Ten Years of Vegetation Succession Following Ground-Applied Release Treatments in Young Black Spruce Plantations

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ABSTRACT: *Responses of planted black spruce [*Picea mariana *(Mill.) BSP] and associated vegetation were studied for 10 years after conifer release options on two northeastern Ontario sites. Six treatments were compared to untreated check plots, including directed foliar application of glyphosate herbicide, basal bark treatment with triclopyr herbicide, glyphosate capsule injection with the EZ-Ject system, spot-treatment with hexazinone herbicide, manual cutting with brushsaw, and five growing seasons of annual vegetation removal with repeat applications of glyphosate. Ten years after treatment, black spruce survival averaged 86% and varied little among treatments (*$P > 0.5$*). Annual vegetation removal treatments resulted in nearly complete domination by spruce, with treated trees exhibiting 16–55% gains in height and 112–476% gains in stem volume growth over untreated trees. Despite rigorous vegetation control on these plots, each of the vegetation groups studied were well represented at the end of the observation period, including deciduous trees, tall shrubs, low shrubs, forbs, ferns, and grasses/sedges. Directed foliar treatment provided good control of herbaceous and woody vegetation around individual crop trees, providing an 8–46% gain in height and a 43–246% gain in stem volume growth. Both spruce and hardwoods shared dominance on these plots. Spot treatments with hexazinone provided similar short-term reductions in herbaceous vegetation, but tended to release shrub species that had a negative net effect on spruce growth. The other release treatments provided only short-term reductions in woody vegetation, which ultimately led to young stands dominated by deciduous tree species. North. J. Appl. For. 21(3): 123–134.*

Key Words: Vegetation management, conifer release, black spruce, trembling aspen, boreal mixedwoods.

Integrated forest vegetation management involves achieving silvicultural objectives through the use of a variety of complementary tools that are ecosystem-based, economical, and socially acceptable (Wagner 1994). Current options for managing competing vegetation in young forest plantations in Canada include four registered herbicides (glyphosate, triclopyr, hexazinone, and 2,4-D) coupled with a full range of application methods; one biological control tool (*Chondrostereum purpureum*, formulated as Myco-Tech Paste); manual brushing; a variety of cultural measures (including harvest method and system, species/site matching, genetically-improved and/or nutrient-loaded planting stock, etc.); and some useful but less practical methods such as mulching and grazing (Wagner et al. 2001).

Aerial application of glyphosate has been the most widely used combination, accounting for 60% of the approximately 210,000 ha of Crown Lands tended annually in Canada (Thompson 2000, Canadian Council of Forest Ministers 2001). Manual brushing also is commonly used, with

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nearly 70,000 ha treated in 1999 and areas increasing steadily over the past 10 years (Canadian Council of Forest Ministers 2001). In contrast, ground application of herbicides has received relatively little attention in research or practice.

To a large extent, selection of vegetation management options has been shaped by the nature of forest management during the past quarter-century. In the boreal forest, large clearcuts with emphasis on even-aged, single-species regeneration programs have been the operational norm. Broadcast vegetation management methods (especially aerially applied herbicides) have had a logical economic and practical role in this type of silviculture. During the last decade, however, there has been significant movement in many jurisdictions toward the use of smaller clearcuts, greater partial harvesting, and more emphasis on producing mixed-species stands (McCormack 1994). If these silvicultural trends continue, we are likely to see greater emphasis on the development and use of ground-applied methods that focus on managing the growth of individual trees.

Toward this end, a study was established in 1990 to compare the effectiveness of several ground-applied herbicide methods and manual brushing for the release of individual planted black spruce in northern Ontario. The study was part of a wider effort during that time to seek viable alternatives to aerial application, and the use of herbicides in general, through the Vegetation Management Alternatives Program (VMAP; Wagner et al. 1994). Five release treatments were compared to an untreated check and five growing seasons of continuous vegetation control. In this article, we present planted black spruce growth response and vegetation succession trends through 10 growing seasons after the application of these treatments. These data begin to address a dearth of longer-term data needed by forest managers to justify vegetation management, quantify managed stand responses, and develop more integrated vegetation management programs in the northeast.

Methods

Experimental Design

Two black spruce plantations, scheduled for operational release in 1990, were identified on the Nipigon Crown Management Unit, northeast of Thunder Bay, Ontario (Table 1). Both sites represented vegetation management sce-

Table 1. Description of study areas.

Site	Geology	Preharvest stand conditions*	Harvest	Site preparation	Planting
1 Corrigal Twp. basemap 491 881	Glacial outwash plain; fresh to moist, coarse loams (ES 21)†	B_5 Sb_3 Bw_1 Sw_1 age 61	Clearcut; full-tree, conventional cut-and skid, 1986/87	TTS disk trencher, 1987	Black spruce bareroot, 2.2–3.0 m spacing, 1988
2 Hele Twp. basemaps 487 882, 491 883	Glacial outwash plain; fresh to moist, fine loam (ES 27)	Bw_4 B_3 Sb_1 Po_2 age 72	Clearcut; full-tree, feller-buncher/grapple-skidder, 1985/86	Bracke, 1986	Black spruce bareroot, 2.2–3.0 m spacing, 1987

* Ontario Forest Resource Inventory stand description: B = balsam fir, Sb = black spruce, Bw = white birch, Po = Poplar, Sw = white spruce. Subscripts refer to the proportion of total stocking (out of 10) occupied by a species.

† Chambers et al. 1997.

Table 2. Summary of treatments applied.

Treatment reference	Details	Date (work hr/ha)
Untreated	Plots left undisturbed.	–
Directed foliar	1.7 kg ai/ha of Vision (356 g/L ai glyphosate as a water-soluble liquid) applied in a total spray volume of 300 L/ha (1.58% solution). Spray was directed at all noncrop vegetation within a 1-m radius of crop trees using a truck-mounted reel and hose system.	Aug. 27 (Corrigal), 29 (Hele), 1991 (2 hr)
EZ-Ject	One capsule containing 0.15 g of glyphosate (isopropylamine salt) was injected into the basal stem for every 5 cm dbh. Only popular stems within a 1-m radius of crop trees were treated.	Nov. 2, 1990 (25 hr)
Thin-line	Garlon 4 (now Release, 480 g/L ai triclopyr as a butoxyethyl ester) was applied, undiluted, to the entire circumference of woody stems in a horizontal, pencil-thin line, 15 cm aboveground. Approximately 11.1 L of product were applied per ha using a backpack sprayer equipped with a Gunjet Model 30 and straight-stream tip nozzle. Only stems within 1-m radius of crop trees were treated.	Oct. 29, 1990 (25 hr)
Brushsaw	All noncrop vegetation within a 1-m radius of crop trees was cut at 25 cm aboveground line with a Husqvarna 165 clearing saw.	Sept. 20 (Corrigal), Oct. 15 (Hele), 1990 (4–8 hr)
Spot gun	Velpar L (240 g/L ai hexazinone as a water-soluble liquid) was applied as a 50% solution using a backpack sprayer equipped with a metering nozzle. The area within a 1-m radius of each crop tree was treated. Problems with nozzle tip freezing reduced effectiveness of dosage metering.	Oct. 24, 1990 (na)
Annual removal	Annual directed foliar applications using a 1.58 or 2% solution of Vision. Applications were made with a backpack sprayer equipped with a flat fan nozzle.	Aug. 1990, 1991, 1992, 1993, and 1994

