

## The effects of herbaceous and woody competition on planted white pine in a clearcut site

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### ARTICLE INFO

#### Article history:

Received 23 June 2008

Received in revised form 10 November 2008

Accepted 22 November 2008

#### Keywords:

Eastern white pine (*Pinus strobus* L.)

Trembling aspen (*Populus tremuloides* Michx.)

White pine weevil (*Pissodes strobi* Peck.)

Competition

Vegetation management

Silviculture

### ABSTRACT

We investigated the effects of herbaceous and woody vegetation control on the survival and growth of planted eastern white pine (*Pinus strobus* L.) seedlings through six growing seasons. Herbaceous vegetation control involved the suppression of grasses, forbs, ferns, and low-shrubs, and was maintained for 0, 2, or 4 years after white pine seedlings were planted. Woody control involved the removal of all tall-shrub and deciduous trees, and was conducted at the time of planting, at the end of the second or fifth growing seasons, or not at all. Seedling height and basal diameter responded positively and proportionally to duration of herbaceous vegetation control. Gains associated with woody control were generally not significant unless some degree of herbaceous vegetation control was also conducted. Only herbaceous control increased pine crown closure and rate of crown closure. Herbaceous control and the presence of 5000–15,000 stems per ha of young overtopping aspen were associated with reduced weevil (*Pissodes strobi* Peck.) injury and increased pine height growth. The study suggests that white pine restoration strategies on clearcut sites should focus on the proactive, early management of understory vegetation and the gradual reduction of overtopping cover from woody vegetation to create a seedling light environment that supports acceptable growth with minimal weevil damage.

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### 1. Introduction

Eastern white pine (*Pinus strobus* L.) has made significant contributions to the economy of northeastern North America since colonial times and, despite being absent or greatly reduced over its former range (Aird, 1985; Frelich, 2002; Pinto et al., 2008), continues to be among our most valued species. Consistent demand for quality lumber (Wray, 1985), coupled with growing appreciation for its ecological, wildlife, and social benefits, has prompted ongoing interest in white pine regeneration and restoration in a variety of forest ecosystems.

Where mature white pine exists, the preferred regeneration method involves some form of partial harvesting, in combination with microsite/understory treatment to enhance natural and/or artificial regeneration (OMNR, 1998; Burgess and Wetzel, 2000). However, on the many sites where quality white pine has largely been extirpated, foresters have been forced to rely on artificial regeneration methods for the restoration of this species, with

notably variable results. Damage to regeneration caused by white pine blister rust (*Cronartium ribicola* J.C. Fisch.) and white pine weevil (*Pissodes strobi* Peck.) has often been devastating, prompting foresters in some jurisdictions to abandon such restoration efforts altogether (Wray, 1985; Gross, 1985). Competition from vigorous herbaceous and woody species can exacerbate the effects of these pests and has the direct effect of reducing seedling survival and growth through critical reductions in available light, moisture, and nutrients (Stiell, 1985). The declining presence of frequent, low-intensity fires that may alleviate pressure from these factors and create favourable environments for white pine regeneration has also been problematic, contributing to wide variation in regeneration success (Weyenberg et al., 2004; Thompson et al., 2006). As a result, foresters are recognizing that successful white pine regeneration and restoration requires an integrated, holistic suite of intensive silviculture measures that include avoidance of high-hazard environments, timely and adequate vegetation management, stem density regulation, and, possibly, pruning, and direct pest-control tactics (Pitt et al., 2006).

Consistent operational application of timely and adequate vegetation management has been particularly difficult to achieve due to debate among foresters concerning the most appropriate

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competition control strategy for white pine, especially in restoration scenarios where a protective, mature white pine overstory and seed for natural regeneration are absent. Although past regeneration surveys of white pine plantations have invariably shown competition to be a primary factor responsible for poor survival and growth (Hosie, 1953), little research has been conducted to examine vegetation management scenarios for white pine plantations. This dearth of research has resulted in reliance on operational experience to formulate vegetation management prescriptions. Presently, there are two general and opposing viewpoints regarding appropriate competition control for white pine. One perspective is that all competition detracts from artificially established seedling survival and growth, while the other view is that some competition is beneficial in mitigating white pine weevil damage and promoting crop height growth. Unfortunately, little follow-up data documenting successes and failures of these two fundamental approaches are available, and formal experiments to test these views have not been undertaken. As a consequence, current operational vegetation management strategies for white pine plantations range widely from early competition control during the site preparation phase, to delayed intervention several years after plantation establishment.

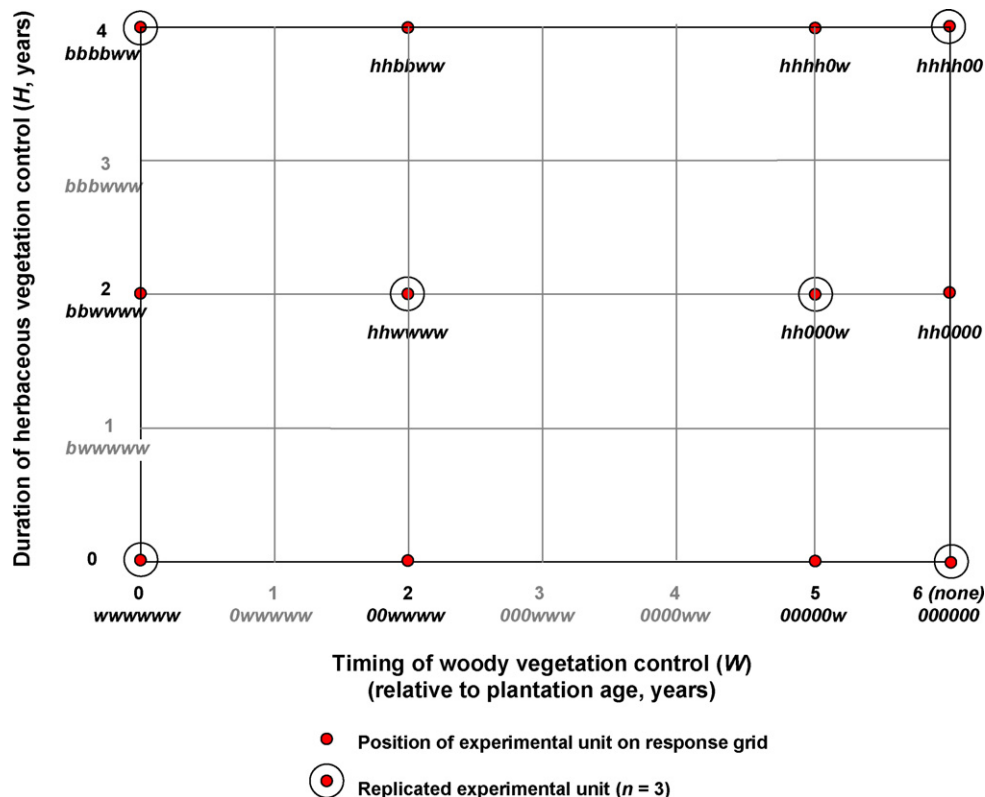
Through recent efforts to restore this species to its historical range, foresters have identified the need for a more rigorous understanding of what vegetation components most compete with white pine, and when, during seedling development and early growth, competition is greatest. To address this need, we established a field study in 2000 that employs a response-surface design aimed at identifying vegetation conditions that favour planted white pine survival, growth, and stem quality. In this paper, we present the resulting age-6 response surfaces for white

pine survival and growth as guides to the development of more effective and consistent vegetation management prescriptions for white pine restoration.

