiell, 1976). In the north-eastern USA, Lancaster and Leak (1978) indicated that removing all of the understory hardwoods and removing from 40 to 60% of the canopy would facilitate white pine regeneration on hardwood sites with a hardwood site index less than 60 ft (base 50). The authors did not recommend white pine regeneration on more productive hardwood sites because of the intense competition by hardwood trees and shrubs. Several authors (Heckman, 1992; Pinto, 1992; Rajala, 1992) throughout the Great Lakes region have documented the successful establishment of white pine regeneration using shelterwood techniques.

Shelterwood treatments are designed primarily to stimulate advance regeneration by protecting seedlings from temperature and moisture extremes (Smith, 1962). However, Ammer (1996) and Lieffers et al. (1993) have suggested the potential for using canopy trees to reduce the need for weed control. The literature referring to white pine shelterwood plantings has indicated that the source of seedling competition varies with site quality, overstory species composition, understory density and their interactions. On mesic aspen sites, the impact of understory competition was more important than canopy density for white pine seedlings (Shirley, 1945; Logan and Farrar, 1953; Logan, 1962; Clements, 1966). On mixed hardwood sites, Freeman and van Lear (1977) found that understory competition impacted seedling growth in a clearcut but not in a shelterwood treatment. In a mesic aspen-northern hardwood stand,

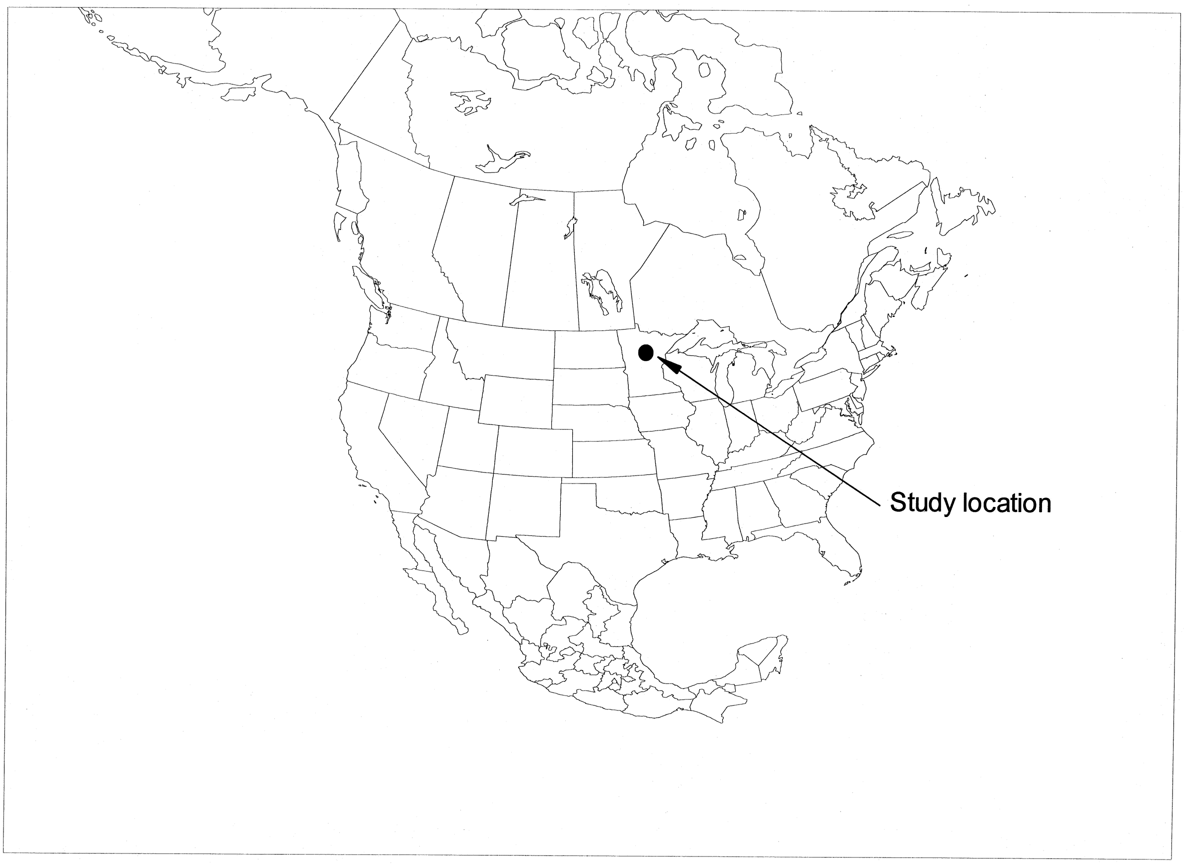

Fig. 1. Location of sampled underplanted white pine stands in Minnesota, USA.

white pine seedling recruitment was inhibited by the low light due to shade tolerant midstories (Roberts, 1992), whereas in a drier aspen-white pine stand, recruitment was limited by below ground competition and not by low light (Squires and Klosterman, 1981). Based on these results, we hypothesize that complex interactions among the canopy (density, composition, vertical and horizontal structure), and site characteristics (soil texture, fertility, and stand history) influence seedling recruitment and growth.

The existence of previously established underplantings under various shelterwood and understory treatments provided the opportunity to examine the effect of canopy and understory removal on the growth of underplanted white seedlings. The study objectives were to determine: (a) how differences in basal area and understory cover and height affected white pine seedling growth within stand types (stands grouped by species composition); (b) how stand types differ in terms of these competitive effects; and (c) whether canopy species composition and its corollaries (site quality, disturbance history, and stand structure) interact with the effects of canopy and understory competition.