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narios commonly encountered on small harvest blocks in the region. On the Corrigal Twp. site, three replicates of each of six conifer release treatments were established in a randomized complete block design. As detailed in Table 2, treatments included an untreated check, glyphosate applied with directed foliar application, glyphosate applied with the EZ-Ject system, basal bark treatment with triclopyr and the thin-line technique[1], manual cutting using a brushsaw, and five growing seasons of annual nonspruce vegetation removal (annual removal) using repeated applications of glyphosate. All treatments, except annual vegetation removal, were applied to a 1-m radius around each spruce. On the Hele Twp. site, a similar design was used to compare spot gun treatment with hexazinone to an untreated check, directed foliar, and annual removal treatments, the latter being applied in the same fashion as Corrigal. Treatment plots were 60 m × 80 m in each case.

Vegetation Assessments

Within each treatment plot, 20 representative black spruce seedlings were systematically located within a 40 × 60 m area situated in the center of each treatment plot. Each seedling was identified with a pin-mounted, numbered aluminum tag. Prior to treatment, in Aug. 1990, total height (nearest cm, from groundline to the base of the terminal bud) and rootcollar diameter (nearest mm, 1 cm aboveground line) of each seedling were recorded. Vegetation surrounding each spruce was assessed within a 1.13-m radius of each tree's center. Cover and height were recorded for each species present within the following vegetation classes:

- Poplar, mainly trembling aspen [*Populus tremuloides* (Michx.)];
- Other tree species, predominantly white birch [*Betula papyrifera* (Marsh.)];
- Tall shrubs, mainly mountain maple [*Acer spicatum* (Lamb.)] at Corrigal; and beaked hazel [*Corylus cornuta* (Marsh.)], speckled alder [*Alnus rugosa* (Du Roi) Spreng.], and willow [*Salix* spp.] at Hele;
- Low shrubs, mainly red raspberry [*Rubus ideaus* (L.)];
- Forbes, mainly fireweed [*Epilobium angustifolium* (L.)] and large-leaved aster [*Aster macrophyllus* (L.)];
- Ferns; and
- Grasses, including sedges and rushes.

Cover assessments were facilitated by placing two 2.26-m lengths of plastic pipe at right angles to each other over the subplot center and visually estimating the portion of ground occupied by the vertical projection of the plant crown(s), to the nearest 5%, for each quadrant. Trace amounts of vegetation were assigned 2% cover.

All spruce and vegetation subplots were reassessed at the end of the growing seasons of 1991, 1992, 1993, 1995, and 2000. In the final measurement year, crown widths were also recorded for each spruce (one measure parallel to the planted row and a second perpendicular to the row). Crown area was estimated from these measures, assuming elliptical form (Zedaker and Miller 1991).

Data Analysis

Response variables used in the comparison of spruce growth included rootcollar diameter, total height, stem volume (assuming conical form), and percentage survival. Cover (%) and cover-weighted height of the vegetation surrounding each spruce were analyzed by vegetation class. Statistical comparisons were made before treatment and 10 growing seasons after treatment using analysis of variance (ANOVA) and the model appropriate for a randomized complete block design. Pretreatment values were included as covariates in the analyses of posttreatment data, when significant ($P \leq 0.05$). Linear contrasts were used to address specific questions posed in the study objectives about spruce growth, stand composition, and stand structure. These included:

- Do release-treated (excluding annual removal) and untreated stands have the same outcome: treated versus untreated?
- Does 5 years of annual vegetation removal differ from the other release treatments: annual removal versus other treatments?
- Does directed foliar treatment with glyphosate differ from the other release treatments: directed foliar versus EZ-Ject, thin-line, and brushsaw (Corrigal); spot gun (Hele)?
- Do the two individual-stem treatments differ: EZ-Ject versus thin-line (Corrigal)
- Does a single release with brushsaw provide any benefit over no treatment: brushsaw versus untreated (Corrigal)?

In addition, spruce response trends over time were compared among treatments using repeated measures analyses of covariance. For these analyses, polynomial response functions were fit to the repeated measures for each experimental unit (i.e., each plot of each treatment) and the estimated orthogonal polynomial coefficients (mean, linear, and quadratic) used as primary data in the underlying ANOVA structure [see Meredith and Stehman (1991) for details]. In this manner, rates of growth were compared among the treatments. In all cases, model residuals were examined to verify that the assumptions of homogeneity of variance and normality were met.

Finally, we explored the relationship between spruce growth and the abundance of surrounding vegetation by regressing 2000 spruce stem volume on total herbaceous and woody vegetation cover in the second season (1992) after treatment. Individual plot means were used for this analysis and data from both sites were pooled.

Results

Effects on Black Spruce

At the initiation of the experiment in 1990, bareroot black spruce planted at the Corrigal site were in their second growing season and averaged 46 cm in height ($P = 0.66$; Table 3, Figure 1) and 7 mm in diameter ($P = 0.83$). At the same time, bareroot black spruce planted at Hele were in their third growing season and were slightly larger than

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Table 3. Summary of P-values from ANCOVA and RM-ANCOVA of black spruce response variables.

