Effectiveness of Delayed Brush Cutting and Herbicide Treatments for Vegetation Control in a Seven-Year-Old Jack Pine Plantation in Northwestern Ontario, Canada

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Efficacy of three conifer release treatments, i) single application of glyphosate (Vision™) herbicide, ii) multiple application of glyphosate herbicide, and iii) motor-manual brush cutting for controlling competing plants, particularly trembling aspen (*Populus tremuloides*), pin cherry (*Prunus pensylvanica*), green alder (*Alnus viridis* spp. *crispa*), and beaked hazel (*Corylus cornuta* spp. *cornuta*), was studied in a seven-year-old jack pine (*Pinus banksiana*) plantation in northwestern Ontario, Canada. The single and multiple glyphosate applications were equally effective in controlling trembling aspen and pin cherry, causing over 90% stem mortality. The brushsaw treatment caused an initial decrease followed by an increase in stem density of these two species. A high degree of stem thinning by natural mortality in the untreated control plots was observed in trembling aspen (23–46%) and pin cherry (41–69%) over four years. As with trembling aspen and pin cherry, stem density of green alder and beaked hazel initially decreased and then increased following the brushsaw treatment, mainly due to resprouting. Stem mortality in green alder and beaked hazel was 45% and 97%, respectively, two years after the operational glyphosate treatment. Competition index (CI) was low (mean CI = 52, ranging from 18 to 115) in all the plots including the untreated control. There was a significant increase in basal diameter of jack pine in the brushsaw and herbicide-treated plots compared to the control three years after the treatments. Jack pine seedlings in the brushsaw and glyphosate treated plots were taller compared to that of control but differences were not significant. Lower species richness and diversity were recorded in the herbicide-treated plots compared to the brushsaw and control plots in the third growing season following treatment.

Keywords conifer release treatments, glyphosate, brushsaw, competition index, *Pinus banksiana*, species diversity, species richness
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1 Introduction

In northwestern Ontario, clearcutting often results in prolific regrowth of hardwood species from basal sprouting and root suckering (Bell 1991). This has been observed even on coarse-textured, pine-dominated sites associated with lowbush (*Vaccinium angustifolium* Ait.) and velvet-leaf blueberry (*V. myrtilloides* Michx.) (Mallik et al. 1997, Bell 1991). Success of conifer plantations is often predicated upon the control of competing plants, which reduce the growth and yield of the crop species and potentially increasing in the rotation length (Radosevich and Osteryoung 1987). In the last three decades, conifer release with herbicides has become increasingly common (Campbell 1990). Ontario has traditionally had the largest aerial herbicide program in Canada; 430 000 ha of forests were sprayed with herbicides from 1983 to 1990. In the 1990's, forest management policy in Ontario shifted to favour multiple resource management over single resource (timber) management. At the same time, public concern about herbicide use in forestry stimulated research to find non-chemical vegetation management alternatives such as motor-manual cutting.

Although motor-manual brush cutting is a herbicide alternative that is preferred by the public (Wagner et al. 1998), its econonmic and ecological effects have not been adequately studied. In addition to relatively high costs (Campbell 1984, Bell et al. 1997), motor-manual cutting may have the disadvantage of stimulating sprouting in certain broadleaf trees and shrubs that compete with conifers (Jobidon 1997, Mallik et al. 1997, Bell et al. 1999). This study was established to compare the efficacy of 1.5 kg acid equivalent (a.e.) glyphosate/ha formulated as Vision™ in Canada, and brushsaw cutting to control competing vegetation, such as trembling aspen (*Populus tremuloides* Michx.), pin cherry (*Prunus pensylvanica* L. f.), green alder (*Alnus viridis* [Villars] DC. spp. *crispa* [Ait.] Turril.), and beaked hazel (*Corylus cornuta* Marsh. spp. *cornuta*), in a seven-year-old jack pine (*Pinus banksiana* Lamb.) plantation in northwestern Ontario.

Blueberry responds to clearcutting by enhanced vegetative regeneration in the first year followed by increased fruit production in subsequent years until the canopy above it reaches crown closure. Thus deferring conifer release treatments for a few years after plantation establishment can accommodate blueberry pick as well as berry consumption by wildlife. A comparison study on the same site indicated that dry weight of velvet-leaf blueberry fruit was significantly increased after brushsaw cutting but significantly decreased by herbicide treatments (Moola et al. 1998). However, from a forest management perspective the concern is that jack pine may not respond to release treatments applied this late. Good forest management must deal with the competing demands, of blueberry production and use by wildlife on one hand and successful early growth of jack pine on the other. Is it possible to accommodate both objectives by delayed application of release treatments?

The specific objectives of this study were: i) to determine the growth response of four primary competing plants as well as the jack pine crop to delayed conifer release treatments, and ii) to determine the effects of the treatments on the diversity, evenness and composition of the resulting plant community.