## 2. Methods

### 2.1. Experimental design

In this experiment, we employed a response-surface design to study the effects of *duration of herbaceous vegetation control (H)* and *timing of woody vegetation control (W)* on planted white pine survival and growth. Herbaceous vegetation control, herein referring to the suppression of grasses, forbs, ferns, and low-shrub vegetation types, was maintained for 0, 2, or 4 years after planting. Woody vegetation control, involving the removal of all tall-shrubs (species capable of achieving at least 2 m in height) and deciduous trees, was conducted at the time of planting, at the end of the second or fifth growing seasons, or not yet as of the time of the year-6 assessment. The measured responses to the resulting treatment combinations (Fig. 1) were used to build a model or “response surface” (Montgomery, 2001) to guide forest managers in developing vegetation management prescriptions aimed at optimizing white pine seedling growth and stem quality. The advantage of this approach is that it allows for simultaneous interpolation across duration of herbaceous control and the timing of woody control in this optimization process. Since hardwood density may influence the nature of the response surface, 3 different nominal hardwood densities were studied; 5000, 10,000, and 15,000 stems per ha (sph). This range was chosen to reflect the densities that are commonly encountered in white pine plantation settings following some form of site preparation. As comparative



**Fig. 1.** Response-surface design for studying the effects of competition on white pine establishment and growth. The combinations of *duration of herbaceous vegetation control (H)* and *timing of woody vegetation control (W)* lead to 12 treatments. These treatments may be coded in terms of “0” no vegetation control, “w” woody control, “h” herbaceous control, and “b” both woody and herbaceous control, with 6 characters representing years 1 through 6, respectively. Each of the 4 corners and center points on the grid were replicated 3 times (total of 18 experimental units, or plots). The response grid was replicated at 3 aspen densities (5000, 10,000, and 15,000 stems/ha), requiring a total of 60 plots (those with woody control in year 0 being common to each density). Reference treatments included complete vegetation control (bbbbbb, n = 3) and operational broadcast release (00b000, n = 3 × 3 densities). The entire experiment required 72 plots.

benchmarks or references, our experiment also included continuous complete vegetation control and simulated operational broadcast release of both woody and herbaceous vegetation after the second growing season.

## 2.2. Study site and installation

The study site is located in the Great Lakes–St. Lawrence forest region, northeast of North Bay, Ontario, on the Nippising Forest (WGS 84: N46°42'44.3"; W79°22'14.4"). It represents ecosite 20.1 (Chambers et al., 1997) and is regionally typical of white and red pine-dominated mixedwood sites. Soils are fine loamy sands (first 10 cm) over deep, medium- to coarse-textured sands, with an effective rooting depth greater than 70 cm and no signs of mottling or gleying.

The area was harvested in spring of 2000 using a full-tree system. Subsequent to this harvest, a 3-ha portion of the cutover was subjected to manual cutting and removal of all remaining residual trees to emulate a true “clearcut” harvest condition. In August of 2000, a total of seventy-two 18-m × 18-m treatment plots were established on this 3-ha site, with 2-m corridors between each (Fig. 2). At this time, the plots were regenerating to trembling aspen (*Populus tremuloides* Michx.), bracken fern (*Pteridium aquilinum* L.), low-shrub vegetation dominated by blueberry (*Vaccinium* spp.) and bush honeysuckle (*Diervilla lonicera* Mill.), and a variety of forbs, dominated by spreading dogbane (*Apocynum androsaemifolium* L.), large-leaved aster (*Aster macrophyllus* L.), and wild sarsaparilla (*Aralia nudicaulis* L.). Following visual inspection, the plots were stratified, based on stem density of aspen and other deciduous tree species, into lower, middle, and upper third percentiles. The study's 14 treatments (Fig. 1) were then randomly assigned to plots within these density classes.

Plots receiving both woody and herbaceous vegetation control (b) (Fig. 1) in the first growing season were treated with a broadcast foliar application of glyphosate during early September 2000. A Solo<sup>®</sup> backpack sprayer was used for these applications, equipped with an 18 in. wand and 8004 nozzle, delivering a 3% solution of Vision<sup>®</sup> herbicide. Plots receiving herbaceous-only vegetation control (h) were similarly treated, but with care taken to avoid any contact with aspen and other deciduous tree species on the site. Plots receiving initial woody-only vegetation control (w) were treated at the end of the 2000 growing season with a basal bark treatment (*streamline* method) and the herbicide Release<sup>®</sup> (25% product mixed in mineral oil, applied with very

low pressure, directly to the lower 30 cm of target stems with a backpack sprayer equipped with an 18 in. wand and a SS1502 nozzle).

All plots were planted at 2-m spacing on May 15, 2001, with Multipot 67, 1-0 containerized white pine. At the time of planting, these trees averaged 11 cm in height and 3 mm in stem diameter, measured 5 cm above ground line (AGL). To augment natural aspen densities and ensure uniform distributions across the plots, containerized aspen (Multipot 67, dormant 1-0 stock) were planted, where necessary, in plots that had not yet received woody vegetation control. Bias in planting location was avoided by using plot maps of randomly generated planting locations to guide tree positions within each plot.

On complete vegetation control plots and herbaceous-only control plots, vegetation control was maintained during each growing season dictated by the experimental design (Fig. 1) via periodic manual clipping and directed foliar applications of glyphosate (2% Vision<sup>®</sup>) at the end of the preceding growing season (late August/early September). Planted pine were protected with cups or plastic bags, when necessary, to prevent herbicide injury. On plots receiving later woody-only control, basal bark treatment was used at the end of the preceding growing season. Once woody control occurred within the response-surface experiment, either through complete vegetation control or woody-only control, woody control was maintained through subsequent years, as needed, via manual clipping. Plots assigned to the simulated operational release treatment received a broadcast application of glyphosate (2% Vision<sup>®</sup>) at the end of the second growing season, with no subsequent follow-up treatments or manual clipping.

At the beginning of the second growing season, aspen and other deciduous tree species on the plots were thinned to the target densities of 5000, 10,000, and 15,000 sph for plots previously stratified as low-, medium-, and high-density. Hand shears were used for this and bias in stem selection was avoided by retaining those stems closest to the mapped positions of randomly generated tree locations for each density. This process was repeated each spring, as needed, to maintain the plots as close as possible in the target density classes.

To avoid reduction in white pine sample size due to fatal blister rust infections, all planted pine were treated with a single application of triadimefon during mid July of each of the first five growing seasons. The fungicide Bayleton<sup>®</sup> was mixed with water at a rate of 300 mg active per L, each seedling being sprayed to wet with a Solo<sup>®</sup> backpack sprayer, equipped with an 18 in. wand and 8004 nozzle.

## 2.3. Field measurements

Within each treatment plot, we established a centrally located 10-m × 10-m measurement plot. The 25 planted pine within each of these measurement plots (5 trees × 5 trees) were identified with a pin-mounted, numbered aluminium tag. At the end of each of the first 6 growing seasons, surviving trees were measured for total height (ground line to the tip of the tallest bud; cm), stem diameter (5 cm AGL; mm), and crown diameter (geometric mean of the widest point between opposite lateral branch terminal bud tips, and a similar measure taken perpendicular to the first, through the central mass of the crown; cm).

Cover of vegetation within the measurement plots was estimated from five 2-m × 2-m subplots during peak growing season (mid August) of each of the first 6 years. Subplot centers were randomly located within each measurement plot and permanently identified. Cover and cover-weighted height were recorded for deciduous trees, tall-shrubs, low-shrubs, forbs, ferns, grasses, planted pine, and other conifers. Cover assessments were



Fig. 2. Aerial view of the research site taken near the end of its sixth growing season. Each of the study's 72 treatment plots is 18 m × 18 m; the corridors between plots are 2-m wide.

facilitated by placing two, 2-m lengths of graduated plastic pipe at right angles to each other over the subplot center, and visually estimating the portion of the subplot ground surface occupied by the vertical projection of the plant crown(s), to the nearest 5%. Trace amounts of cover were assigned a value of 1%. For each vegetation group (except grass/sedge) in each subplot, the proportion of group cover occupied by the dominant 5 species was also recorded.