Source of variation	Root-collar diameter (mm)					Height (m)					Stem volume index (cm^3)				
		Over time*					Over time*					Over time*			
	Pretreat.	M	L	Q	2000	Pretreat.	M	L	Q	2000	Pretreat.	M	L	Q	2000
Corrigal															
Mean	–	<0.01	<0.01	**<0.01**†	–	–	<0.01	<0.01	**<0.01**	–	–	<0.01	<0.01	**<0.01**	–
Treatment	**0.83**	<0.01	<0.01	0.32	<0.01	**0.66**	0.20	0.01	0.01	0.02	**0.75**	<0.01	<0.01	<0.01	<0.01
Root mean square error	1.4	3.8	0.8	0.1	8.1	7.1	19.6	4.1	0.4	44.9	4.5	265.8	129.0	17.6	1,266
Treated vs. untreated	0.82	0.25	0.02	0.14	0.03	0.49	0.59	0.03	**<0.01**	0.07	0.99	0.19	0.13	0.08	0.13
Annual removal vs. other treatments	0.27	<0.01	**<0.01**	0.74	**<0.01**	0.26	0.08	**0.02**	0.14	**0.02**	0.21	<0.01	<0.01	**<0.01**	**<0.01**
Directed foliar vs. EZ-Ject, thin-line, and brushsaw	0.93	0.05	**<0.01**	0.14	**<0.01**	0.28	0.12	0.03	0.07	0.04	0.61	0.03	0.02	**<0.01**	**0.01**
EZ-Ject vs. thin-line	0.50	0.99	**0.50**	0.52	0.61	0.61	0.69	0.73	0.15	0.87	0.49	0.99	0.93	0.84	0.93
Brushsaw vs. control	0.83	0.37	**0.05**	0.19	**0.07**	0.35	0.51	0.03	0.01	**0.06**	0.94	0.29	0.22	0.14	**0.21**
Hele															
Mean	–	<0.01	<0.01	<0.01	–	–	<0.01	<0.01	<0.01	–	–	<0.01	<0.01	**<0.01**	–
Treatment	**0.56**	0.05	0.01	0.03	0.02	**0.41**	0.37	0.18	0.07	0.22	**0.42**	0.04	0.03	0.02	0.03
Root mean square error	1.3	3.6	0.9	0.1	9.6	7.9	18.2	4.7	0.5	52.8	9.2	306.2	150.4	20.2	1,490
Treated vs. control	0.44	0.98	0.66	**0.50**	**0.73**	0.28	0.42	0.86	0.43	0.77	0.43	0.91	0.82	0.69	0.82
Annual removal vs. other treatments	0.28	0.02	<0.01	0.07	**<0.01**	0.25	0.22	0.11	**0.07**	0.14	0.20	0.02	0.01	**0.01**	**0.01**
Directed foliar vs. spot gun	0.45	0.11	0.03	0.02	**0.03**	0.34	0.23	0.12	**0.07**	0.14	0.33	0.11	0.09	**0.06**	**0.08**

* Analysis of polynomial coefficients for trends over time. M = mean response averaged over time (growing seasons 1 through 10 posttreatment); L = linear trends; Q = quadratic trends.
† Values shown in bold have been referenced in text.

Corrigal trees, averaging 71 cm in height ($P = 0.41$; Table 3, Figure 2) and 11 mm in diameter ($P = 0.56$). Stem volume index on the two sites averaged 8 and 27 cm^3/tree, respectively, neither site exhibiting evidence of pretreatment volume differences ($P > 0.42$).

Spruce survival through the observation period was quite high, averaging 86% at Corrigal and 87% at Hele by the end of the 2000 growing season. Differences between treatments were not statistically significant at either location ($P > 0.50$); however the lowest survival (78%) was observed on annual removal plots at Corrigal and spot gun plots at Hele.

Both rootcollar diameter and total height increased in a curvilinear or quadratic fashion over the observation period ($P < 0.01$; Figures 1 and 2). Diameter growth rates exhibited greater treatment separation than height, with trees on annual removal plots growing faster than trees in the other release treatments ($P < 0.02$). At Corrigal, the other treatments, including brushsaw, generally supported more rapid diameter increases than untreated plots ($P < 0.05$), and trees in directed foliar treatments exceeded the growth rates observed in brushsaw, thin-line, and EZ-Ject treatments ($P < 0.01$). Diameter growth rates in the latter two treatments did not differ ($P = 0.50$). By the end of the tenth growing season after treatment, stem diameters averaged 80 mm in the annual removal plots: a 140% gain over untreated trees and a 30% gain over the best of the release treatments, directed foliar ($P < 0.01$). At an average of 62 mm, directed foliar–treated trees were 87% larger than untreated trees and at least 33% larger than the other treatments ($P < 0.01$). Brushsaw treatment provided a marginal gain (40%) over no release ($P = 0.07$).

At Hele, trees in annual removal and directed foliar treatments performed identically to Corrigal trees following the same treatments, despite being a year older. Untreated trees were larger at Hele than at Corrigal, perhaps leading to less distinct treatment differences there (growth rates, $P = 0.50$; year 2000, $P = 0.73$). Spot gun-treated trees had lower

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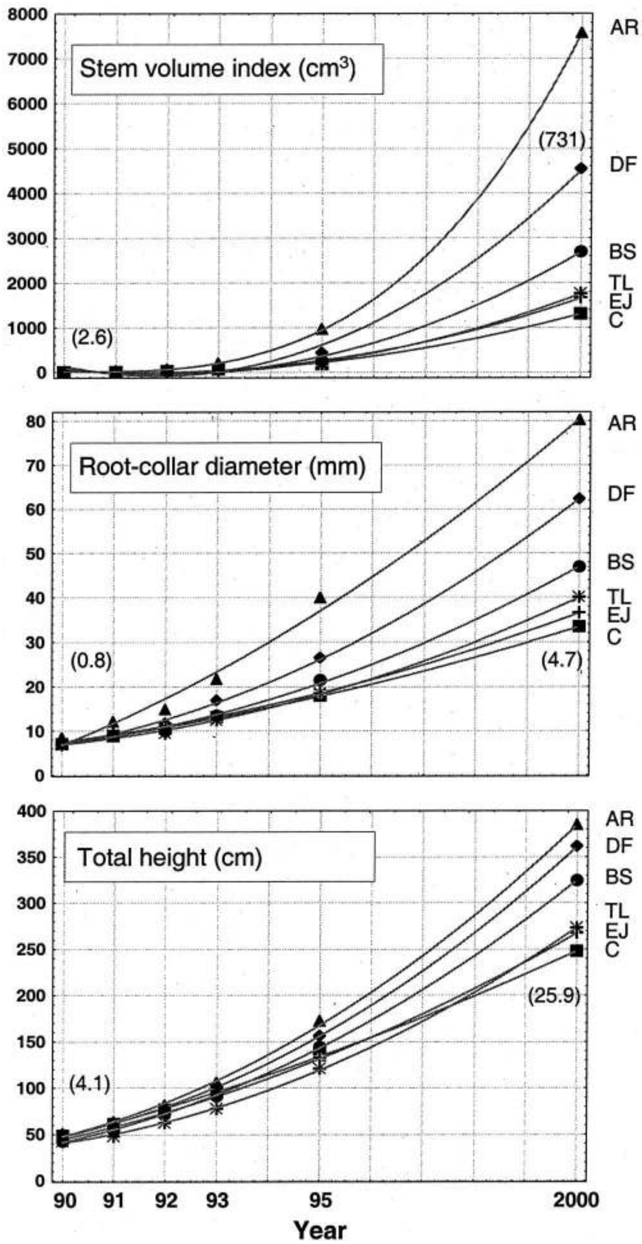

Figure 1. Growth of Corrigal black spruce through 10 growing seasons after treatment. Lines represent functions estimated by polynomial contrasts from repeated-measures analysis of covariance; points represent least-squares treatment means, after adjustment to common pretreatment size. C (■), untreated check; AR (▲), annual removal; DF (♦), directed foliar; BS (●), brushsaw; EJ (+), EZ-Ject; and TL (*), thin-line. Numbers in brackets are standard errors for the end-point least-squares means.