2. Methods

An extensive effort to catalog recently underplanted stands throughout Minnesota, USA, was followed in the fall of 1995 by a survey of underplantings established prior to June 1993. After excluding stands with low seedling survival, very heavy incidence of deer browse damage ($>80\%$ ocular estimate), and canopy treatments since planting, 20 underplanted stands remained for sampling. The stands were located in the north-central Minnesota counties of Aitkin, Cass, Crow Wing, Hubbard, Itasca, and Morrison (Fig. 1). Most stands were on landforms with well-drained loamy sand to sandy loam soils while two were on landforms with moderately well-drained and poorly-drained dense sandy loam soils. Old white pine stumps or remnant white pine trees indicated the historical presence of white pine on or near the stands.

Transects and plot spacing were arranged to fit 12 to 15 systematically located plots across each stand. Stand areas ranged from 1 to 8 ha. Plots in planting gaps or with no surviving white pine seedlings were skipped. The basal area was quantified by species with a 1-m basal area factor (BAF) prism at the plot center, and total overstory canopy cover (%) over a 50-m^2 circular plot was estimated ocularly. The mean height of the shrub layer within the 50-m^2 plot was estimated.

Within the same 50-m^2 plot, two white pine seedlings were selected systematically from those seedlings that were greater than, or equal to, mean seedling height within the plot. Moving in a clockwise direction from opposing compass points (north and south), the first unmeasured seedling between the plot center to plot edge was selected. Since understory and canopy conditions were relatively even within the small plot area, it was assumed that the smallest seedlings within the plot represented poor planting technique, poor planting site selection, or poor planting stock or other random factors rather than growing conditions. Seedlings with visible leader damage in the three years prior to sampling or

Table 1
Mean and range of canopy basal area and cover and mean of shrub height and understory cover for each stand type in 1995

Stand type	Canopy				Shrub height	Understory
	Basal area (m^2/ha)		Cover (%)		(m)	Cover (%)
	Mean (s)	Range	Mean (s)	Range	Mean (s)	Mean (s)
1	8.8 (3.0)	4–15	38 (16)	10–70	1.1 (0.4)	46 (16)
2	14.5 (4.3)	4–23	49 (12)	25–75	0.9 (0.4)	30 (19)
3	12.3 (4.5)	3–24	35 (13)	10–70	1.1 (0.5)	23 (15)
4	9.2 (5.8)	0–22	30 (19)	0–75	1.1 (0.4)	43 (24)
5	16.5 (5.5)	7–31	50 (10)	25–75	0.7 (0.3)	12 (9)
6	14.6 (6.0)	3–29	34 (13)	10–60	0.9 (0.5)	27 (18)

Years since canopy and understory treatment vary within stand type. Standard deviations (s) are in parentheses.

with signs of blister rust infection were also excluded. On the selected seedlings, we measured seedling height, diameter at 30 cm, and the internode length for the year prior to sampling. Signs of leader damage more than three years prior to sampling were noted. Within a 1-m radius of the seedling stem, the understory cover (%) that exceeded one half of the seedling's height was estimated ocularly.

Cutting or girdling prior to planting produced the variation in basal area and canopy cover (Table 1). For three of the six stand types, mean canopy cover was considerably lower than the 40 to 60% recommended by Lancaster and Leak (1978) for New England. The remaining three had canopy cover ranging from 38 to 50%. Mean basal area varied from 8.8 to 14.6 m^2/ha. Understory densities and heights were manipulated by scarification, herbicide treatment, or mechanical weeding prior to or just after planting. Mean understory cover ranged from 12 to 46% among stand types while mean understory height varied little (0.7 to 1.1 m) among stand types. The negative correlation between understory cover and basal area (Pearson corr. coeff. $= -0.50$) and shrub height and basal area (Pearson corr. coeff. $= -0.42$) demonstrated the strong relationship between the understory and canopy density.

Stands were subjectively grouped into stand types using several steps. Stand types were differentiated by the combination of two or three dominant species. First, stands were separated by the presence or absence of red pine (*P. resinosa* Ait.). Sugar maple (*Acer saccharum* Marsh.), American basswood (*Tilia americana* L.), balsam fir (*Abies balsamea* (L.) Mill.), and quaking aspen (*Populus tremuloides* Michx.) frequencies were used to define stand types with little or no red pine. Northern red oak (*Quercus rubra* L.) and sugar maple frequencies were used to define the stand types with red pine. Our ability to group the stands based on more objective criteria was limited since partial canopy removal occurred prior to sampling. The species frequencies from variable radius plots (number of plots with species occurrence/total number of plots) for each stand and stand types groups are presented in Table 2.

Table 2
Canopy species frequency for each stand and stand types. Species are BA = balsam fir, SM = sugar maple, BW = American basswood, WP = white pine, RM = red maple, RO = northern red oak, PB = paper birch (*Betula papyrifera* Marsh.), QA = quaking aspen, RP = red pine, and JP = jack pine (*Pinus banksiana* Lamb.)