#### 2.4. Statistical analyses

To describe the vegetation conditions created by the various treatment regimes in the study, we plotted treatment means for cover and height of each of the principal vegetation groups over time. Data for the planted white pine were analysed using a response-surface approach, based on a second-order polynomial model (Montgomery, 2001), using PROC RSREG of the SAS<sup>®</sup> system (SAS Institute Inc. 2004). These analyses were used to determine the nature and magnitude of the effects of duration of herbaceous vegetation control, timing of woody control, and their interaction, on crop-tree response. To do this, the full model (1) was reduced to contain only statistically significant factors ( $p < 0.10$ ), using a process of backward elimination:

$$Y = \beta_0 + \beta_1 \text{DENSITY} + \beta_2 \mathbf{W} + \beta_3 \mathbf{W}^2 + \beta_4 \mathbf{H} + \beta_5 \mathbf{H}^2 + \beta_6 \mathbf{WH} + \varepsilon, \quad (1)$$

where  $\mathbf{Y}$  is pine response,  $\beta_0, \dots, \beta_6$  are parameters to be estimated, **DENSITY** is hardwood stem density,  $\mathbf{W}$  and  $\mathbf{H}$  are as previously defined, and  $\varepsilon$ , are random errors. Where necessary to stabilize variance in these regressions, data were weighted by the inverse of the variance of the response variable, estimated from a linear regression of the variances calculated for repeat observations, on values of  $\mathbf{H}$  (Draper and Smith, 1998). Repeat observations on the response surface (Fig. 1) were used to test model (1) for lack of fit ( $p < 0.10$ ) in each case (Montgomery, 2001).

Response variables used in model (1) were treatment plot means for sixth-year white pine survival, measures of growth [stem diameter, height, and crown closure (calculated by summing the crown area, derived from crown diameter, for each tree and dividing by plot area)], and percentage weevil incidence. For each of the growth variables, we also included age-6 growth rates in these analyses. These values were obtained by fitting a second-order polynomial to the 6 years of growth data for each plot, and then evaluating the first derivative of the resulting function at age 6:

$$Y = b_0 + b_1 \text{Year} + b_2 \text{Year}^2, \quad (2)$$

$$Y' = b_1 + 2 \times b_2 \times \text{Year}, \quad (3)$$

and

$$Y'(6) = b_1 + 2 \times b_2 \times 6, \quad (4)$$

where,  $\mathbf{Y}$  is a measure of growth response,  $b_0, \dots, b_2$  are parameter estimates from least squares regression, **Year** is the number of years after plantation establishment,  $\mathbf{Y}'$  is the first derivative, or growth rate, and  $\mathbf{Y}'(6)$  is the growth rate at year 6. The resulting age-6 growth rates for each plot were then used as raw data for model (1).

To study the separate effects of herbaceous- and woody-control (i.e., on their own, in the absence of each other) and address hypotheses related to the reference treatments, white pine responses were further subjected to analysis of variance (ANOVA). Contrasts were used to identify linear and quadratic (i.e., proportional and disproportional) trends related to the individual levels of  $\mathbf{H}$  and  $\mathbf{W}$  (specifically, 000000, hh0000, hhhh00; and

000000, 00000w, 00wwww, wwwwww), as well as test for differences between 4 and 6 years of complete vegetation control (bbbbww vs. bbbbbb), and differences between broadcast release and 2 years of herbaceous control plus second-season woody control (00b000 vs. hhwwww). In these analyses, model residuals were examined to verify that the assumptions of homogeneity of variance and normality were met; data transformations were not necessary.

### 3. Results

#### 3.1. Vegetation dynamics

While the nominal hardwood densities chosen for this study were intended to reflect those commonly encountered in plantation scenarios, initial pretreatment densities were, on average, much higher, ranging between 32,000 and 67,000 sph in plots grouped as low- and high-density, respectively. On this particular site, virtually all of the hardwood regeneration present was trembling aspen. Second and third growing season thinnings brought these densities very close to the nominal targets for the three groups of plots: 5000, 10,000, and 15,000 sph. Thereafter, minor self-thinning reduced densities below the target values by an average of 11–25% by year 6.

Patterns in vegetation cover and height development on the site offer unique reflections of the study's 14 vegetation-control treatment combinations and the competitive environments they create (Appendix A). While these data are not integral to the crop-tree analyses presented in this paper, they do offer validation of the treatments applied, and may provide important site and stand-condition context for some readers.

#### 3.2. Planted white pine response

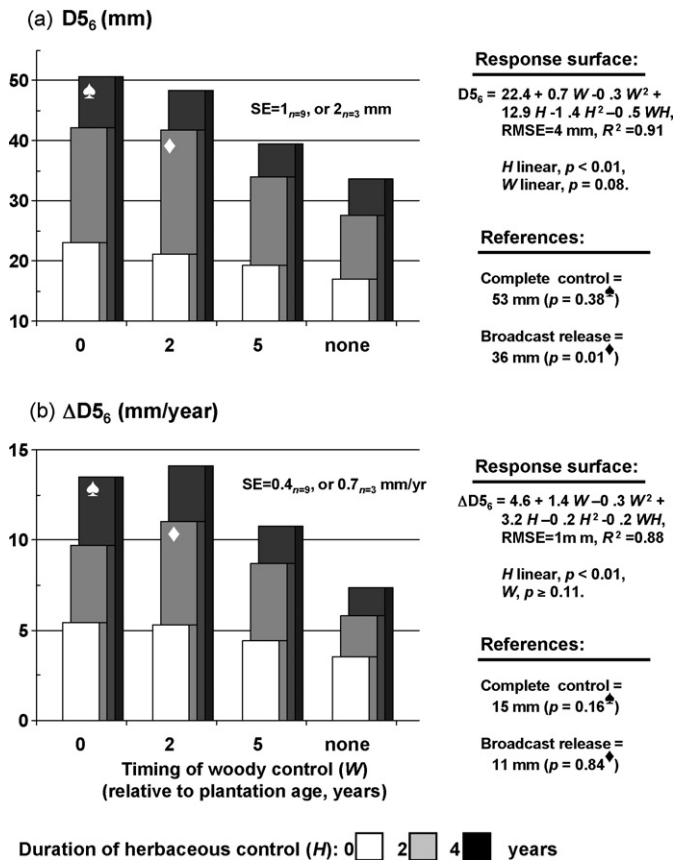
##### 3.2.1. Survival

By age 6, planted pine mortality across the site ranged from 1 to 9% and was not treatment ( $p = 0.24$ ) or aspen density ( $p = 0.68$ ) related.

##### 3.2.2. Stem diameter

Planted white pine stem diameter at age-6 showed positive, responses to both herbaceous and woody vegetation control (Fig. 3a). Parameter estimates from model (1) suggest that any delay in woody control beyond about the second growing season resulted in decreased age-6 diameter (change in diameter,  $\text{mm} = 0.7 \times \mathbf{W} - 0.3 \times \mathbf{W}^2$ ). For example, a delay of 5 years resulted in an 18% reduction in stem diameter (22–4). In contrast, increases in the duration of herbaceous control were associated with large increases in stem diameter (change in diameter,  $\text{mm} = 12.9 \times \mathbf{H} - 1.4 \times \mathbf{H}^2$ ); 1 year resulting in a 50% gain (11.5 mm) and 2 years resulting in a 90% gain (20.2 mm). However, the diameter gains achieved through herbaceous control appear to be reduced as woody control is delayed (reduction in diameter,  $\text{mm} = -0.5 \times \mathbf{WH}$ ) (i.e., the negative slope of the response surface becomes steeper as woody control is delayed and duration of herbaceous control is increased). Aspen stem density, within the range tested, did not influence these outcomes ( $p = 0.40$ ).