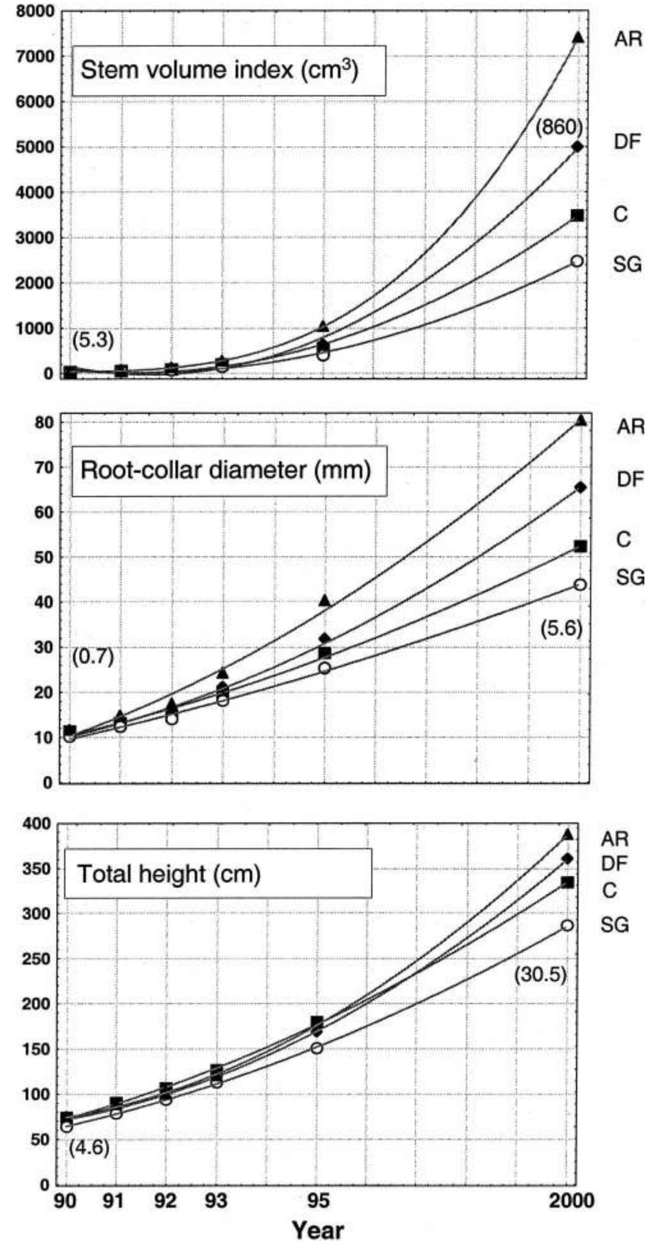

Figure 2. Growth of Hele black spruce through five growing seasons after treatment. Lines represent functions estimated by polynomial contrasts from repeated-measures analysis of covariance; points represent least-squares treatment means, after adjustment to common pretreatment size. C (■), untreated check; AR (▲), annual removal; DF (♦), directed foliar; and SG (○), spot gun. Numbers in brackets are standard errors for the end-point least-squares means.

growth rates than untreated trees, likely due to minor phytotoxic effects of the hexazinone. By the end of the tenth growing season after treatment, stem diameters averaged 80 mm in the annual removal plots, providing a 54% gain over untreated trees and a 23% gain over those in the directed foliar treatment ($P < 0.01$). At an average of 65 mm, directed foliar-treated trees were 25% larger than untreated trees and 49% larger than spot gun-treated trees ($P = 0.03$).

In many studies based on early growth response data, conifer height is typically not influenced by release treatment (Morris et al. 1990, Longpré et al. 1994, Pitt et al. 1999, Wagner et al. 1999, Pitt et al. 2000). After 10 growing seasons on these sites, however, treatment differences were evident with black spruce height. At Corrigal, height growth rates were greater in treated than untreated trees ($P < 0.01$). In fact, the same pattern of statistical significance observed among treatments with diameter growth was evident with height. After 10 years, annual removal trees averaged just over 3.8 m in height; a 55% gain over untreated trees and at least a 6% gain over the release treatments ($P = 0.02$). At 3.6 and 3.2 m, directed foliar- and brushsaw-treated trees

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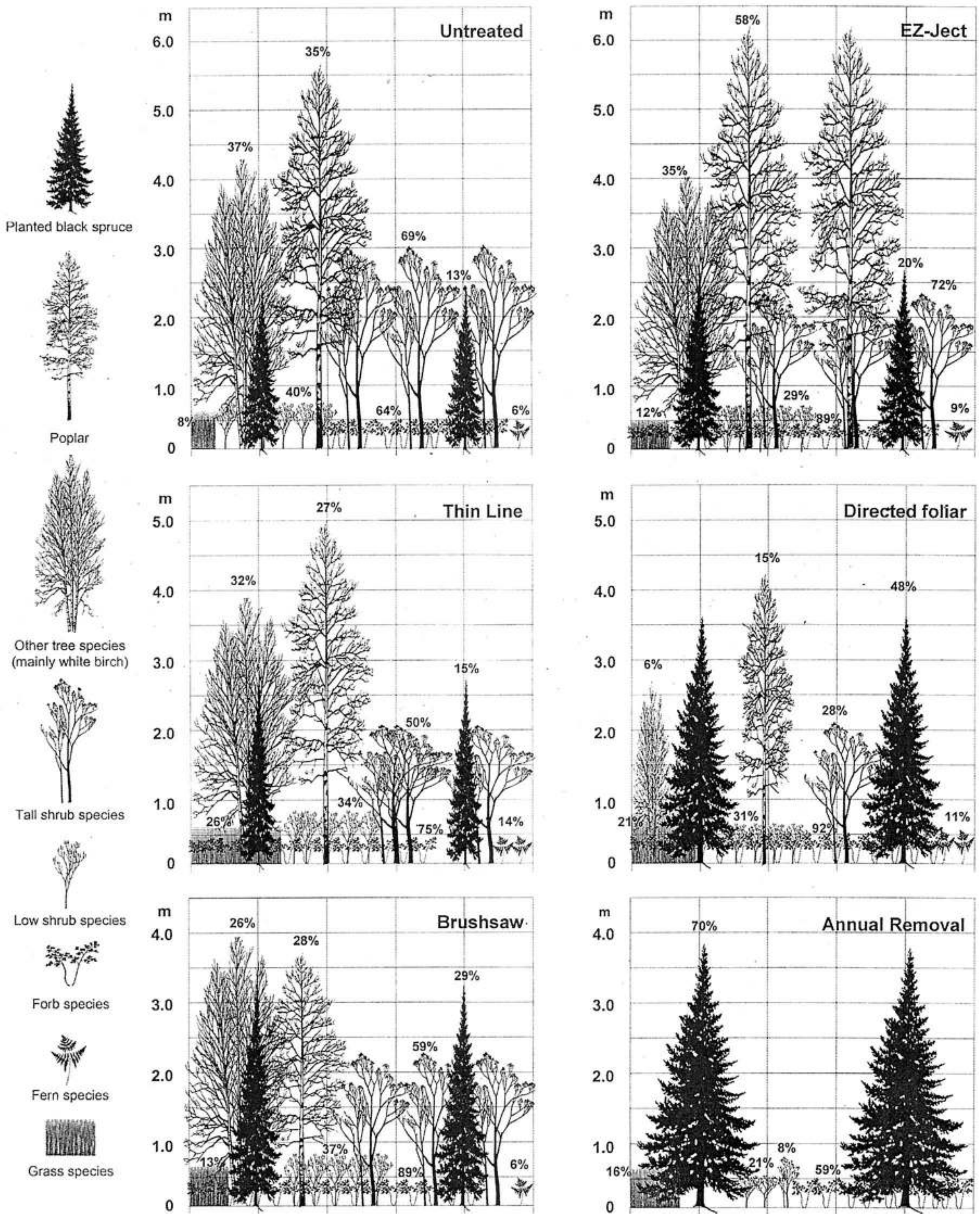