2 Methods

2.1 Site Description

The study site was located 58 km north of Atikokan, Ontario, (49°57´22´´N, 92°02´05´´W; and 49°75´41´´N, 92°03´00´´W) near the southwest shore of Clearwater West Lake. Prior to harvesting the site was dominated by jack pine and classified as a V-17 (jack pine/mixedwood/shrub rich) forest (Sims et al. 1989). In 1987, the entire experimental area was harvested and prepared with heavy drags (i.e., barrels and chains). In spring 1988, Block 1 was regenerated with jack pine Cerkon shelter cones and Blocks 2–4 were planted with nursery grown container stock (Spencer Lemaire 6) at the rate of 3000 jack pine seedlings/ha at 1.8 m × 1.8 m spacing. When this study was initiated (summer 1992), the jack pine seedlings (80% stocked) were approximately 32 cm tall and 7 mm in diameter. The pines were overtopped by competitive species, such as trembling aspen, white birch (*Betula papyrifera* Marsh.), green alder, beaked hazel, and fireweed (*Epilobium angustifolium* L.) with average heights of 186, 149, 113, 75 and 44 cm respectively. Pin cherry and willow (*Salix* spp.) were also common on the site. Ground vegetation consisted of bunchberry (*Cornus canadensis* L.), wild lily-of-the-valley (*Maianthemum canadense* Desf.), creeping snowberry (*Gaultheria hispidula* [L.] Muhlenb. ex Bigelow.), large-leaved aster (*Aster macrophyllus* L.), red raspberry (*Rubus ideaus* L. ssp. *idaeus*), bluebead lily (*Clintonia borealis* [Ait.] Raf.), violet (*Viola* L.), lowbush blueberry, velvet-leaf blueberry, bracken fern (*Pteridium aquilinum* [L.] Kuhn), sedges (*Carex* spp.), and grass (plant names followed Newmaster et al. 1998). The soil was composed of a thin (4.16 cm) layer of organic matter overlaying rapidly drained, coarse loamy to fine sand.

2.2 Experimental Design

A randomized block design with four treatments and four replications per treatment was used to monitor the efficacy of the release treatments. The treatments were: 1) brushsawing, where the competing vegetation was cut at ground level between late June and early July after maximum leaf flush (B); 2) operational single aerial treatment with glyphosate at 1.5 kg acid equivalent [a.e.] / ha from a Bell 206 helicopter in late August 1992 (SG); 3) non-operational multiple glyphosate treatment, consisting of the operational single aerial treatment followed by two annual backpack glyphosate treatments with 2% solution of glyphosate (400 ml glyphosate in 20 L water) in September 1993 and August 1994 (MG); and 4) control where apart from the site preparation treatment, the post-logging vegetation was left undisturbed (C). Since the objective of the multiple glyphosate treatment was to remove all competing vegetation, the amount of glyphosate sprayed by backpack application varied in different plots depending on the amount of vegetation that survived previous applications but this treatment was not intended to compare the effectiveness of different rates of glyphosate. Each treatment plot was 2.0 to 2.5 ha with a 60 m × 80 m sampling area at its centre. Within each sampling area, three 5 m × 10 m permanent data collection sub-plots were marked. Data were collected prior to treatment in August 1992, as well as post-treatment in August-September of 1993, 1994, and 1995.

2.3 Population Dynamics of Selected Woody Species

Population dynamics of trembling aspen, pin cherry, green alder, and beaked hazel were studied by determining density, mortality, and recruitment of stems. The number of trembling aspen and pin cherry stems were counted in 5 m × 10 m sub-plots to determine stem density per hectare. For green alder and beaked hazel, the number of clumps in each sub-plot was counted, then the mean number of stems per clump was determined from five clumps in each sub-plot. The mean stem number per clump was multiplied by the total number of clumps to estimate stem density. Mean stem heights of trembling aspen and pin cherry were determined from individual stem heights taken from ground level to the tip. For green alder and beaked hazel, stem heights were determined by taking the mean height of five random stems per clump.

2.4 Competition and Conifer Growth

In the second growing season following the treatments (August 1994), cover of all vascular and non-vascular plants was determined visually, to the nearest five percent, from three randomly located seedling-centred 1.41-m-radius (area 6.24 m^2) quadrats within each 5 m × 10 m sub-plot. Competition was assessed by measuring and evaluating cover of potentially competitive species, photosynthetically active radiation, and jack pine growth and calculating a competition index described below (Equation 2).