Expressed in terms of untreated pine response, woody vegetation control alone resulted in a 14–36% increase in age-6 stem diameter, depending on how early it was applied (earliest being the time of planting, year 0). These incremental diameter gains were generally proportional to the timing of woody control ( $\mathbf{W}$  linear,  $p = 0.08$ ). Herbaceous control alone, on the other hand, resulted in a 63% to 2-fold gain in stem diameter through 2 and 4 years duration ( $\mathbf{H}$  linear,  $p < 0.01$ ). Diameter gains achieved

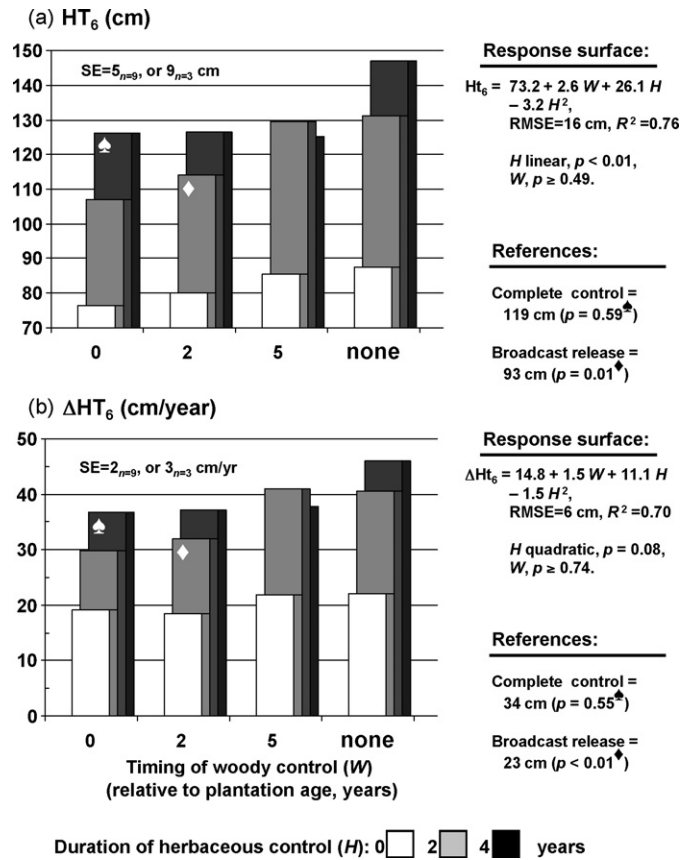


**Fig. 3.** 3-D response surface for age-6 seedling diameter 5 cm above ground level (D5<sub>6</sub>), (a), and rate of diameter growth (ΔD5<sub>6</sub>), (b). Plotted values are least squares means from ANOVA. The equation for response surface generated from the data is provided, all parameters being significant at  $p < 0.10$ . SE = standard error; RMSE = root mean square error; and  $p$  = probability of a greater  $F$ -value. Reference treatments consisting of continuous complete vegetation control and second-season broadcast release are contrasted with specific treatments on the response surface denoted by ♠ and ♦, respectively.

through both woody and herbaceous control ranged from 2- to 3-fold, depending on how early woody control was conducted and how long herbaceous control was maintained.

At age 6, we observed no difference in the diameter of pine subjected to 4 years compared to 6 years of total competition suppression ( $p = 0.38$ ). Trees receiving 2 years of early herbaceous control plus second-season woody control exhibited 15% larger stem diameters than those subjected to second-season broadcast release ( $p = 0.01$ ).

Treatment-related patterns in diameter growth rate at age 6 (Fig. 3b) generally resembled those of age-6 stem diameter, with the exception that growth rates were somewhat less sensitive to delays in woody control. Such delays did not appear to reduce diameter growth rates until about age 4 or 5, and woody control alone did not statistically increase growth rates over those observed in untreated plots ( $p \geq 0.11$ ). However, herbaceous vegetation control was associated with faster growing trees at age 6, with 1 year of control providing 65% faster diameter growth, and 2 years of control more than doubling diameter growth rates. Alone, herbaceous control increased diameter growth rate in proportion to the duration of control ( $p < 0.01$ ). We observed no difference in growth rate of pine subjected to 4 years compared to 6 years of total competition suppression ( $p = 0.16$ ), or between trees receiving 2 years of early herbaceous control plus second-season woody control and those subjected to second-season broadcast release ( $p = 0.84$ ).



**Fig. 4.** 3-D response surface for age-6 seedling height (HT<sub>6</sub>) (a), and rate of height growth (ΔHT<sub>6</sub>) (b). Plotted values are least squares means from ANOVA. Equations for response surfaces generated from the data are provided, all parameters being significant at  $p < 0.10$ . SE = standard error; RMSE = root mean square error; and  $p$  = probability of a greater  $F$ -value. Reference treatments consisting of continuous complete vegetation control and second-season broadcast release are contrasted with specific treatments on the response surface denoted by ♠ and ♦, respectively.

### 3.2.3. Stem height

Planted white pine stem height at age-6 (Fig. 4a) responded to herbaceous and woody vegetation control in a somewhat different manner than diameter. In the case of height, each year that woody control was delayed resulted in an average increase of nearly 3 cm in mean pine height. Most surprising, however, was that herbaceous control was associated with substantial height increases on the planted pine. For example, 1 year of control resulted in a 31% gain (23 cm) and 2 years in a 54% gain (40 cm) in age-6 height. These gains were generally consistent across the different levels of woody control tested ( $W \times H$  interaction not significant,  $p = 0.23$ ). Aspen stem density did not influence these outcomes ( $p = 0.50$ ).

Woody vegetation control in the absence of any herbaceous control resulted in a 2–13% reduction in age-6 stem height relative to untreated pine seedlings, depending on how early it was conducted, although these differences were not statistically significant ( $W$ ,  $p \geq 0.49$ ). Herbaceous control by itself, on the other hand, resulted in a 1.5–1.7-fold gain in height through 2 and 4 years duration. Incremental gains in height appear to diminish with increased duration of herbaceous control, however, only the linear trend was significant ( $H$  linear,  $p < 0.01$ ). The tallest pine seedlings were observed in the 4-year duration herbaceous-only control plots. When woody control was combined with herbaceous control, height gains fell to between 1.2- and 1.4-fold, depending on how early woody control was applied and how long herbaceous control was maintained.

We observed no difference in the age-6 height of pine subjected to 4 years vs. 6 years of total competition suppression ( $p = 0.59$ ). Trees receiving 2 years of herbaceous vegetation control plus second-season woody control, were 22% taller than trees subjected to second-season broadcast release ( $p = 0.01$ ).

Treatment-related patterns in height growth rate at age 6 (Fig. 4b) were similar to those of age-6 stem height. Each year that woody control was delayed was associated with a 1.5 cm/year increase in mean pine height growth rate. Herbaceous control increased pine height growth rates, independent of the timing of woody control ( $p = 0.08$ ); 1 year of control resulting in a 65% gain (10 cm/year); and 2 years resulting in more than a 2-fold gain (16 cm/year). Aspen stem density did not influence these outcomes ( $p = 0.22$ ). No difference was observed in the height growth rate of pine subjected to 4 years vs. 6 years of total competition suppression ( $p = 0.55$ ). Trees receiving 2 years of herbaceous control plus second-season woody control, were 40% faster growing at age 6 than trees subjected to second-season broadcast release ( $p < 0.01$ ).