Stand type	Stand	Species									
		BF	SM	BW	WP	RM	RO	PB	QA	RP	JP
1	1	0.40	0.87	0.07	0.20	0.53	0.73	0.53	0.07	0.00	0.00
	2	0.77	0.77	0.08	0.08	0.31	0.85	0.31	0.15	0.00	0.00
2	3	0.00	0.93	0.67	0.13	0.20	0.67	0.47	0.00	0.07	0.00
	4	0.00	0.93	0.93	0.00	0.00	0.00	0.73	0.13	0.00	0.00
	5	0.07	0.93	0.67	0.00	0.67	1.00	0.60	0.20	0.00	0.00
3	20	0.00	0.20	0.07	0.00	0.40	0.40	1.00	0.87	0.00	0.00
	19	0.00	0.06	0.13	0.00	0.56	0.75	1.00	0.31	0.00	0.00
	18	0.00	0.17	0.67	0.00	0.17	0.75	0.00	0.59	0.25[a]	0.08
4	11	0.50	0.92	0.17	1.00	0.00	0.00	0.08	0.00	0.67	0.00
	13	0.13	0.73	0.07	0.60	0.73	0.07	0.40	0.07	0.20	0.00
	12	0.29	0.21	0.14	0.36	0.50	0.00	0.64	0.14	0.21	0.00
5	17	0.00	0.00	0.00	0.33	0.87	1.00	0.27	0.87	0.80	0.07
	14	0.00	0.00	0.00	0.27	0.40	0.93	0.47	0.67	0.47	0.20
	15	0.00	0.00	0.00	0.67	0.60	0.87	0.93	0.33	0.47	0.27
	16	0.00	0.00	0.00	0.40	0.53	0.87	0.20	0.53	0.33	0.00
6	6	0.00	0.00	0.00	0.87	0.13	0.00	0.27	0.07	1.00	0.00
	7	0.27	0.00	0.00	0.27	0.40	0.00	0.73	0.07	1.00	0.00
	8	0.07	0.00	0.00	0.20	0.80	0.00	0.60	0.13	1.00	0.20
	9	0.20	0.07	0.00	0.13	0.33	0.00	0.20	0.20	1.00	0.00
	10	0.80	0.00	0.00	0.27	0.00	0.00	0.27	0.27	1.00	0.33

[a] Inflated by 30–40 year old red pine plantation on stand boundary.

Differences in seedling age (time since planting) among the stands were accommodated by comparing height in 1995 to height of open grown white pine seedlings of the same age. The percent of open grown height (pogh) was simply the observed height divided by the predicted open grown height (ogh). The open grown height was predicted using the height of seedlings growing in relatively open conditions (gap diameter > 1 canopy tree height) from each age class (age) using a quadratic model (Eq. (1)). Other applicable model forms produced little difference in predicted ogh in the age range considered.

$$\text{ogh}\,(\text{cm}) = 117.65 - 6.22 * (\text{age}) + 2.02 * (\text{age}^2), \quad R^2 = 0.88, P > F = 0.0374 \qquad (1)$$

To reduce the correlation between understory variables (mean shrub height and understory cover) and basal area and the resulting problems due to collinear independent variables, the understory variables were standardized with respect to basal area. The maximum values of mean shrub height and understory cover were identified within each basal area class (1 m^2/ha). The standardized values were derived by dividing the observed value by the maximum value at the given basal area. This reduced the correlation (Pearson corr. coeff.) of understory variables and basal area (ba) from -0.50 and -0.42 to -0.05 and -0.18 for mean shrub height (sh) and understory cover (uc), respectively.

The first step in the analysis was the examination of differences within stand types. This was accomplished by analysis of covariance that related percent of open grown height (pogh) to the continuous variables (V_i = ba, uc, and sh) (Eq. (2)). Stand differences were investigated through a stepwise selection ($P < 0.15$) of stand indicator variables (S_j), and stand and continuous variable combinations ($V_i S_j$). Stepwise selection was also performed on leader damage (L equalled 1 if present, 0 if absent) and continuous variable interactions (V_i = ba * uc, ba * sh, and uc * sh).

$$\text{pogh} = a_0 L + b_0 + b_1 V_1 + \ldots b_p V_p + \gamma_1 S_1 + \gamma_2 S_2 \ldots \gamma_n S_n + \delta_{11} S_1 V_1 + \delta_{12} S_1 V_2 + \ldots \delta_{np} S_n V_p \qquad (2)$$

The estimated coefficients, b_0, b_i, γ_j, and δ_{ij}, were used to predict percent open grown height and compare the results within stand types. The stepwise selection option within the procedure REG from the SAS Statistical package (SAS Institute, 1987) was used.

Table 3
Stand type model statistics including R^2 and the semi-partial correlation coefficients (sums of squares (SS) effect/SS total) for the variables, basal area (ba), understory cover (uc), shrub height (sh), and their interactions

Stand type	R^2	Intercept	Variables (V_i)					
			ba	uc	sh	ba * uc	ba * sh	uc * sh
1	0.36	na * *	0.28 * *	0.06 * *	0.06 * *	0	0	0.11 * *
S_j							0.08 * * (1)	
2	0.63	na * *	0.08 * *	0.01	0	0.05 * *	0	0.02 * *
S_j		0.04 * * (3)						0.02 * (4)
3	0.64	na * *	0	0.01	0	0	0	0
S_j		0.03 * * (19)	0.01(20)		0.06 * * (18)	0.06 * * (18)		
4	0.47	na * *	0.24 * *	0.02 *	0	0.02 *	0	0
S_j		0.10 * * (13)						
5	0.44	na * *	0.03 * *	0.04 * *	0.03 * *	0.01 * *	0	0
S_j					0.08 * * (17)			
6	0.61	na * *	0.08 * *	0	0.01 *	0	0.03 * *	0
S_j		0.02 * * (6)			0.02 * * (7) 0.04 * * (10)		0.01 * (10)	

The stand numbers (S_j) corresponding to the coefficients are indicated in parentheses. The significance of F values are indicated at $P < 0.10$ (*) and $P < 0.05$ (* *), na indicates not applicable.

The next step was to identify the differences among stand types. For that task, the stand type indicator variable (ST_j) was substituted for the stand indicator variable (S_j) in an analysis of covariance procedure similar to the one described previously. The term $ST_j L$ was added to account for differences in the effect of leader damage among stand types.

The final step was to identify relationships among coefficients (b_i and δ_{ij}) and the species composition. Those relationships were identified by a regression of the estimated coefficients for ba, uc, and sh with stepwise selection ($P < 0.15$) of species and 6 species groups (hardwood or softwood and shade tolerant, mid tolerant, or intolerant) frequencies. The modelled coefficient values were the sum of the coefficient and all the interactions that included that variable. Mean values of the two other variables were used to determine the value used in the regression since the interactions, ba * uc, ba * sh, and uc * sh, affected the sum of the coefficients.