Figure 3. Schematic side view of the average cover (%) and height (m) of major vegetation groups at Corrigal, 10 growing seasons after treatment. Values are least-squares means from ANOVA. Pretreatment values are depicted in Figure 4.

were 46% and 31% taller than untreated trees, respectively ($P < 0.06$). At Hele, treatment differences were not as pronounced, but still evident. Trees in annual removal plots grew faster than those in the other treatments and directed foliar-treated trees grew faster than the spot gun-treated trees ($P = 0.07$ in each case). Annual removal and directed foliar treatments provided 16 and 8% gains in height growth over no treatment. Spot gun treatment compromised height growth by 14%.

Integrating diameter and height growth, stem volume index trends were strongly quadratic in nature on both studies ($P < 0.01$). Annual removal plots consistently contained the fastest-growing trees ($P \leq 0.01$), and directed foliar-treated trees consistently exceeded the growth of trees in the other release treatments ($P \leq 0.06$). After 10 growing seasons, annual removal provided a 476% gain over no treatment at Corrigal and a 112% gain at Hele. This treatment also provided at least a 50% gain in volume growth

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over any of the other release treatments, at either site ($P \leq 0.01$). Directed foliar treatment resulted in the best volume response of the release treatments tested, providing a 246% gain over doing nothing at Corrigal and a 43% gain at Hele ($P \leq 0.08$). Again, the reduced response observed at Hele is likely attributable to the single growing season delay in release applied there. At Corrigal, although brushsaw release provided a 105% gain in volume growth over untreated trees, the absolute volumes of these two treatments did not differ ($P = 0.21$). The gains provided by EZ-Ject and thin-line treatments, as applied, were marginal at best. Spot gun treatment at Hele resulted in a net loss in growth of 29%, measured 10 growing seasons after treatment.

Effects on Hardwood, Shrub, and Herbaceous Vegetation

Poplar and White Birch

At the time of treatment, poplar was the most dominant woody species on the two sites, representing between 13 and 23% cover and more than 2 m in height (Figures 3 and 4). Trembling aspen was much more prevalent than balsam poplar, representing at least 85% of the combined cover, both before and after treatment. In the absence of release treatment, poplar retained its dominance on both sites, achieving 35% cover and over 5.5 m in height at Corrigal and 22% cover and over 6 m in height at Hele. An abundance of tall shrubs (mountain maple at Corrigal; alder, willow, and hazel at Hele) likely prevented poplar from achieving greater cover levels and site dominance.

Annual removal treatments had the greatest effect on poplar, reducing tenth-year cover to less than 5% at Corrigal ($P < 0.01$; Table 4) and 10% at Hele. Remaining stems were less than 1 m in height ($P < 0.01$) and comprised of young germinates that became established after the treatments were discontinued. Surviving poplar in directed foliar plots consisted of untreated individuals, damaged and recovering stems, and new posttreatment germinates. This treatment reduced poplar cover to about half the levels observed in untreated plots and marginally reduced mean poplar height. At Corrigal, directed foliar plots had less poplar cover than the other release treatments tested there ($P = 0.03$). The brushsaw treatment did not reduce long-term poplar cover ($P = 0.52$) but did reduce its height ($P = 0.06$); resprouting stems were just beginning to overtop the planted spruce 10 growing seasons after treatment. Neither the thin-line nor the EZ-Ject treatments had any effect on poplar. Inexplicably, the latter treatment supported the highest poplar covers observed in the experiment (58%). The spot gun treatment reduced poplar dominance in a fashion similar to the directed foliar treatments.

Other hardwood species, largely represented by white birch, were present at both sites, but only achieved reportable levels (>5% cover) at Corrigal. On untreated plots there, white birch cover reached 37% and over 4 m in height by year 10. Over the period of assessment, brushsaw, thin-line, and EZ-Ject treatments had no effect on this species, with both cover and height reaching levels similar to untreated plots. As with poplar, directed foliar treatments reduced both white birch cover ($P < 0.01$) and height. Annual removal treatments substantially reduced, but did not eliminate the species, with 2000 cover averaging about 1%.

Tall Shrub Species

Prior to treatment, cover averaged 25% for tall shrub species on both sites and consisted of mountain maple, speckled alder, serviceberry (*Amelanchier* spp.), beaked hazel, dogwood (*Cornus* spp.), pin cherry [*Prunus pensylvanica* (L.f.)], choke cherry [*Prunus virginiana* (L.)], willow, mountain ash [*Sorbus americana* (Marsh.)], and *Viburnum* species. Mountain maple was dominant at Corrigal, and alder, willow, and hazel shared dominance at Hele. Ten growing seasons after surrounding plots were treated, all of the original species were still present in untreated plots, as were the original patterns of dominance. At this time, untreated shrub cover averaged 69% and 3 m height at Corrigal and 88% and 3.5 m at Hele, overtopping the planted spruce in both cases.