The fraction of full sunlight reaching the top of each jack pine seedling was determined by measuring photosynthetically active radiation (PAR) with a sunfleck ceptometer (Model SF-80, Decagon Device Inc., Pullman, WA). The ceptometer was placed horizontally on top of the seedlings and two readings were taken at right angles to each other, keeping the leader of the seedling at the centre. Four readings were taken at the half canopy level from the edges of the canopy outward in four directions. PAR readings were taken at three seedlings marked in each sub-plot for a total of 144 seedlings for each treatment. Light measurements were taken on cloudless days between 11 am and 2 pm in mid-September 1994. Total PAR was determined on open ground. PAR transmission (PT) for individual jack pine seedlings was calculated using the equation:

$$1\ PT = (I_g / I_o) \times 100 \quad (1)$$

where I_o is the total incoming PAR on open ground and I_g is the mean transmitted PAR around the seedling. For each seedling, the mean I_g value was determined by averaging the top crown and mid-crown PAR readings.

In 1995, five seedlings were randomly marked in each of the 5 m × 10 m sub-plots, for a total of 240 seedlings in each treatment. Their stem height, basal diameter, and crown diameter were measured. A competition index (CI) was calculated using equation:

$$CI = (H_b / H_t)(((R_b / R_t) + 1)^{-1})(C) \quad (2)$$

where H_b is the mean height of the brush species, H_t is the sample crop tree height, R_b is the mean distance of the brush foliage from the sample tree stem, R_t is the crop tree crown radius, and C is the percent cover of the competing brush species around the sample tree (Brand 1986). This competition index is a function of the relative height of the competing vegetation to the tree, the relative distance to the competitor's foliage as a ratio to crown width, and the ground cover of competitors around the 1.14-m radius of the crop tree (Brand 1986).

2.5 Floristic Composition

Species richness (S), Hill's diversity (N1) and evenness were calculated using importance values (IV) of the species occurring in each treatment plot in September 1995. The importance values were calculated by adding the percent cover and frequency of each species for each plot followed by calculating the average for each treatment. Hill's diversity index (N1) was calculated as follows (Ludwig and Raynold 1988):

$$N1 = e^{H'}$$
$$H' = \sum^{s}_{i=1} [(ni / n) / \ln(ni.n)] \quad (3)$$

where e is natural logarithm, s is number of species in the sample plot, ni is the number of the ith species, and n is the total number of individuals in the sample – in this case the sum of importance value of all species. The evenness index employed was the 'modified Hill's ratio' computed by the following equation:

$$E = (N2 - N1) / (N1 - 1) \quad (4)$$

where N1 and N2 are defined as diversity measures (Ludwig and Raynold 1988).

Mallik and Robertson (1998) used these methods successfully in determining species diversity in old growth white pine forests in northwestern Ontario, Canada.

2.6 Statistical Analysis

Treatment-related differences in stem density and height of trembling aspen, pin cherry, green alder, and beaked hazel in the three treatments and control plots were compared using a non-parametric Kruskal-Wallis test, followed by a non-parametric multiple comparison procedure (Zar 1984). Differences in height and basal diameter of jack pine, and species richness, Hill's diversity, and evenness were also analysed using the above procedures.

3 Results

3.1 Population Dynamics of Selected Woody Species

Stem density of trembling aspen and pin cherry decreased ($p = 0.035$) dramatically following both of the glyphosate treatments when compared to the control and brushsaw treatments (Table 1). The operational single glyphosate treatment was

Table 1. Stem density (mean number/ha ± S.E.) of trembling aspen, pin cherry, green alder, and beaked hazel in the control, brushsaw, and glyphosate-treated plots.

	Treatment			
	Control	Brushsaw	Single Glyphosate	Multiple Glyphosate
Trembling aspen				
1992 (pre-treatment)	4588[a)] ± 1160b[b)]	6516 ± 1068ab	11184 ± 1838a	10984 ± 1750a
1993	3350 ± 440a	2218 ± 500a	1650 ± 584a	1716 ± 690a
1994	2500 ± 560a	4350 ± 1096a	1434 ± 648b	34 ± 22b
1995	3400 ± 858a	6066 ± 1116a	366 ± 104b	116 ± 68b
Pin cherry				
1992 (pre-treatment)	3600 ± 1200a	2984 ± 590a	4516 ± 898a	3934 ± 818a
1993	2120 ± 600a	2244 ± 626a	1550 ± 330a	934 ± 218a
1994	1120 ± 240a	3484 ± 922a	234 ± 182b	300 ± 204b
1995	1150 ± 808a	3234 ± 664a	184 ± 94b	266 ± 124b
Green alder				
1993	25600 ± 6580a	28272 ± 9094a	15424 ± 4302a	10324 ± 3088a
1994	25920 ± 7720a	12266 ± 4900a	8434 ± 2286a	5366 ± 2466a
1995	25910 ± 7726a	27144 ± 10056ab	6670 ± 3614b	3970 ± 2378b
Beaked hazel				
1993	14578 ± 4850a	16160 ± 8258a	13818 ± 7550a	18744 ± 3816a
1994	14360 ± 4140a	10234 ± 5890ab	484 ± 484b	7434 ± 2880ab
1995	14360 ± 4134a	26674 ± 15018ab	1504 ± 566b	15826 ± 7114ab

[a)] Numerals are presented using European conventions (i.e., 4588 = 4,588 in North America).
[b)] Species' means, within each year, followed by the same letter are not significantly different when $p \leq 0.05$. For alder and hazel pre-treatment data were not collected.

as effective as the experimental multiple glyphosate treatment. In the second and third year after the treatments stem mortality was mostly over 90% in both the single and multiple glyphosate treatment plots. The brushsaw treatment decreased stem density by 66% after one year. By the third year after the brushsaw treatment stem density had returned almost to the pre-cut levels due to stem base sprouting. Pin cherry stem density was reduced by 25% the first year after cutting. In the second and third year, pin cherry stem density increased by 5 and 8% relative to the pre-cut condition (Table 1).