White pine weevil can have a considerable negative effect on the height growth of young white pine, and might be expected to have influenced the treatment effects observed. The percentages of planted pine with leaders attacked by weevil during the sixth growing season exhibit clear responses to the treatment-induced vegetation conditions created (Fig. 5). Response-surface analysis suggested that woody vegetation control alone had very little effect on percent weevil incidence ( $p \geq 0.37$ ), but the interaction between woody and herbaceous control was a critical ( $p < 0.01$ ) factor related to level of damage suffered from this insect. Early woody control, in combination with herbaceous control, resulted in 20–40% of trees being attacked, with 60% of trees being attacked in the continuous vegetation control plots (*bbbbww* vs. *bbbbbb*,  $p = 0.04$ ). Second-season broadcast released trees fared no better than trees receiving early herbaceous control plus second-season woody control ( $p = 0.28$ ). In contrast, later (year 5) or no woody control generally kept weevil incidence under 10%. However, herbaceous control in the absence of any woody control still exhibited increased weevil attack that was proportional to the duration of vegetation control applied ( $p = 0.02$ ). Under these conditions, the data suggest that on average, aspen density

reduced attack rates by about 2.5% for every 5000 sph present over the range of stem density tested ( $p = 0.07$ ).

### 3.2.4. Crown closure

Response-surface analysis of age-6 planted pine crown closure (Fig. 6a) suggested that only duration of herbaceous control was associated with gains in this measure ( $W$ ,  $p \geq 0.44$ ;  $W \times H$ ,  $p = 0.90$ ). Each year that herbaceous control was applied resulted in a 1-fold gain over the crown closure observed in plots not receiving any herbaceous control ( $p < 0.01$ ). As a result, crown closure was increased from 5% in untreated plots, to 15% following 2 years of herbaceous control, and 20% following 4 years of control. At age 6, the additional 5% of crown closure found in continuous vegetation control plots was not statistically different from that observed after just 4 years of control ( $p = 0.56$ ), and aspen stem density did not appear to influence crown closure ( $p = 0.60$ ). Second-season broadcast release resulted in just 9% crown closure, compared to the 16% found in plots receiving early herbaceous control plus second-season woody control ( $p < 0.01$ ).

Analyses of crown closure growth rates at age 6 (Fig. 6b) closely paralleled those for crown closure. Only duration of herbaceous vegetation control was associated with increased growth rate ( $W$ ,  $p \geq 0.39$ ;  $W \times H$ ,  $p = 0.96$ ), with each year of herbaceous control being associated with an additional 2%/year increase in the rate of crown closure ( $p < 0.01$ ). Growth rates found in continuous

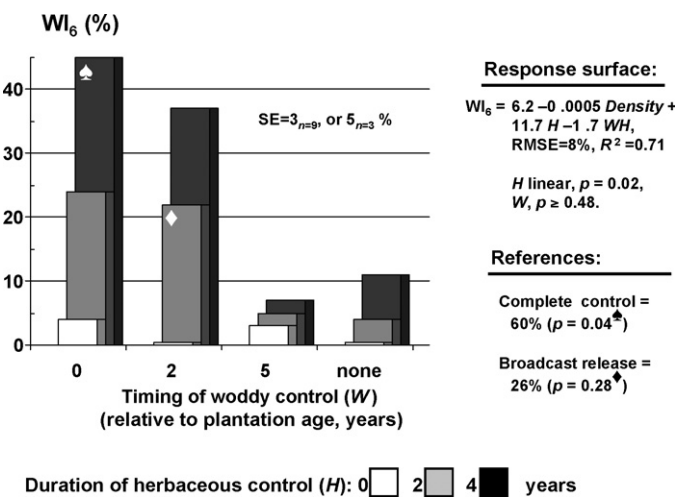


Fig. 5. 3-D response surface for age-6 incidence of white pine weevil attack ( $WI_6$ ) (%). Plotted values are least squares means from ANOVA. The equation for the response surface generated from the data is provided, all parameters being significant at  $p < 0.10$ . SE = standard error; RMSE = root mean square error;  $p$  = probability of a greater  $F$ -value; and Density = the stems per hectare of surrounding aspen. Reference treatments consisting of continuous complete vegetation control and second-season broadcast release are contrasted with specific treatments on the response surface denoted by  $\blacktriangle$  and  $\blacklozenge$ , respectively.

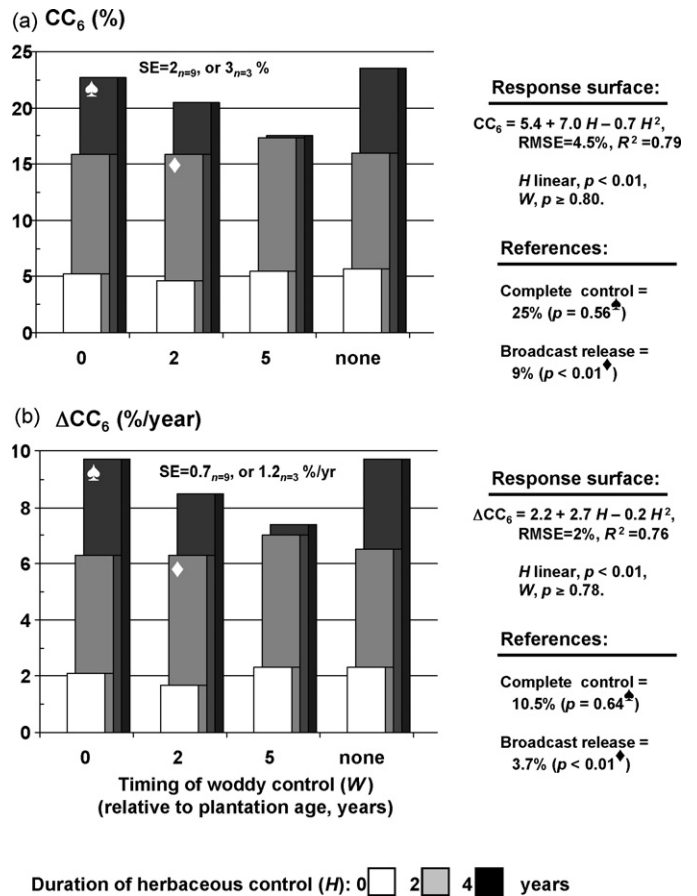


Fig. 6. 3-D response surface for age-6 seedling crown closure ( $CC_6$ ) (a), and rate of crown closure ( $\Delta CC_6$ ) (b). Plotted values are least squares means from ANOVA. Equations for response surfaces generated from the data are provided, all parameters being significant at  $p < 0.10$ . SE = standard error; RMSE = root mean square error; and  $p$  = probability of a greater  $F$ -value. Reference treatments consisting of continuous complete vegetation control and second-season broadcast release are contrasted with specific treatments on the response surface denoted by  $\blacktriangle$  and  $\blacklozenge$ , respectively.

vegetation control plots were not statistically different from those observed after 4 years of control ( $p = 0.64$ ), and aspen stem density did not appear to influence rate of crown closure ( $p = 0.59$ ). Growth rates in second-season broadcast release plots were approximately half of those found in plots receiving early herbaceous control plus second-season woody control ( $p < 0.01$ ).

#### 4. Discussion

This study was established to generate better understanding of how white pine interacts with surrounding vegetation so that foresters might develop more consistent, effective, and scientifically based vegetation management prescriptions for white pine restoration scenarios. Our goal was not to compare and contrast vegetation management tools, but rather to identify vegetation conditions that appear to favour early growth and stem quality of white pine, such that these conditions may be recreated or emulated using one or more available tools. This goal arose from the desire to resolve two opposing and prevailing operational paradigms for vegetation management in white pine restoration: (1) all forms of competition pose a threat to pine regeneration and growth, and (2) competition, particularly from overhead woody vegetation, is generally tolerated by white pine and promotes good height growth and weevil protection. Results from our study suggest that neither of these views explicitly support the vegetation management required to optimize early white pine growth in restoration applications. Rather, the interaction between woody and herbaceous competition with white pine is spatially and temporally dynamic, suggesting that optimum response will likely occur from more thoughtful modification of the general prescriptions currently embraced.