In contrast, annual removal treatments reduced 10th-year shrub cover to 8% at Corrigal and 2% at Hele, with heights averaging less than 1 m. The rigorous vegetation control provided by these treatments seriously reduced recovery of tall shrub species; however, all the species present before treatment were still present in year 10 at Corrigal, and only hazel and mountain ash were not detected in the sample at Hele. Among the release treatments tested, only the directed foliar treatment reduced shrub cover to about 30% and reduced mean heights to levels well below those of the planted spruce by the end of the observation period. None of the original species were eliminated by this treatment. On average, the other treatments were not as effective at reducing shrub cover ($P < 0.01$), leading to cover levels only marginally less than observed in untreated plots. Spot gun treatment may have stimulated shrub growth, with plots averaging nearly 100% cover by year 10. Only in brushsaw and thin-line plots were the planted spruce consistently taller than surrounding shrubs.

Low Shrub Species

Red raspberry accounted for more than 80% of pretreatment low shrub cover on the two sites. Bush honeysuckle [*Diervilla lonicera* (Miller)], Canada honeysuckle [*Lonicera Canadensis* (Bartram)], *Ribes* spp., and wild rose [*Rosa acicularis* (Lindl.)] also were present in trace amounts, contributing to nearly 35% low shrub cover overall. After 10 years, the same species were present on untreated plots, but bush honeysuckle had assumed dominance over raspberry at Corrigal, and raspberry had generally reduced its dominance to 55% of total low shrub cover at Hele. Untreated low shrub cover changed little over the observation period, reaching 40% at Corrigal and falling to 28% at Hele.

In the absence of complete crown closure by the spruce, low shrubs remained well represented on annual removal plots, reaching just over 20% cover by the end of the observation period. All species remained represented in these plots; however, raspberry accounted for more than

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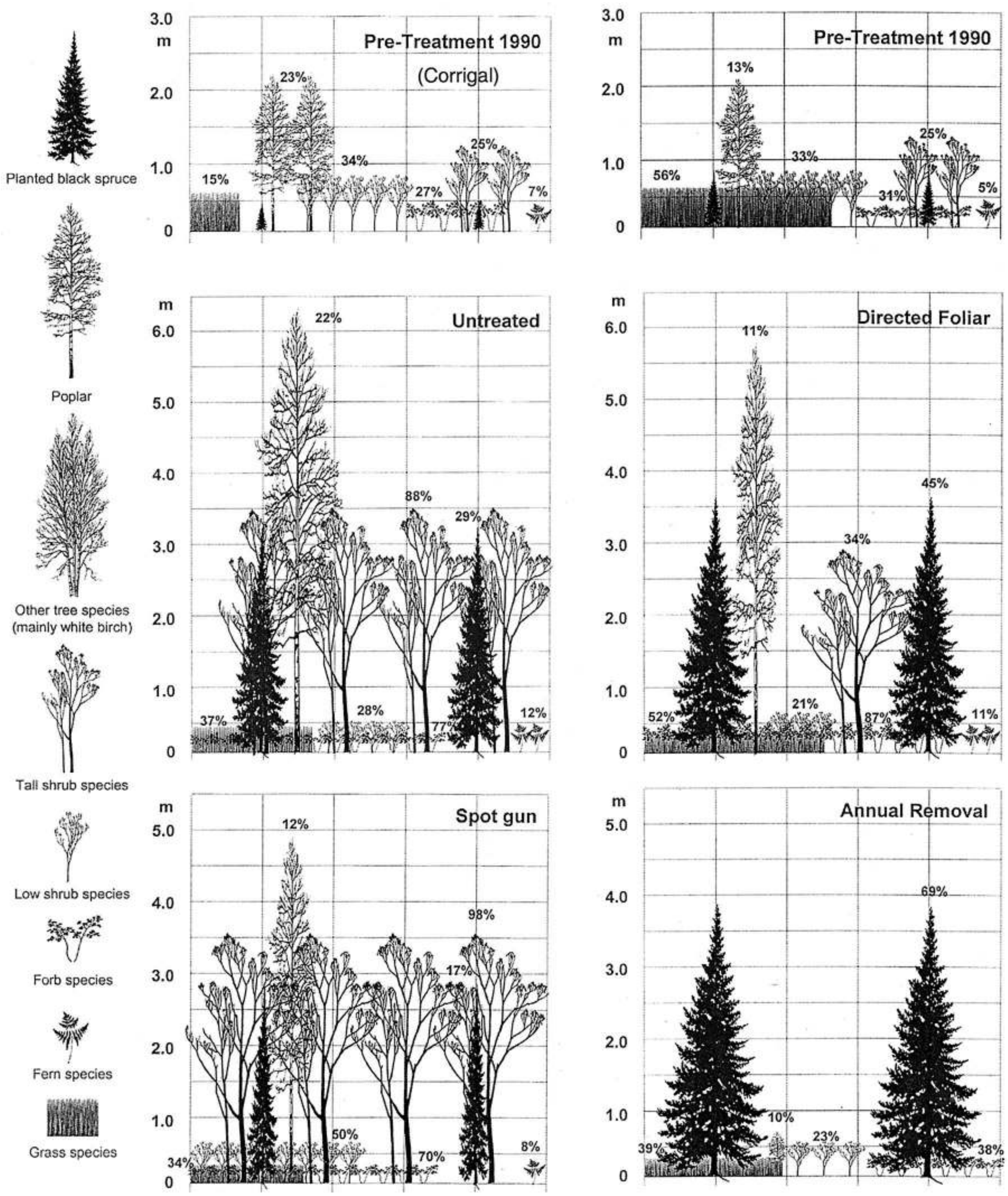

Figure 4. Schematic side view of the average cover (%) and height (m) of major vegetation groups at Hele, 10 growing seasons after treatment. Values are least-squares means from ANOVA.

90% of the cover present, contrasting with untreated areas. While most of the other treatments reduced low shrub cover for 1 or 2 growing seasons after treatment, recovery was typically rapid and levels did not differ from those in untreated plots 10 growing seasons after treatment ($P > 0.29$). Patterns of species dominance within these low shrub communities generally reflected those of untreated plots. As observed with tall shrubs, the spot gun treatment appears to have stimulated low shrub development, with year-10 cover averaging 50%.

Forbs and Ferns

Forb cover averaged approximately 30% at the two sites before treatment. We do not present a species breakdown for this group, but species such as fireweed, large-leaved aster, and other broadleaved herbs were well represented. In the absence of treatment, cover gradually increased to 46% at Corrigal and 77% at Hele.

Annual removal treatments had minimal effect on this vegetation group after 10 years, with cover increasing to 59% at Corrigal and 38% at Hele through 6 years after

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Table 4. Summary of P-values from ANOVA or ANCOVA of 2000 cover of vegetation groups.