It was assumed that all of the individual relationships between percent of open grown height and basal area, understory cover, and shrub height were linear. This assumption resulted from the interpretation of plots of the individual relationships and with plots of residuals versus predicted values of percent of open grown height.

3. Results

As expected with a retrospective study, some individual stand differences were present within stand types (Table 3). However, within all stand types, except stand type 3, the variance explained by the stand type variables was greater than that explained by individual stand interactions. Further, individual stand coefficients, when significant, usually produced little difference in predicted percent of open grown height at average values of ba, uc, and sh (Fig. 2).

Only small stand differences existed within stand types 1, 2, 4, and 6 for the relationship between percent of open grown height (pogh) and the main

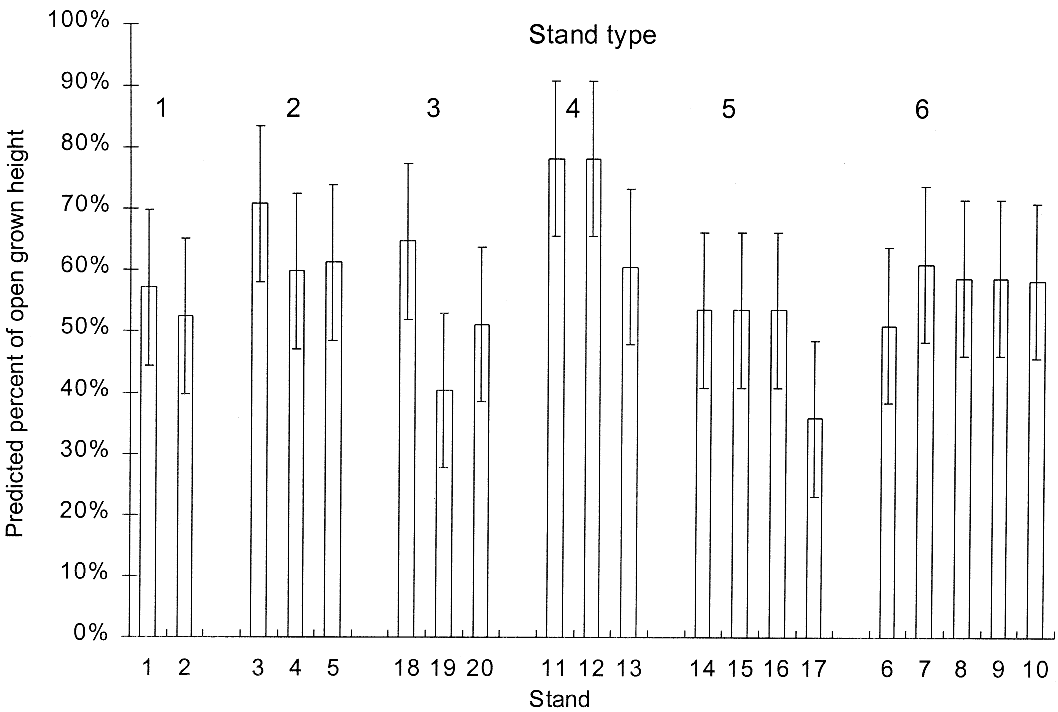

Fig. 2. Predicted percent of open grown height and 90% confidence interval at mean values of basal area, understory cover, and shrub height.

variables, basal area (ba) and understory cover (uc) (Table 3). Significant stand interactions within these stand types produced nearly constant differences within the range of observed levels of ba and uc, i.e., the adjustment was additive. As an example, stand type 6 is shown in Fig. 3. For at least one of the stands in stand types 3 and 5, the relationship of percent of open grown height to the main variables was different in magnitude, sign, or both (Fig. 4). In general, the similarity within stand type was greatest in stand types 1 and 2, intermediate in stand types 4 and 6, and poorest in stand types 3 and 5.

Although larger differences in predicted values were observed for stand 13 in stand type 4 and stand 17 in stand type 5 (Fig. 2), estimated coefficients for individual stands were similar in magnitude and sign to the stand type coefficients. However, the coefficients for stand type 18 differed in both magnitude and sign from the stand type 3 coefficients (Fig. 4). Heavy cutting within stand 18 and an adjacent pine plantation made its classification according to the described procedures difficult. Therefore, stand 18 was removed from stand type 3 before proceeding.

The next step in the analysis was to identify whether significant differences were present between stand types. Stand types differed mainly in the effect of basal area and understory cover on percent of open grown height (Table 4). Most of the stand type coefficients entered during the stepwise selection were highly significant ($P < 0.05$).

Finally, trends between coefficient estimates and species or species group frequencies were used to help identify important compositional or structural elements of the stands. Generally, one species or species group was strongly related to each of coefficient estimates (Table 5). Basal area coefficient estimates were negatively correlated with the frequency of shade tolerant softwoods. Understory cover coefficient estimates were significantly correlated to the frequencies of red maple (*A. rubrum* L.), sugar maple, shade intolerant hardwood, and intolerant softwood. Among those, the red maple frequency