Green alder stem density was decreased for two years following the herbicide treatments (Table 1), but no significant change in alder stem density was achieved by the brushsaw treatment. The brushsaw treatment decreased alder stem density 57% in the first growing season after the treatment. Enhanced sprouting two years after the treatment resulted in an increase in stem density close to the pre-cut level.

Stem density of beaked hazel was reduced due to both the single and multiple glyphosate treatments. Stem density was reduced by 37% one year after the treatment followed by a 65% increase above the initial level two years after the treatment (Table 1).

Brushsaw cutting significantly reduced stem height of trembling aspen and pin cherry. In the glyphosate treated plots, stem height of these plants were not different than that of control. In subsequent years however, plants in the control plots were taller than those in the treated plots (Fig. 1).

No significant difference in stem height of alder existed one year after the treatments, but two and three years after treatments stem heights were reduced. Brushsaw cutting did not significantly reduce the stem height of hazel but both glyphosate treatments did, particularly in the second year after the treatments.

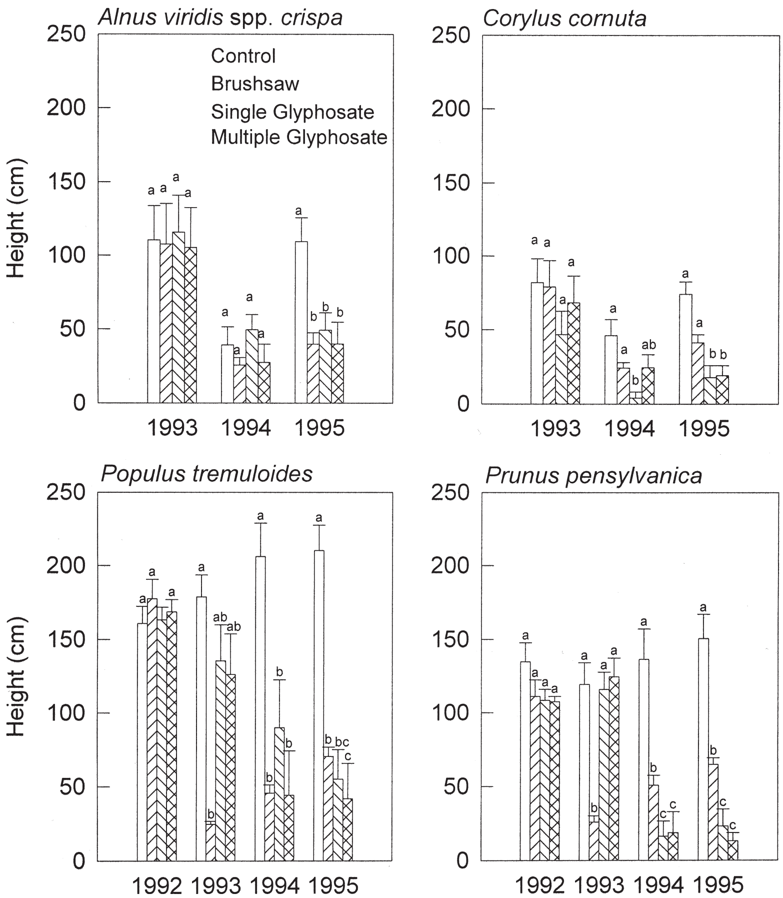

Fig. 1. Mean stem height of trembling aspen, pin cherry, green alder, and beaked hazel in the control, brushsaw, and glyphosate multiple-treated plots three years after the treatments. Vertical bars indicate standard error of means. Unlike letter(s) on the bars indicate that the treatment values within the same year are significantly different from that of control at p = 0.05.

3.2 Brush Competition and Conifer Growth

Mean cover of competing plants was 52 ± 4.1% in the controls with a competition index (CI) of 41 ± 3.7 (Table 2). Although CI ranged from 11 to 41, both cover and competition index are low indicating that competition on this site was limited, at least up until 1994. The release treatments increased PAR. Linear relationships between cover and PAR of brush species were found on control and single glyphosate treated plots (R^2 from 0.39 to 0.63; p from 0.001 to 0.05) (Fig. 2). No linear relationship was found between cover of compet-

Table 2. Cover, competition index (CI), and transmitted photosynthetically active radiation (PAR) in control and treated plots.