Source of variation	Poplar cover	Poplar height	Other tree species	Tall shrubs	Low shrubs	Forb species	Fern species	Grasses, sedges
Corrigal								
Treatment	0.01	<0.01	<0.01	<0.01	0.59	0.03	0.04	0.12
Covariate (1990 cover)	<0.01	0.14	0.26	0.35	0.03	0.42	0.04	0.13
Root mean square error	12.2	116.5	11.4	9.9	12.8	12.4	4.03	7.4
Treated vs. untreated	0.64	0.25	0.11	0.02	**0.44***	0.02	0.21	**0.07**
Annual removal vs. other treatments	**0.01**	**<0.01**	**<0.01**	<0.01	0.19	**<0.01**	**<0.01**	0.76
Directed foliar vs. EZ-Ject, thin-line, and brushsaw	**0.03**	0.52	**<0.01**	**<0.01**	0.80	0.36	0.63	0.40
EZ-Ject vs. thin-line	0.03	0.28	0.75	0.02	0.63	0.19	0.16	0.04
Brushsaw vs. untreated	**0.52**	**0.06**	0.24	0.23	0.79	0.04	0.96	0.46
Hele								
Treatment	0.15	<0.01	0.69	<0.01	0.02	<0.01	0.04	0.05
Covariate (1990 value)	<0.01	0.05	0.79	0.03	0.56	0.26	0.93	0.09
Root mean square error	5.6	114.7	3.4	13.9	8.8	10.1	4.1	6.1
Treated vs. control	0.05	0.38	0.53	0.08	**0.29**	0.87	0.29	**0.21**
Annual removal vs. other treatments	0.71	**<0.01**	0.30	<0.01	0.08	**<0.01**	**0.02**	0.55
Directed foliar vs. spot gun	0.89	0.38	0.69	**<0.01**	<0.01	0.08	0.35	0.01

* Values shown in bold have been referenced in text.

treatments were discontinued ($P < 0.01$). The other release treatments provided short-term reductions in forb cover, but supported cover levels in year 10 that were equal to or greater than those observed in untreated plots. It is likely that this vegetation group, capable of rapid recovery following disturbance, benefited from the control of shrubs and hardwoods.

Fern cover remained fairly constant across treatments and over time, ranging between 5 and 14% cover. Annual removal treatments significantly reduced fern cover ($P < 0.02$), but did not eliminate it, with year 10 values averaging about 1%.

Grass and Sedge Species

Grass and sedge species generally maintained a minor presence on the Corrigal site throughout the observation period. Pretreatment cover levels averaged 15% and were generally echoed 10 growing seasons after treatment, ranging from 8% in untreated plots to 26% in thin-line plots. Annual removal and directed foliar plots, which caused short term reductions in grass cover following treatment, contained as much or more cover than untreated plots by year 10 ($P = 0.07$).

Grasses and sedges were more dominant at Hele, averaging just under 60% cover in 1990 and ranging from 34% in spot gun plots to 52% in directed foliar plots by the end of the observation period. All of the treatments tested at Hele reduced grass cover for 2 or more years after treatment but exhibited no longer-term effects on this group ($P = 0.21$).

Relationship Between Degree of Release and Spruce Growth

The different degrees of vegetation control produced by the release treatments tested in this study offer the opportunity to examine the relationship between spruce growth and degrees of vegetation manipulation. Scatter plots of spruce stem volume in 2000 over cover in each of the vegetation groups for 1991, 1992, and 1993 revealed some interesting patterns. Cover in 1991, which reflected the immediate effect of the vegetation treatments, was generally not correlated with spruce growth over the 10 years. Vegetation data collected in subsequent years, however, reflected posttreatment vegetation recovery and tended to be a better predictor of longer-term spruce growth. Rapid recovery of all vegetation (except forbs) in the years immediately after treatment was correlated with substantially reduced rates of spruce volume growth. The best relationship was found for total vegetation cover in 1992 (Figure 5). The relationship between spruce volume growth over the 10 years and total vegetation cover in 1992 was negative exponential, where the most dramatic reductions in future size were related to very small initial increases in the cover of surrounding vegetation.

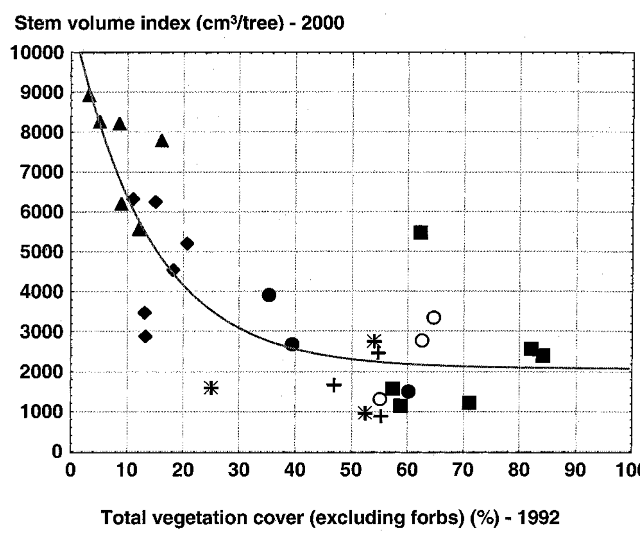

Figure 5. Black spruce stem volume index 10 growing seasons after treatment versus total vegetation cover (excluding forb cover) two growing seasons after treatment. Data from Corrigal and Hele are combined; symbols reflect untreated check (■), annual removal (▲), directed foliar (♦), brushsaw (●), EZ-Ject (+), thin-line (*), and spot gun (○).

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Discussion

Although 5 years of annual vegetation removal may not be a practical vegetation management approach, this treatment serves as a benchmark for black spruce growth potential on these sites. The annual removal treatment provided a 6–7% gain in height growth and 50–65% increase in stem volume growth over the best operational release treatment tested. Based on results from this study, if the objective of early stand management is to achieve rapid crown closure for planted spruce, then broadcast methods of vegetation control that can provide two or more growing seasons of substantially reduced vegetation cover are needed.

One notable finding from both study sites was that, despite five growing seasons of continuous vegetation control, none of the seven species groups studied were eliminated, and nearly all of the species present at the time of treatment were present 10 growing seasons later (six growing seasons after the last repeat treatment). Although the long-term effects of vegetation management on plant diversity are still being evaluated, our results suggest that most plant species in early-successional northern forests are able to withstand a relatively intensive vegetation control regime, despite arguments to the contrary (Mosquin et al. 1995). Our findings are also consistent with the results of other studies of plant community dynamics after intensive vegetation management treatments (Lund-Høie and Grønvold 1987, Sullivan et al. 1998, Haeussler et al. 1999, Boateng et al. 2000).