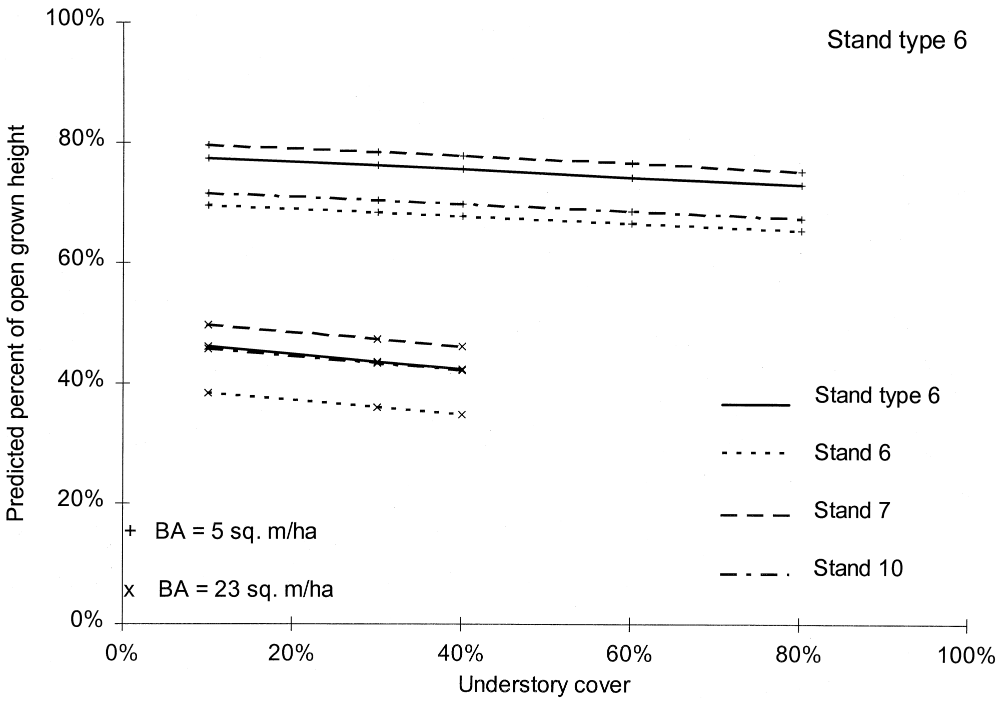

Fig. 3. Predicted percent of open grown height for stand type 6 for levels of basal area (BA) and understory cover. Individual stands with significantly different parameters are also displayed.

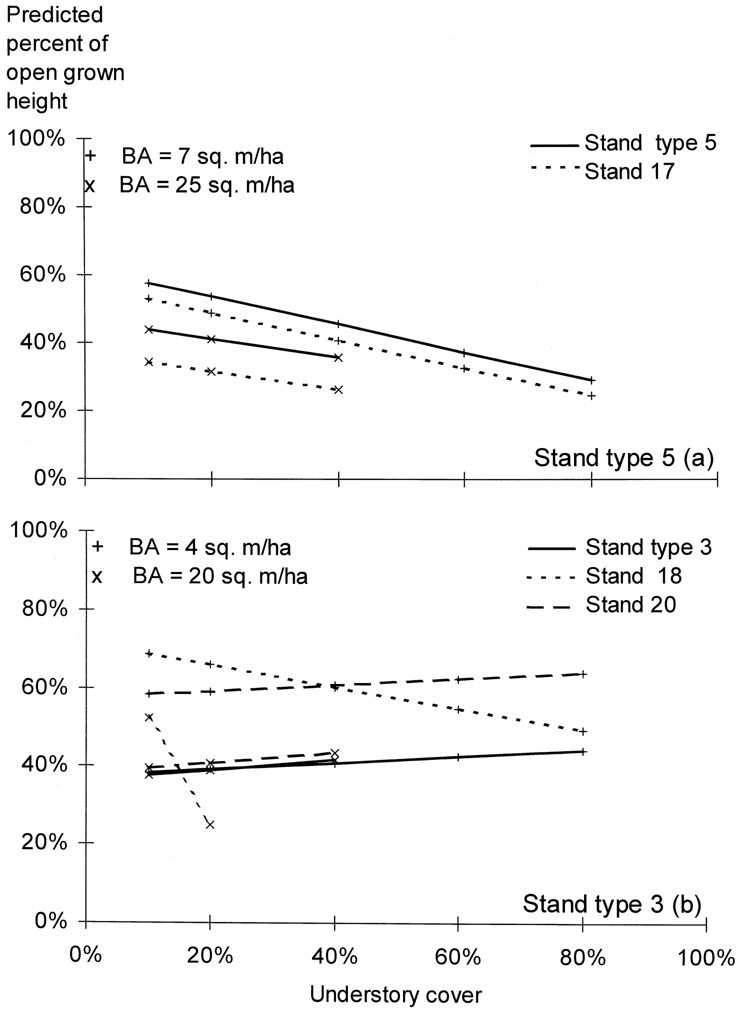

Fig. 4. Predicted percent of open grown height for stand types 5 (a) and 3 (b) for levels of basal area (ba) and understory cover. Individual stands with significantly different parameters are also displayed.

Table 4
Coefficient estimates from the analysis of covariance for the combined stand types with stepwise selection ($P < 0.15$) of leader damage ($ST_j L$) stand type effects (ST_j) and stand type and continuous variable combinations ($V_i ST_j$)

Effects	Base model coefficient (V_i)	Stand type coefficients (ST_j, $ST_j L$, and $V_i ST_j$)					
		1	2	3	4	5	6
Intercept	0.797**	0	0	−0.123**	0.217**	0	0
Leader damage	−0.184**	0	0	0.107**	0	0	0
Basal area (ba)	−0.016**	−0.015**	0	0	−0.011**	0	0
Understory cover (uc)	−0.166**	0	0	0	0	−0.260**	0
Shrub height (sh)	0.020	0	0	0	0	0	0
ba* uc	0.013**	0	0	0	0	0	−0.007**
ba* uh	0	0	0.005	0	0	0	0.006**
uc* uh	0	0	−0.183**	0	0	0	0

The significance of F values are indicated at $P < 0.10$ (*) and $P < 0.05$ (**).