Treatment	Cover (%)	Competition index	PAR (%)
Control	52 ± 4.1a [a)]	41 ± 3.7a	25
Brushsaw	34 ± 3.7b	37 ± 2.3a	63
Single Glyphosate	20 ± 3.2c	11 ± 2.3b	68
Multiple Glyphosate	15 ± 2.6c	12 ± 2.8b	79

a) Means with unlike letters indicate significant difference (p = 0.001).

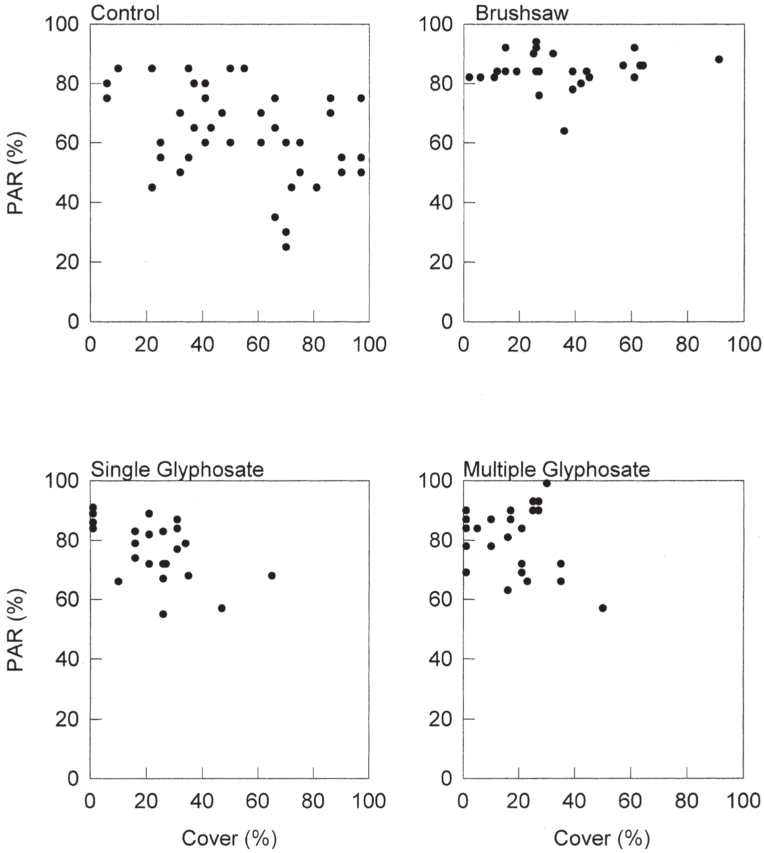

Fig. 2. Relationship between cover of competing plants and light transmission (% PAR) in the control, brushsaw, and glyphosate-treated plots.

ing plants and PAR in the brushsaw and multiple glyphosate treated plots ($p=0.627$).

Transmitted PAR for the top half crown of jack pine seedlings in mid-September ranged from 22 to 99%. Most (80%) of the jack pine seedlings received more than 50% PAR transmission in the control plots. PAR transmission was higher for jack pine seedlings with reduced competition index following the release treatments (Table 2). On the single and multiple glyphosate treated plots a nearly significant negative correlation was found between transmitted PAR and CI ($p=0.526$) (Fig. 3).

Three years after the release treatments, there was no significant difference ($P \leq 0.05$) in jack pine height between the control and treated plots (Table 3). Basal diameter of jack pine was significantly increased ($P \leq 0.05$) by all the release treatments with the greatest increase apparent in the multiple glyphosate-treated plots followed by single glyphosate and brushsaw treatments (Table 3).

Table 3. Height and basal diameter of jack pine on the control and conifer release treated areas in 1995.

Treatment	Height (cm)	Basal diameter (cm)
Control	121.5 ± 36.1a [a)]	1.79 ± 0.64a
Brushsaw	113.8 ± 26.1a	2.46 ± 0.68b
Single Glyphosate	122.4 ± 14.8a	3.03 ± 0.69bc
Multiple Glyphosate	107.8 ± 26.6a	3.24 ± 0.94c

[a)] Mean (± S.E.) Means followed by the same letter are not significantly different when $p \leq 0.05$.