##### 4.1. Support for the paradigm that “all competition is bad”

Based solely on the effects of our vegetation treatments on white pine stem diameter, the assertion that all competition detracts from crop growth is clearly supported. The largest age-6 stem diameters (51–53 mm) were observed in plots receiving at least 4 continuous seasons of complete control of both woody and herbaceous vegetation. Any competition from tall woody or low-growing “herbaceous” vegetation, including ferns, grasses, forbs, and low-shrub species resulted in early, measurable reductions in stem diameter. For example, just one growing season after planting, we observed a 12% reduction in mean maximum seedling diameter associated with competition from either herbaceous or woody components, and a 22% reduction from their combined effects ( $p < 0.01$ ). Through the first four growing seasons, such treatment-related differences continued to diverge, and were closely associated with effects of competing vegetation on seedling microclimate and resource availability (Parker et al., unpublished data). In the first two growing seasons, the rapid growth of herbaceous vegetation reduced the availability of soil moisture (and very likely nutrients) during the growing season to a greater extent than 5000–15,000 sph of young aspen. Competition for soil moisture shortly after plantation establishment likely contributed to our finding that early control of understory vegetation was at least twice as effective in increasing white pine stem diameter as early woody control. Other studies have reported similar growth responses to herbaceous vegetation control (e.g., Wagner et al., 1999; Zutter and Miller, 1998). Based on long-term vegetation management experience (Wagner et al., 2006), it is not unreasonable to expect the age-6 diameter differences reported herein (Fig. 3) will persist into the stand development phase.

However, it would be unwise to optimize vegetation management prescriptions for white pine plantations based on stem diameter growth alone. Our open-grown seedlings were notably

more heavily branched and weevil infested than trees grown with some level of overhead woody competition. While we have yet to obtain direct measures of stem quality in this study, overall height growth may be a good early surrogate and, based on our results, maximizing this response is not a simple matter of applying rigorous, broadcast competition control on clearcut sites.

##### 4.2. Support for the paradigm that “overhead woody competition is necessary”

White pine height growth was maximized in the presence of overhead shade provided by an aspen canopy consisting of 5000–15,000 sph, largely through reduced terminal shoot damage by weevil that this cover afforded (Fig. 5). It is unclear whether such protection was derived from a degree of spring shading offered by the aspen (Belyea and Sullivan, 1956), or pest preference for leaders of a particular thickness (Graham, 1918). In other studies, moderate overhead competition also provided white pine with increased protection from blister rust infection (Van Arsdell, 1972), pine bark adelgids (Krueger and Puettmann, 2004), and browse damage (Saunders and Puettmann, 1999), although light levels below about 25% of full sunlight significantly reduced white pine height growth and compromised canopy recruitment (Logan, 1962, 1966).

Although the presence of an aspen canopy was associated with increased height growth, it is important to note that we only observed these substantive benefits when understory vegetation was controlled (Fig. 4). White pine growing in association with aspen and herbaceous vegetation sustained low levels of weevil attack, but did not achieve height dominance over this type of ground layer competition through 6 growing seasons after planting (Fig. A2). Further, these seedlings were at least 32% shorter and 40% smaller in diameter than those that had early relief from such competition. Similar interactions were observed by Clements (1966), when white pine were planted beneath a 13-year-old aspen stand. While competition-induced mortality is yet to appear in this study, the data suggest that suppression will continue to erode growth in untreated plots, to the point where subsequent vegetation control will likely offer little benefit. Thus, a strategy of planting and postponing all tending activities to provide overhead woody cover and protection from weevil will also result in significant, irrevocable growth losses.

##### 4.3. A new paradigm?

An optimal vegetation management strategy for white pine restoration must therefore strike a balance between maximizing stem diameter growth and height growth, since the two parameters respond differently to intensity and timing of woody and herbaceous vegetation control. Contour plots of the response surfaces presented in Figs. 3a and 4a may be used to identify a range of treatment options that lead to similar target crop-tree dimensions under the conditions encompassed by this study. If, for example, a minimum stem diameter of 40 mm is desired by age 6, this might be achieved through at least 2 years of early herbaceous control, with woody control on or before about year 4 (Fig. 7a). If a minimum tree height of 130 cm is specified for the same period, this may be attained through at least 2 years of early herbaceous control, with woody control occurring sometime after the second growing season (Fig. 7b). A strategy that reasonably meets both of these objectives will require at least 2 years of early herbaceous vegetation control, coupled with woody control between years 2 and 4.

While these relationships may not be expected to hold on other site types and growing conditions, they do illustrate the relative importance of early herbaceous vegetation control in the presence

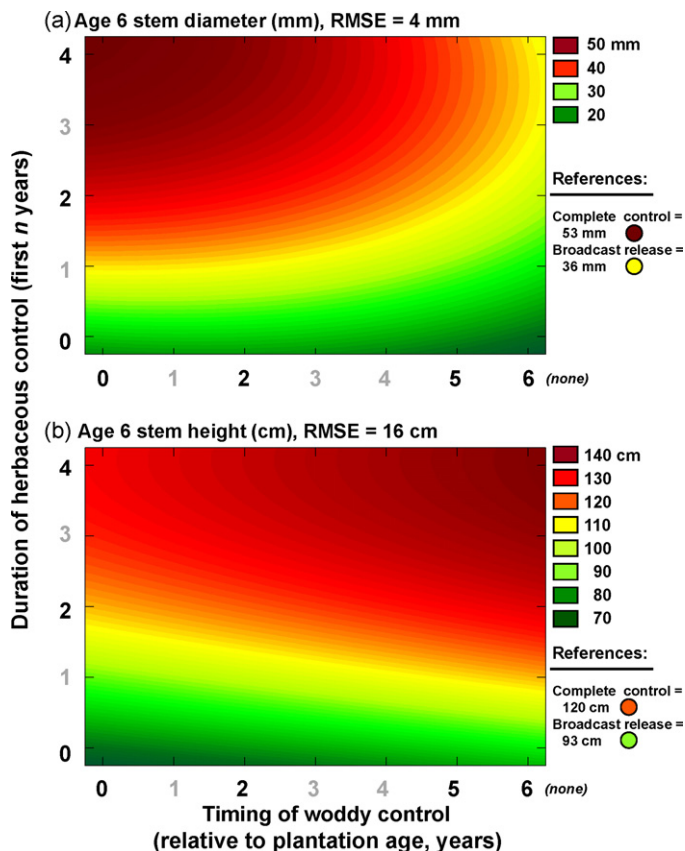


Fig. 7. Two-dimensional representations (contour plots) of the response surfaces outlined in Figs. 3a and 4a for age-6 stem diameter (a) and stem height (b), respectively ( $n=60$  observations for each). Average values for the reference treatments are provided.

of some overhead shade in promoting combined stem diameter and height growth. For both these growth parameters, incremental gains in size and growth rate associated with herbaceous control were typically an order of magnitude larger than those achieved through woody-only control. In fact, substantive positive growth gains through woody control were typically only realized in the presence of some degree of herbaceous vegetation control (Fig. 7). It is also important to note that only herbaceous control increased crown closure and rate of crown closure (Fig. 6), an important measure of site capture by the crop.

Although our results are consistent with findings of some of the earliest white pine studies in the literature (Shirley, 1945; Logan, 1962), they strongly contradict some persistent and often prevailing philosophy, aptly summarized by Jaciw (1972):

*“A dense ground cover of Aralia, Aster, and Pteridium tends to set back the development of seedlings and causes some mortality generally among the smallest and weakest individuals. However, as a rule, a sufficient number of conifers manage to overcome this first and relatively “low” barrier of ground vegetation. A considerably more serious phase in the course of succession is the competition with the many shrubs and young hardwoods . . .”*

Such conclusions are often arrived at in field visits and studies that only retrospectively assess the results of competition and do not offer separation of the individual factors involved. This perception is reflected in a common vegetation management strategy for white pine and many northern conifers, where competition control is delayed at least 2 growing seasons after planting (Thompson and Pitt, 2004). Emulation of this treatment in

our study resulted in weevil damage equivalent to open-grown trees, coupled with inferior growth characteristics, when compared to trees receiving early herbaceous vegetation control and second-season woody control. Specifically, early herbaceous control resulted in larger stem diameters and heights, superior crown closure, and faster height and crown closure growth rates ( $p \leq 0.01$ ) than delayed intervention.