Table 5
Regression of average coefficients for basal area, understory cover, and shrub height (see Table 4) with stepwise selection ($P<0.15$) of species and species group frequencies

Model	Effects	Coefficient	F value	$P>F$	R^2
Basal area	Model	na	7.105	0.0561	0.6398
	Intercept	−0.0078	6.94	0.0580	na
	Tolerant softwoods	−0.0261	7.11	0.0561	0.6398
Understory cover	Model	na	22 446.7	0.0050	1.000
	Intercept	0.1929	12 996.6	0.0056	na
	Red maple	−0.2003	5.23	0.0842	0.5666
	Intolerant hardwoods	−0.2493	15.40	0.0294	0.3627
	Intolerant softwoods	−0.0810	15.00	0.0607	0.0624
	Sugar maple	−0.0373	745.35	0.0233	0.0083
Shrub height	Model	na	13.19	0.0221	0.7673
	Intercept	0.0013	0.01	0.9204	na
	Red pine	0.0870	13.19	0.0221	0.7673

Tolerant softwoods are balsam fir, black spruce, and northern white cedar; intolerant hardwoods are quaking aspen, bigtooth aspen (*Populus grandidentata*, Michx.), and paper birch; and intolerant softwoods are red and jack pine. In some cells, values are not applicable (na).

showed the strongest negative correlation to the understory cover coefficient estimates. The shrub height coefficient estimates were positively correlated to only red pine frequency.

Fig. 5 shows the range of the basal area coefficient estimates within each of the stand types. For stand types 2, 3, 5, and 6, the effect of basal area on pogh was near zero, and the continuous variable

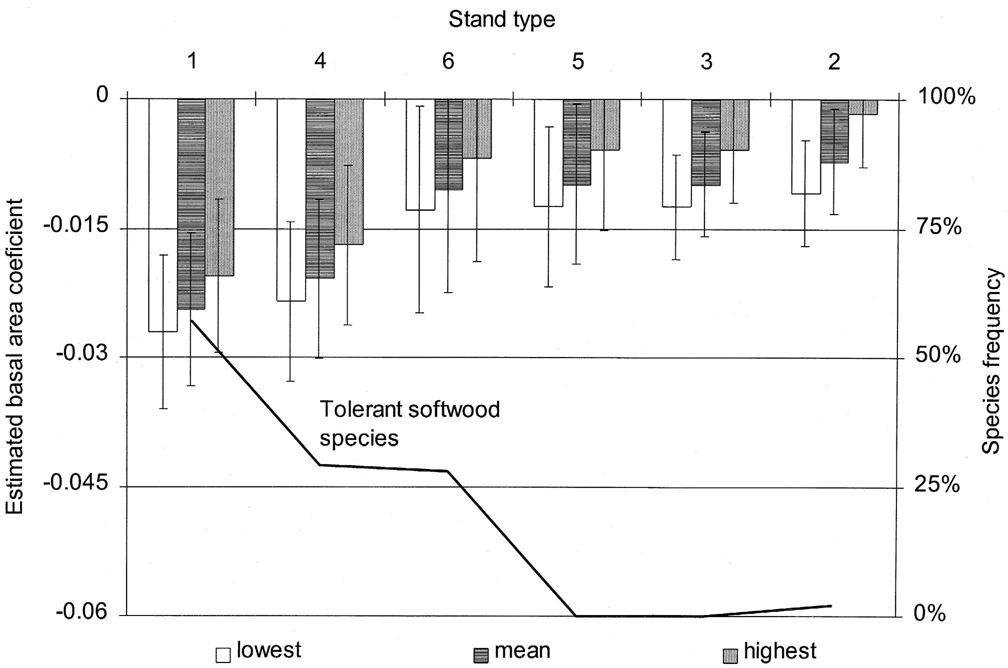

Fig. 5. Estimates of basal area coefficients at the lowest, mean, and highest observed values of understory cover and shrub height within each stand type. The range of one standard error is displayed for each of the estimates. The frequency of tolerant softwoods (balsam fir, black spruce (*Picea mariana* (Mill) B.S.P.), and northern white cedar *Thuja occidentalis* L.) is plotted for each stand type.

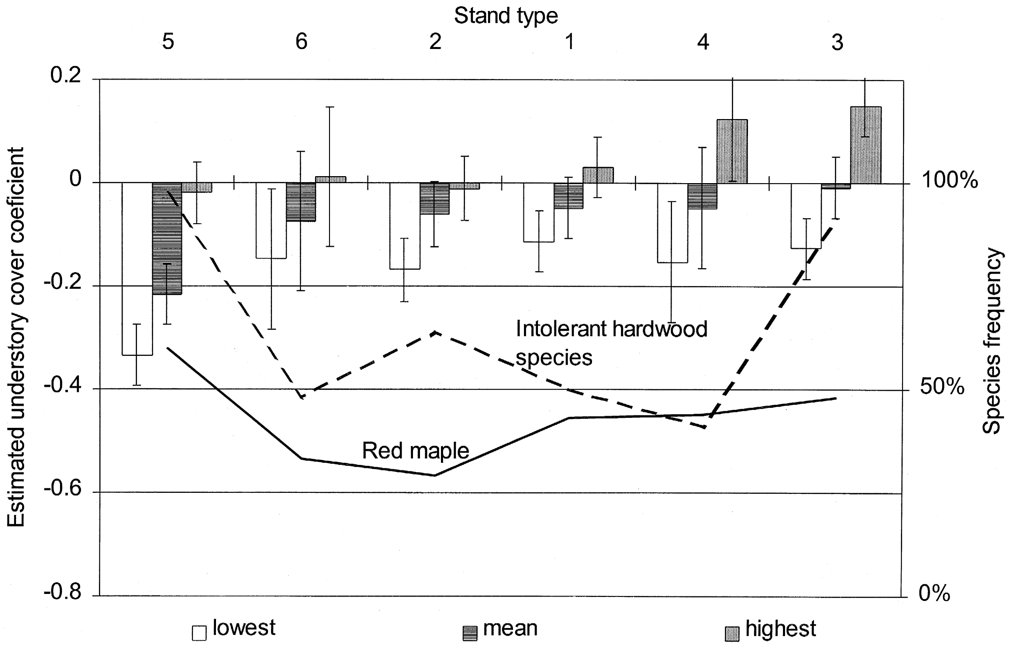

Fig. 6. Estimates of understory cover coefficients at the lowest, mean, and highest observed values of basal area and shrub height within each stand type. The range of one standard error is displayed for each of the estimates. The frequencies of red maple and intolerant hardwoods (bigtooth aspen, paper birch, and quaking aspen) are plotted for each stand type.