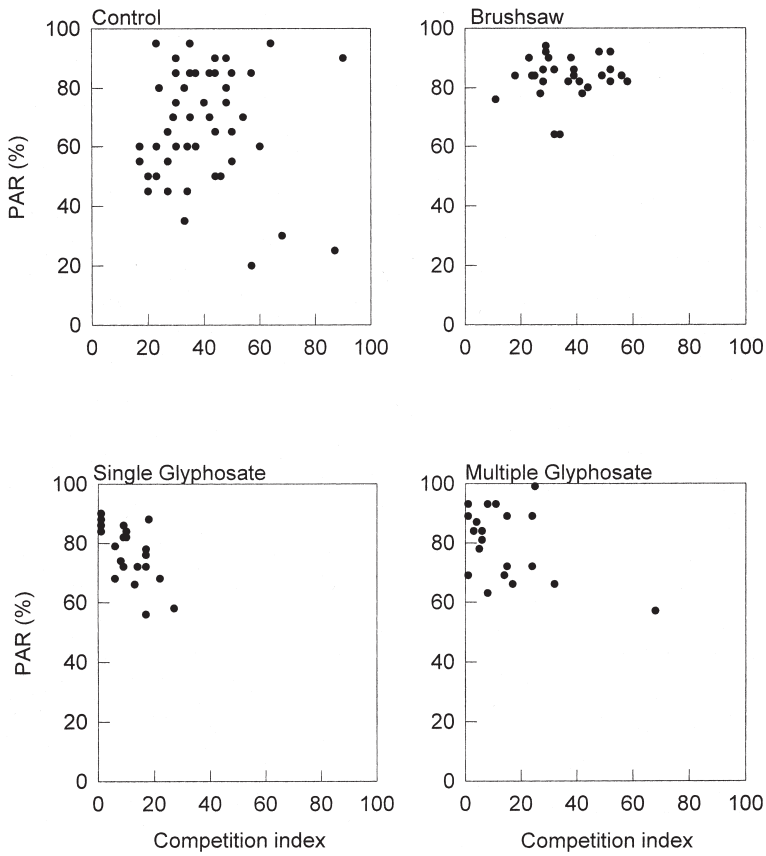

Fig. 3. Relationship between competition index and light transmission (% PAR) in the control, brushsaw, and glyphosate-treated plots.

3.3 Floristic Composition

In the third growing season following the release treatments plant species composition of control and brushsaw treated plots were similar. Cover of some species, for example green alder, beaked hazel, trembling aspen, pin cherry, paper birch (*Betula papyrifera* Marsh.), blueberry (*Vaccinium angustifolium* and *V. myrtilloides*) and bracken fern, were lower in brushsaw, single glyphosate, and multiple glyphosate-treated plots than in control plots. On the other hand, cover and frequency of red raspberry, wild lily-of-the-valley and grasses were increased following the glyphosate treatments (Table 4). Trailing arbutus (*Epigaea repens* L.) and several lichen species observed in the control and brushsaw treated plots were not found in the herbicide treated plots, whereas red pine (*Pinus resinosa* Sol. ex Ait.), certain ferns, and asters (*Aster* spp.) observed in the glyphosate-treated plots were not found in either the control or the brushsaw plots. Species richness (S) remained relatively unchanged by the treatments. Forty-one species were observed in the controls, 40 in the brushsaw, and 42 in the herbicide treatments (Table 4). Hill's diversity index (N1) and evenness index were significantly reduced in the glyphosate-treated plots compared to controls, but there were no significant differences between the brushsaw and control plots (Fig. 4). Species evenness was decreased significantly by glyphosate treatments but not the brushsaw treatment (Fig. 4).

Table 4. Mean cover, frequency and importance value (IV) of the vascular and non-vascular plants in the control, brushsaw, single glyphosate, and multiple glyphosate treatment plots three years after the treatments.