Increasingly, management objectives are including provisions for small patch cuts, mixed species stand targets, and partial overstory removals, necessitating a change in the way vegetation management is executed (McCormack 1994). Several of the ground-applied, individual tree techniques tested in this study may be well suited to these management approaches. Of those tested, directed foliar release with glyphosate provided the best growth response in spruce, with an 8–46% gain in height growth and a 43–246% gain in stem volume growth over no release. This treatment provided a good mix of early herbaceous and woody vegetation control in proximity to the spruce seedlings. This result also is consistent with other studies that have demonstrated significant conifer growth increases following the control of herbaceous vegetation (e.g., Creighton et al. 1987, Pitt et al. 1999, Wagner et al. 1999).

Directed foliar treatment modified vegetation succession in a manner that favored the conifer and hardwood components of the stand while also leaving other vegetation groups represented in the stand. Aspen and other species situated outside the treatment radius around individual crop trees were left untouched by this treatment, allowing potential for future development of a mixedwood stand, as well as a high degree of within-stand species and structural diversity. Although further research is needed to determine optimum densities, this method might be used to encourage high-quality mixedwood stands by planting a relatively low density of spruce (e.g., 500–1,000 sph) for future sawlogs and then releasing them at the same time that surrounding hardwoods are spaced. Directed foliar treatment also was the least expensive among the five methods tested, requiring less than 10% of the labor required for the thin-line or EZ-Ject treatments, and approximately 25% of the labor required for the brushsaw treatment. The costs of directed foliar treatment are not as strongly influenced by stem density as they are with these latter treatments. This application method has been used for a number of years in the southeastern United States as a low-cost alternative to aerial application where selective applications are needed for silvicultural or environmental reasons, for conifer and hardwood release, as well as applications in site preparation, precommercial thinning, wildlife habitat management, and maintenance of recreation areas (Miller 1990a).

The only other release treatment tested that provided early herbaceous vegetation and grass control was the spot treatment with hexazinone. Applied as a release measure, however, this treatment resulted in both direct and indirect negative influences on the planted black spruce. The stunted spruce growth we observed was very likely caused by hexazinone uptake. The shallow root system of black spruce readily absorbs hexazinone when it is applied after planting; the Velpar L label recommends that spot treatments be kept at least 1 m away from crop trees. In this study, vegetation within a 1-m radius of planted spruce was treated. In contrast, black spruce are fairly tolerant of soils that have been treated with hexazinone at rates up to 4 kg ai,/ha, up to 1 month before planting (Pitt et al. 1999). Indirect effects on spruce growth were caused by the pattern of vegetation recovery that hexazinone initiated. Hexazinone effectively controls broadleaf herbaceous vegetation, *Rubus* spp., and grasses, has moderate influence on aspen, and does not control other woody species. Consequently, when applied for conifer release at Hele, this herbicide had the effect of stunting both spruce and aspen and releasing the tall-shrub vegetation. While hexazinone cannot be recommended as it was applied in this study, it should not be overlooked as a site preparation treatment for reducing grass and broadleaf competition on rich sites prior to planting. Several studies have demonstrated the benefits of this type of application (Deschamps and Mutchmore 1988, Wood et al. 1989, Pitt et al. 1999).

The other release treatments tested were capable of only short-term reductions in woody vegetation levels. Manual cutting with brushsaws did a better job of promoting spruce growth than either the thin-line or EZ-Ject treatments, providing a 31% gain in height growth and a 105% gain in stem volume growth over no treatment at all. Despite this response, the efficacy of this treatment was likely not maximized because of its fall timing. During the dormant period, when carbohydrate reserves in root systems are at their peak, cutting typically results in the rapid resprouting of deciduous tree and shrub vegetation observed in this study. Efficacy may be improved with mid-summer application, when deciduous root systems are at minimum carbohydrate levels (Bell et al. 1999). If a choice is made not to use herbicides, this method presents a viable, although expensive, alternative. Costs vary from \$200 to \$450/ha (CDN)

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depending on stem density (Pitt et al. 2000); productivity in this study varied from 4 to 8 man-hours/ha. As described above for the directed foliar treatment, overall regeneration costs might be reduced if this method were targeted on a reduced number of desired seedlings under mixedwood objectives.

Basal bark applications with triclopyr are particularly suited to low to medium woody stem densities, with basal diameters between 1 and 5 cm, and where competition from other vegetation groups is not anticipated to be a problem. In this study, high stem densities and a lack of operator familiarity with the technique reduced both the efficacy and productivity of this treatment. Resulting spruce growth was only marginally better than observed in untreated plots, and the year-10 composition and structure of the other vegetation was similar on the two groups of plots. Productivity averaged 25 man-hours/ha. This technique is best focused on the selective removal of competitors immediately around the conifers or hardwoods to be released (Miller 1990b).

The EZ-Ject lance system was designed for the removal of a relatively small number of woody stems per ha, usually in combination with other vegetation management tools. The high number of small woody stems that needed to be treated at the Hele and Corrigal sites were not particularly suited to this treatment, as evidenced by the poor efficacy and low productivity rates (25 man-hours/ha) observed.

When vegetation responses resulting from the different treatments in this study are pooled, a negative exponential relationship results between black spruce volume in year 10 and vegetation cover two growing seasons after treatment. The correlation suggests that very small increases in early vegetation cover ($<20\%$) are related to large losses in conifer growth potential (see Figure 5). This pattern has been shown in the literature, is consistent with yield-density relationships, and provides the basis for competition thresholds that are useful for determining objectives for vegetation management (Wagner 2000).

In addition, evidence that growth patterns are determined at an early age was provided by the fact that all of the treatment response patterns observed in this study were statistically detectable at year 5 and, to a lesser degree, year 3. Time only increased the magnitude of these differences. Once black spruce seedlings were established, growth followed a pattern of compound interest over time; the larger the capital a seedling accrued at a young age, the more rapid its future rate of growth. This observation has important implications in the timing of competition release and provides explanation for the long-term divergence in volume growth curves among such treatments (Wagner et al. 2001). Therefore, if achieving near maximum rates of early growth for planted spruce is a silvicultural objective, vegetation management should strive to create near vegetation-free conditions, at least in the immediate vicinity of desired trees, for at least two growing seasons, as early after planting as is feasible. The importance of early vegetation management interventions has been demonstrated in other studies (Wood and von Althen 1993, Pitt et al. 1999, Wagner et al. 1999). Directed foliar treatment with glyphosate was the one operational treatment in our study that achieved this objective.

Results from this study indicate that ground-based competition release around individual trees can play an important role in emerging silvicultural systems in the northern forest, especially where silvicultural prescriptions are required on small, dispersed areas, partial cuts, and/or focused on the development of mixedwood stands.

Endnotes

[1] Dow AgroSciences no longer supports use of the thin-line method and, instead, recommends the "streamline" method.

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