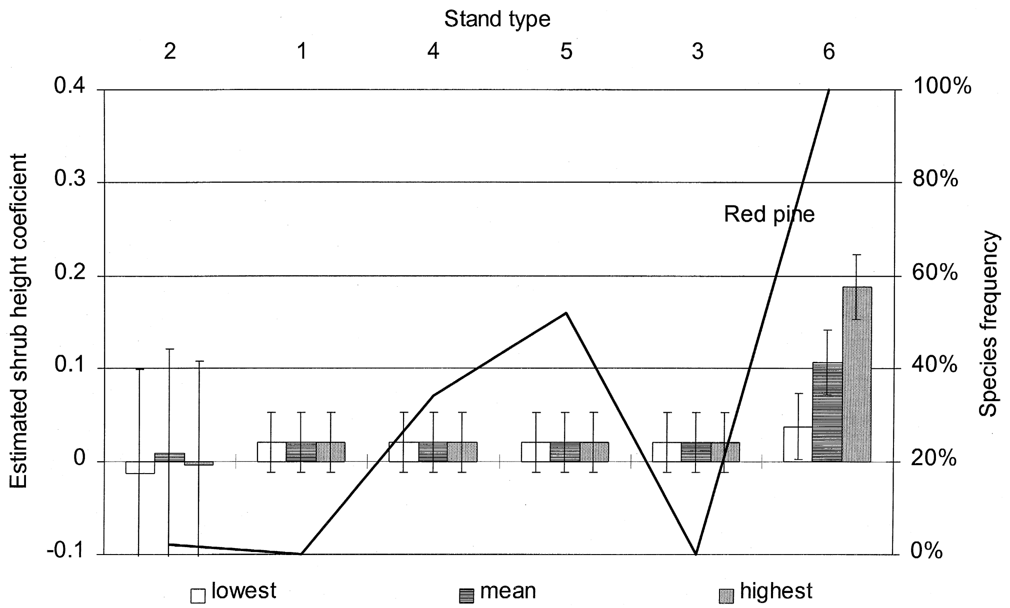

Fig. 7. Estimates of shrub height coefficients at the lowest, mean, and highest observed values of basal area and understory cover within each stand type. The range of one standard error is displayed for each of the estimates. The frequency of red pine is plotted for each stand type.

interactions had a large relative effect on the basal area coefficient. As a contrast, the effect of basal area on pogh was large for stand types 1 and 4 and the continuous variable interactions had a much smaller relative effect on the basal area coefficient. High tolerant softwood frequency distinguished the two groups of stand types with the exception of stand type 6 which had small basal area coefficients but high balsam fir frequency.

Within most stand types, the effect of understory cover varied strongly across the observed range of basal area and shrub height (Fig. 6). Across stand types, the relationships between red maple or intolerant hardwood frequencies and understory cover coefficients were not obvious.

Shrub height coefficients were only slightly affected by the observed range of basal area and understory cover (Fig. 7). Stand type 6 which had the highest red pine frequency was the only stand type with shrub height coefficients greater than 0.

4. Discussion

The shelterwood treatments prior to sampling reduced the utility of stand classification based on criteria such as total basal area, density, and importance values. Therefore, the classification scheme emphasized easily observable differences that helped to minimize the changes in stand composition produced by cutting prior to sampling. The desire to maintain multiple stands within stand types also affected the conservative criteria for retaining stands within larger stand types.

Stand differences present within stand types might cumulatively represent inherent stand variability, subjective classification, and the imperfect correlation of canopy species with site characteristics that affect white pine seedling growth, e.g., nutrient and moisture regimes and disturbance history. Further, the stand types presented do not represent the most appropriate classification because of the lack of replication of white pine underplantings.

Despite the complications in stand type grouping, stand types were fairly homogenous in the effects of basal area, understory cover, and shrub height on seedling height growth. The differences in competitive interactions among stand types helped to identify important diagnostic characteristics that can be used in the application of white pine shelterwood treatments. Intrinsic site differences affected intercepts but did not affect the observed relationships. The variation within some stand types, particularly stand type 3, reflected the limitations in our classification method and in our ability to classify the stands after the shelterwood treatments were applied. We believe that the composition of one stand was altered to the degree that it could not have been correctly classified.

The competition between the canopy trees and white pine seedlings, as expressed by the basal area coefficient, increased when shade tolerant softwoods, especially balsam fir, were present. High competition between balsam fir trees or seedlings and white pine seedlings was also noted by Methven (1973), Methven and Murray (1974), and Ahlgren (1976). The reduced light transmission of shade tolerant trees such as balsam fir (Canham et al., 1994) may be a major source of the reduced growth of white pine seedlings beneath balsam fir. Tolerant hardwood species, such as sugar maple, basswood, or eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch) were more abundant, but there was no correlation, singly or collectively, with white pine seedling growth (Table 5). It is important to note that balsam fir stems were seldom cut in the shelterwood treatments which diminished the possibility that balsam fir competition was entirely responsible for the differences. We hypothesize that tolerant softwood basal area reflects the presence of a shade tolerant midstory which can be quite influential on understory development (Roberts, 1992). Sugar maple, red maple, basswood, and eastern hophornbeam are also common in shade tolerant midstories, but their ability to sprout following logging (the most recent disturbance prior to shelterwood application in all of the sampled stands) meant that their presence was not necessarily an indicator of a shade tolerant midstory. However, balsam fir trees were nearly always in a lower stratum beneath the northern red oak, sugar maple, red pine, or white pine overstory.