## 5. Management recommendations

Currently, with manual brushing or the application of 1 or more of Canada’s registered herbicides, it should be possible to operationally emulate the treatments tested in this study. For example, early herbaceous vegetation control may be achieved with mechanical and/or chemical site preparation with glyphosate. Complete reduction of deciduous tree vegetation may be avoided by using equipment that results in banded, spot, or selective, rather than broadcast treatments. Recently a Canadian *User-Requested-Minor-Use Label Expansion* for spot applications of imazapyr was granted for site preparation in advance of white spruce (*Picea glauca* (Moench) Voss) plantings. Our unpublished data suggest that this would be an excellent treatment for obtaining 2 years or more of herbaceous vegetation control with white pine and we hope to see this application added to the label shortly. Woody control may be achieved with manual brushing or a basal bark application of triclopyr. Until the recent expiration of its registration, *Chondrostereum purpureum* offered a biological means of enhancing the efficacy of cut stump applications on some species (Pitt et al., 1999). Combinations of herbaceous and woody control might be achieved with glyphosate, triclopyr, or 2,4-D; the desired spatial distribution and degree of control being obtained through careful selection an appropriate combination of method of application, dose, and application timing.

While long-term treatment effects on white pine growth and stem quality have yet to be determined in this study, early responses suggest that a strategy for white pine restoration on clearcut sites should focus on the proactive, early management of understory competition to improve growth resource availability, and the gradual modification of overtopping cover to optimize light conditions for height growth (Parker et al., unpublished data). In this study, the tallest, most vigorous age-6 white pine, with maximum crown closure, were achieved by a treatment regime that provided the first 2–4 growing seasons free of competition from ferns, grasses, forbs, and low-shrub species, and retained 5000–15,000 stems of regenerating aspen. On clearcut sites that are prone to hardwood suckering, this type of strategy might be initiated operationally through chemical site preparation immediately prior to planting, with a product, timing, dose, and/or application method chosen to reduce, but not eliminate the hardwood. Many such combinations are possible. Site preparation treatments that reduce existing or forecasted hardwood densities below 5000 sph may require increased white pine planting densities to maintain stem form in the face of weevil attack (e.g., 3000 sph; Lancaster, 1984). Subsequent herbaceous and/or woody vegetation control may be obtained with a broadcast or directed foliar application of glyphosate, as necessary.

Results of a companion study indicate that competition for soil moisture and light between pine and aspen on treatment plots receiving prior herbaceous-only vegetation control increased with time as the aspen canopy expanded (Parker et al., unpublished data). Since white pine have been documented to match hardwood growth rates beyond about age 10 (Kelty and Entcheva, 1993), we suspect that a partial (selective), age-5 removal of the aspen from around these pine to increase light availability to 50–75% of full sunlight might accelerate the transition of pine plantations from sapling to pole stages in these treatment plots by maintaining both

acceptable pine growth and weevil protection. Such an approach would ultimately produce a mixedwood that may fulfill management objectives in addition to white pine regeneration targets (Zenner et al., 2005). Operationally, this type of treatment would require a directed foliar application of glyphosate or manual brushing between age 5 and 10, instead of the broadcast-type treatments applied in this study.

**Acknowledgements**

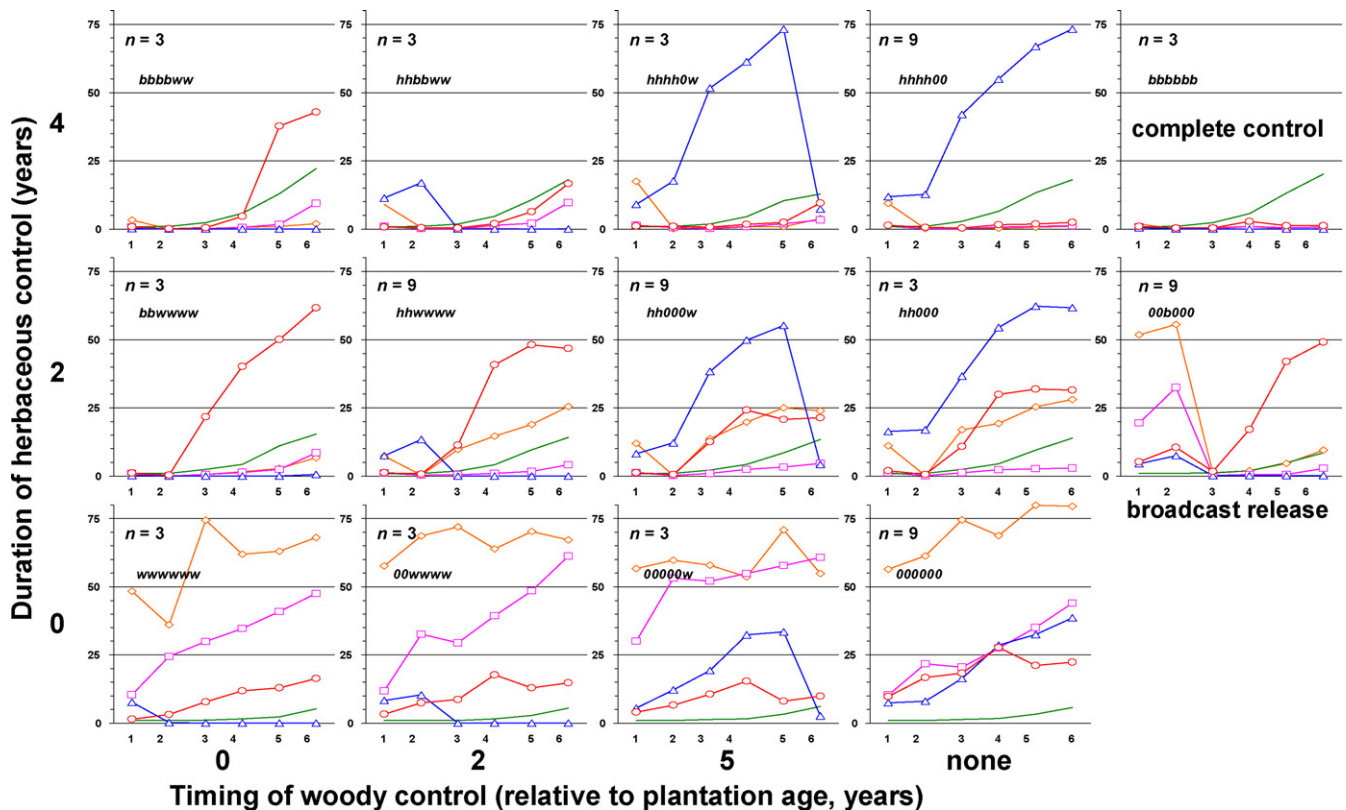
This research would not be possible without the generous financial backing and partnerships offered by the following: Canadian Ecology Centre - Forestry Research Partnership (Tembec, Canadian Forest Service, Ontario Ministry of Natural Resources); Living Legacy Trust; Canada Foundation for Innovation; Enhanced Forest Productivity Science Program - Forestry Futures Trust Ontario; Ontario Innovation Trust Fund; Monsanto Canada Inc., Dow AgroSciences Canada Inc.; Collège Boréal; Domtar Wood Products Inc.; Nipissing Forest Resource Management Inc.; J.D. Irving Limited; Forest Protection Limited; Spray Efficacy Research Group International; Upper Lakes Environmental Research Network; and the U.S. Forest Service. Wayne Bell and Michael Irvine were instrumental in facilitating OMNR funding and support. The research team is also indebted to a growing list of staff, without whose care and effort this study would not be possible: Marc Albert, Allyson Batchelor, Jonny Bélanger, Mathieu Breault, Richard Cossette, Parise Drolet, Ray Ferguson, Andréa Gosselin, Travis Halliday, Joël Hamelin, Marc Heibert, Michael Hoepfing, Ian Kovacs, Natalie Lajeunesse, Victoria Lampkin, Yannick Loranger, Eric Léger, Daniel Marin, Scott McPherson, Marc Nellis, Andriy Obarymskyj, Dianne Othmer, Jorma Paloniemi, Mya Park, Michelle Pest, Lorna Pitt, Rock Rochon, Ryan Séguin, Denis Serré, Megan Smith, Rob Stewart, Kelley Von Bargen, and Chad Yurich.