Species	Control			Brushsaw			Single glyphosate			Multiple glyphosate		
	Mean	% Freq	IV	Mean	% Freq	IV	Mean	% Freq	IV	Mean	% Freq	IV
Acer spicatum	3.5	75.0	78.5	0.4	26.7	27.0	6.0	60.0	66.0	2.6	60.0	62.6
Achillea millefolium	0	0	0	0	0	0	1.0	60.0	61.0	0.6	20.0	20.6
Alnus viridis spp. *crispa*	23.9	81.9	105.8	11.0	54.1	65.0	9.2	48.9	58.1	1.2	36.0	37.2
Amelanchier spp.	0.7	24.2	24.8	1.6	42.5	44.1	0.7	22.5	23.2	0.6	20.0	20.6
Anaphalis margaritacea	0.3	31.5	31.8	0.8	57.6	58.4	0	0	0	0	0	0
Apocynum androsaemifolium	0.9	31.1	32.0	1.6	41.9	43.6	1.9	62.5	64.4	0.8	55.6	56.4
Aralia nudicaulis	0.2	26.7	26.8	0	0	0	0	0	0	0.1	20.0	20.1
Aster ciliolatus	0.2	20.0	20.2	0	0	0	0	0	0	23.8	90.0	113.8
Aster macrophyllus	8.1	87.2	95.3	5.6	74.4	80.0	7.7	86.1	93.8	2.4	64.0	66.4
Aster spp.	0	0	0	0	0	0	10.2	85.0	95.2	8.9	73.3	82.2
Betula papyrifera	6.3	50.0	56.3	1.6	47.3	48.9	1.5	27.9	29.4	0.1	26.7	26.7
Carex spp.	0.7	68.9	69.6	1.1	56.0	57.2	11.0	100.0	111.0	0	0	0
Chimaphila umbellata	0	0	0	0.6	40.0	40.6	0	0	0	0	0	0
Clintonia borealis	2.2	48.2	50.4	0	0	0	2.5	63.6	66.1	0.6	26.7	27.2
Comptonia peregrina	9.7	66.9	76.6	20.3	90.0	110.3	20.2	46.7	66.9	0.8	57.1	58.0
Coptis trifolia	0.2	66.7	66.8	0.0	20.0	20.0	0.1	21.7	21.8	0.4	48.6	48.9
Cornus canadensis	15.6	96.2	111.8	19.3	92.5	111.8	26.4	89.6	116.0	15.7	91.7	107.4
Corydalis sempervirens	0	0	0	0	0	0	0	0	0	0.1	20.0	20.0
Corylus cornuta	16.7	69.1	85.8	4.3	37.3	41.6	0.8	39.8	40.6	4.5	56.7	61.2
Dicranum spp.	0.8	55.3	56.1	1.7	71.0	72.7	3.4	84.2	87.6	3.4	81.8	85.2
Diervilla lonicera	14.7	100.0	114.7	6.1	97.9	104.0	4.2	77.0	81.2	1.2	60.0	61.2
Diphasiastrum digitatum	0.8	100.0	100.8	0.6	100.0	100.6	1.8	40.0	41.8	0	0	0
Epigaea repens	0.2	20.0	20.2	1.0	20.0	21.0	0	0	0	0	0	0
Epilobium angustifolium	0.6	37.6	38.2	0.6	37.2	37.8	5.4	63.2	68.6	1.4	60.0	61.4
Fern	0	0	0	0	0	0	4.0	80.0	84.0	3.0	60.0	63.0
Geranium bicknellii	0	0	0	0	0	0	0	0	0	1.0	100.0	101.0
Grass	13.4	72.7	86.0	11.9	76.5	88.4	28.8	86.7	115.5	25.5	90.0	115.5
Hieracium aurantiacum	0	0	0	0	0	0	0.1	25.0	25.1	0	0	0
Lichen	0.4	40.0	40.4	0.5	45.0	45.5	0	0	0	0	0	0
Linnaea borealis	1.4	65.4	66.8	1.7	58.5	60.2	1.4	75.0	76.4	0.6	45.0	45.6
Lycopodium dendroideum	1.5	65.0	66.5	1.3	55.6	56.9	1.9	56.7	58.6	1.7	67.5	69.2
Lycopodium spp.	0.2	20.0	20.2	0.7	50.5	51.2	0.4	20.0	20.4	0	0	0
Maianthemum canadense	2.4	83.9	86.3	2.5	78.0	80.5	2.6	88.6	91.2	5.6	88.3	93.9
Melampyrum lineare	0.5	51.3	51.8	0.4	42.9	43.4	0.5	49.0	49.5	1.0	54.3	55.3
Moss	0.4	30.0	30.4	0.8	74.3	75.2	2.4	80.0	82.4	1.5	77.1	78.6
Picea glauca	0	0	0	0.6	48.9	49.4	1.7	27.0	28.7	4.0	20.0	24.0
Pinus banksiana	12.8	78.5	91.3	18.8	78.2	96.9	19.5	83.2	102.7	21.6	87.5	109.1
Pinus resinosa	0	0	0	0	0	0	0	0	0	10.0	100.0	110.0
Polygonum clinode	0	0	0	0.1	20.0	20.1	1.9	48.3	50.2	2.1	65.0	67.1
Populus tremuloides	18.4	73.3	91.7	4.5	73.3	77.8	1.7	42.2	43.9	0.3	40.0	40.3
Prunus spp.	8.1	66.5	74.6	2.9	51.8	54.7	2.2	38.6	40.8	0.4	42.5	43.0
Pteridium aquilinum	14.2	86.7	100.9	7.7	50.0	57.7	2.4	55.0	57.4	2.6	60.0	62.6
Rosa acicularis	0.8	36.7	37.5	0.1	20.0	20.1	4.6	60.0	64.6	0	0	0
Rubus idaeus	2.3	64.0	66.3	2.4	60.0	62.4	14.2	86.1	100.3	6.0	77.5	83.5
Salix spp.	5.5	54.2	59.7	3.8	51.4	55.1	5.0	38.8	43.7	4.8	60.0	64.8
Solidago spp.	0.4	26.7	27.0	0.6	47.5	48.1	0.1	28.8	28.9	2.2	40.0	42.2
Sphagnum spp.	1.3	66.9	68.2	4.7	83.8	88.5	3.6	81.7	85.3	0.9	66.7	67.6
Taraxacum officinale	0.2	25.0	25.2	0.2	22.5	22.7	0.1	20.0	20.1	0.1	20.0	20.1
Vaccinium angustifolium	7.8	79.6	87.3	8.0	71.8	79.8	2.9	72.6	75.5	0.3	40.0	40.3
Vaccinium myrtilloides	10.1	74.9	84.9	11.8	80.0	91.8	6.6	71.2	77.8	0.6	42.5	43.1
Viola spp.	0.7	80.0	80.7	0.5	65.8	66.3	0.8	76.2	77.1	1.2	78.0	79.2