We hypothesize that the multilayered canopy (overstory and midstory) might indicate high utilization of nutrients, moisture, and light which inhibited understory reinitiation (Roberts and Richardson, 1985; Roberts, 1992). Since the midstory inhibited the understory prior to cutting, the newly planted white pine had little understory competition. We suspect that in stands that lacked the midstory, the understory was denser prior to cutting, and the understory competition was greater following partial canopy removal. In these stands, the partial canopy removal released the well established understory, and the increased resources were divided simultaneously among the understory, white pine seedlings, and residual overstory.

The characteristics of the understory cover coefficient estimates among stand types support the previous hypothesis. In the two stand types with a shade tolerant midstory (1 and 4) basal area had a large effect on seedling growth (Fig. 5). However, the effect of understory cover was small even in open areas with low basal area where it was expected that understory competition would be the dominant factor (Fig. 6). In stand types without shade tolerant softwoods (2, 3, and 5), the effect of understory cover increased. Generally, at low basal area, i.e., in open areas, the understory cover was the dominant white pine seedling competition. Across all stand types at mean or high basal areas, i.e., little or no overstory removal, the understory cover had no effect on seedling growth indicating canopy control of understory competition. In stand types 3 and 4, high understory cover in combination with high basal area indicated better microsite conditions correlated with increased white pine seedling growth.

Stand type 6 appeared to be the exception from the relationships just described since those stands had high frequencies of shade tolerant softwoods and low basal area coefficients (Fig. 5). Within stand type variability might contribute to this difference since balsam fir frequencies were quite variable (Table 2). Although it might also be explained by the nature of the dominant overstory species, red pine. Since the red pine stems are very large with respect to other species sampled, basal area, as sampled by the 1-m BAF prism, and canopy cover were weakly correlated except in the larger canopy gaps. On the other hand, balsam fir presence near the plot greatly influenced canopy openness, but the smaller stems contributed relatively little to total basal area. The positive relationship between shrub height and percent of open grown height also supports this explanation. In red pine stands, greater shrub height might be an indicator of balsam fir absence and reduced competition between planted seedlings and the balsam fir.

The greater significance of understory cover compared to shrub height in most stand types indicated that it was a more sensitive measure of understory competition. None of the stand types showed a significant negative correlation between shrub height and white pine seedling growth.

We did not attempt to explain any of the observed differences in terms of site quality differences although they certainly affected the results at some level. In this sample of stands, we believe site differences were minimized due to the limited range of nutrient and moisture regimes among them (Kurmis, 1969). Authors who investigated differences in white pine recruitment and growth identified the influence of site quality. Roberts (1992) concluded that light rather than below ground competition inhibited seedling recruitment as site quality increased. The seedling distribution of a drier, less productive aspen-white pine stand (Squires and Klosterman, 1981) was affected primarily by root competition from canopy trees rather than light competition. Yeaton (1978) also indicated below ground competition was more important than light competition for understory white pine growth and survival in an old-field white pine stand. Wendel (1970) and Yawney (1961) observed that white pine seedlings and saplings growth on high quality sites responded more to canopy and understory release than those on low quality sites. Lutz and Cline (1947) documented the extreme difficulty in establishing white pine seedlings on sites with fine textured soils versus the relative ease on coarse textured soils. And finally, Lancaster and Leak (1978) separated poor and better hardwood sites in their white pine shelterwood prescriptions because of the poor competitive ability of white pine on better hardwood sites.

5. Conclusions

As mentioned previously, various authors (for review, see Ammer (1996) and Lieffers et al. (1993)) have suggested the potential for using canopy trees to reduce the need for weed control. Our analysis suggested that the presence of a shade tolerant midstory in addition to the canopy prior to partial canopy removal benefitted seedling growth. We hypothesize that this effect is largely due to the exclusion of understory prior to planting. On the other hand, partial canopy removal in stands with dense understories prior to cutting released the understory at the expense of white pine seedlings. Using simple shelterwood guidelines of either basal area removal or canopy cover removal across a range of site quality or stand structure does not consider the complexity of the interactions between stand composition, site quality, and understory cover.

The recognition of stand structure may provide information for shelterwood management of white pine. Stands in the stem exclusion phase, either young stands or older stands with a shade tolerant midstory, are very favorable for white pine underplanting following partial canopy removal. Higher residual basal areas in shelterwood treatments may inhibit the growth of the understory while allowing time for white pine seedlings to become established. The poor competitive ability of white pine with hardwoods on mesic sites is widely documented, but after 10 or more years of establishment, white pine seedlings can grow at the same rate or faster than many hardwood stems (Kelty and Entcheva, 1993).

On mesic or dry-mesic sites without a shade tolerant midstory, the hardwood understory was a significant competitor following partial canopy removal. On that type of site, Shirley (1945) found that the understory cover reduced light to below that adequate for white pine success regardless of the level of canopy removal. Canopy removal should create the minimum adequate light level for white pine with complete removal of the understory by scarification or herbicide application.

Acknowledgements

We appreciate the financial support of the Iron Range Resources Rehabilitation Board, St. Louis County, and the Minnesota Department of Natural Resources. We would like to thank all landowners for their cooperation. We also extend our appreciation to John Zasada and Dan Pubanz for their assistance in review of an earlier draft of this paper.

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