**Appendix A. Patterns in vegetation development**

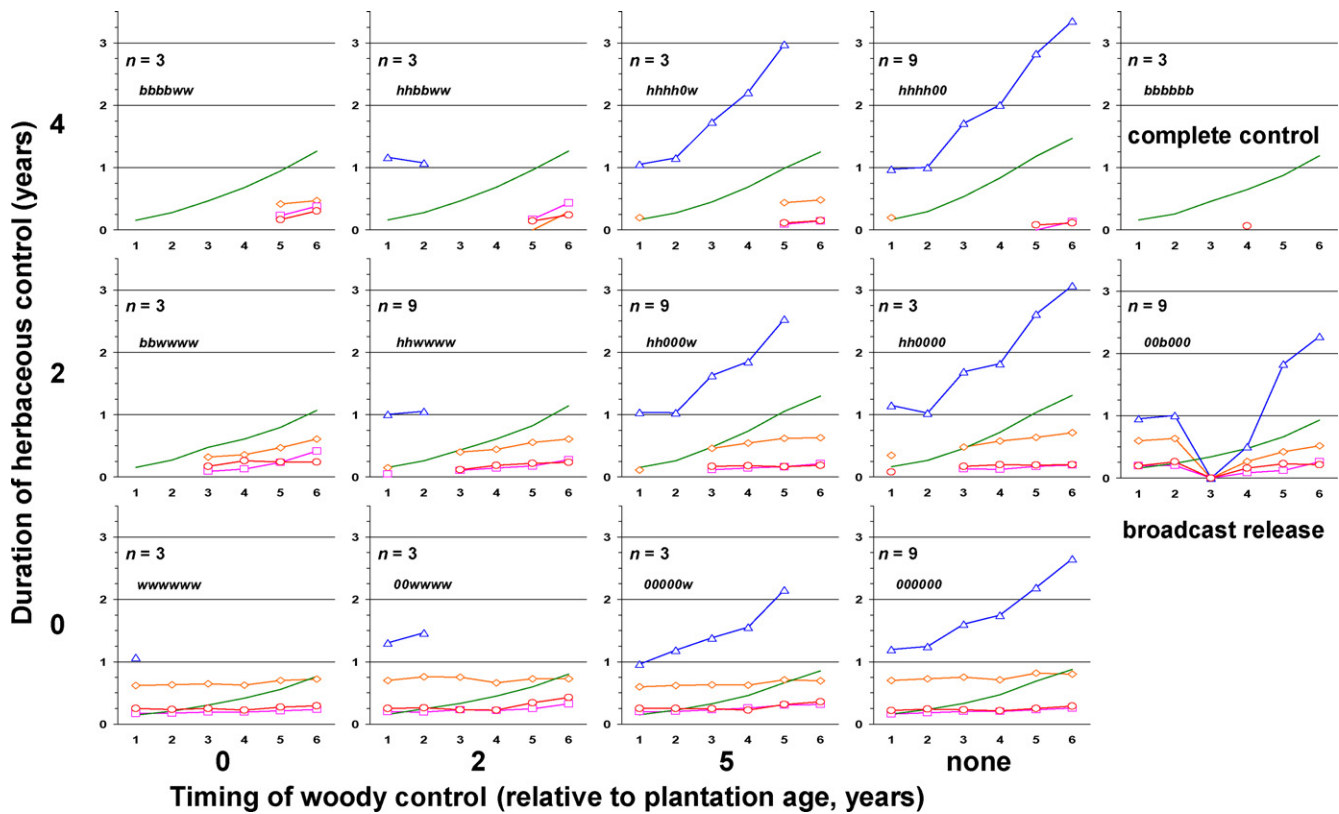
Averaging across three nominal hardwood density classes, patterns in vegetation cover over time reflected the unique character of each of the study's treatment regimes (Fig. A1). Hardwood (aspen) cover gradually increased to 35% in untreated plots, as compared to 62% with 2 years of herbaceous vegetation control, and 75% with 4 years of herbaceous control. Being the main target of woody-control efforts, aspen cover was eliminated following site preparation and the second or fifth year woody-control treatments.

Bracken fern carried the highest cover values in untreated and woody-only control plots (up to 75%), but was reduced to 25% following 2 years of herbaceous control, and all but eliminated with 4 years of control. Low-shrub vegetation on the site was dominated by blueberry (55% of total cover in year 1), bush honeysuckle (32%), and sweet fern (*Comptonia peregrina* (L.) Coult.; 6%). In untreated plots, low-shrub cover was on par with, or slightly greater than aspen cover throughout the observation period. In woody-only control plots, low-shrub covers increased to 50% or more, likely in compensation for the removal of overtopping vegetation and resulting increased light availability. In contrast, early herbaceous control kept low-shrub cover below 10% throughout the observation period. Over time, blueberry levels remained fairly constant across the site, while bush honeysuckle declined to 16%, and sweet fern increased to 16% of total cover.

Forb and grass cover on the site generally remained low (<25%) throughout the observation period, with both components sharing approximately equal stature. Forbs were dominated by spreading dogbane (32% of total cover in year 1), large-leaved aster (23%), wild sarsaparilla (16%), wild lily of the valley (*Mianthemum canadense* Desf.;



**Fig. A1.** Development of vegetation cover (%) on response-surface and reference treatment plots through 6 growing seasons after plantation establishment. Symbols are: (—) planted pine; (—▲—) aspen; (—◇—) ferns; (—□—) low-shrubs; and (—○—) grasses + forbs. Alphanumeric codes introduced in Fig. 1 are shown for clarity.



**Fig. A2.** Development of vegetation height (m) on response-surface and reference treatment plots through 6 growing seasons after plantation establishment. Symbols are: (—●—) planted pine; (—▲—) aspen; (—◇—) ferns; (—□—) low-shrubs; and (—○—) grasses + forbs. Alphanumeric codes introduced in Fig. 1 are shown for clarity.

10%), and violet species (9%). In untreated plots, forb-grass cover was similar to, or slightly less than, aspen and low-shrub cover throughout the observation period. Unlike low-shrub cover, however, woody-only control appeared to have no effect on forb-grass cover and complete vegetation control tended to result in increased grass cover after herbaceous control was ceased. On broadcast release plots, forb-grass was the only component to recover substantively after treatment, again, largely due to increased grass cover. Over time, forb dominance on the site shifted to bristly sarsaparilla (*Aralia hispida* Vent.; 30%) and violet (24%), with wild lily of the valley remaining unchanged (11%), and spreading dogbane and large-leaved aster declining.

The age-6 cover of planted pine increased from 6% in untreated or woody-only treated plots, to 15% in plots with 2 years of herbaceous control, and to nearly 20% in plots with 4 years of herbaceous control. Plots treated continuously contained more than 20% pine cover; those treated with broadcast release contained 9% cover.

Patterns in vegetation height (Fig. A2) showed year-6 dominance by aspen in the absence of woody control; planted pine in the presence of herbaceous and woody control; and bracken fern/pine in the presence of woody-only control. Herbaceous-only control increased average aspen height by more than 16 and 25% with 2 and 4 years duration, respectively. Herbaceous-only control also resulted in increased age-6 pine height.

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