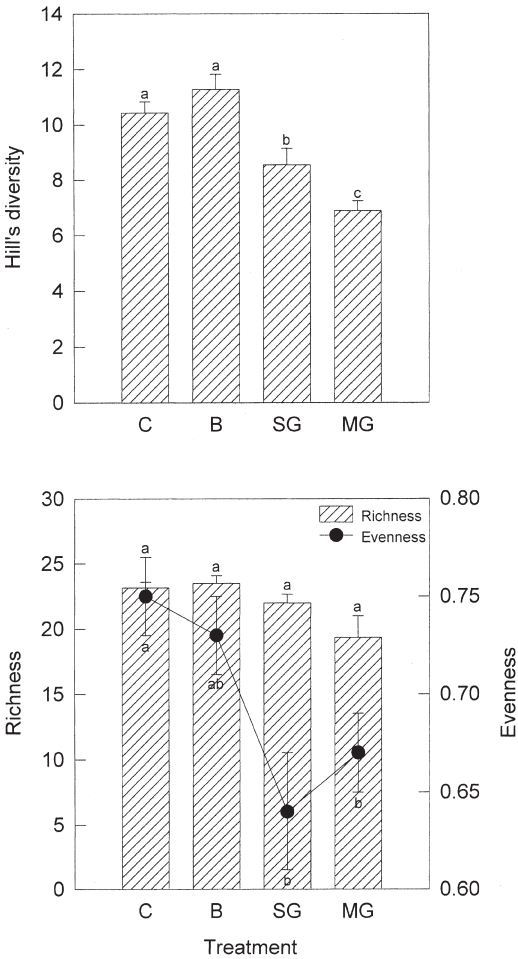

Fig. 4. Diversity (Hill's index), richness, and evenness of plant species in the control, brushsaw (B), single glyphosate (SG) and multiple glyphosate (MG)-treated plots three years after the treatments. Vertical bars indicate standard error of means and unlike letter(s) on bars indicate values are significantly different at p = 0.05.

4 Discussion

4.1 Population Dynamics and Control of Competing Plants

The importance value (% cover plus frequency), density, and height of competing trees and shrubs were reduced by both the brushsaw and glyphosate treatments. This would benefit the growth of jack pine. Single and multiple glyphosate treatments caused the highest stem mortality of both root suckering species (e.g., trembling aspen and pin cherry) and stem-base sprouting species (e.g., green alder or beaked hazel). Glyphosate, being a systemic herbicide, is most effective when applied late in the growing season, a time when carbohydrates are being mobilized to a plant's root system. In this study, despite three successive glyphosate applications, complete removal of woody species was not achieved. In fact, the single glyphosate application resulted in the same level of control as the multiple applications.

Significant number of mature stems of all four competing species died after herbicide application, indicating that glyphosate effectively controlled these species. These results agree with those in the literature (Bell 1991). Sprouting ability of pin cherry, trembling aspen, and beaked hazel was reduced for two years after the herbicide treatment. The fact that the multiple glyphosate applications killed fewer hazel stems than the single application is difficult to explain. Beaked hazel in these plots was robust and had high initial stem densities. Perhaps the high below-ground biomass of hazel (Mallik et al. 1997) and its numerous shoots reduced the amount of active ingredient of glyphosate received by the rhizome system.

Two years after the herbicide treatment green alder was still producing new shoots, indicating that alder is less susceptible to glyphosate than the other species. Other studies have reported variable response of other alders to foliar sprays of glyphosate depending on their age and size (Boateng and Herring 1990, Haeussler et al. 1990). For example, the vigorous growth phase of the plant (age 7 to 12 years) may be more resistant to herbicide treatments than the declining growth phase (age 15 years and over) (Mallik et al. 1997).

The regrowth of the four species following brushsaw cutting was greater than anticipated. Although cutting after leaf flush is not ideal from an operational perspective because crop trees are less visible, total non-structural carbohydrate reserves in the roots are at their lowest annual level immediately after flushing (Tew 1970, Kays and Canham 1991), and post-cut recovery is relatively slow compared to cutting at other times of the year (Buell 1940, Harrington 1984, Bell et al. 1999). In the current study, the brushsaw treatment, although applied in mid-July (i.e., well after leaf flush), did not reduce the density or importance values of competing plants. The treatment enhanced vegetative regeneration by basal sprouting of all four species. First- and second-year sprouts were numerous after brushsaw cutting. Other studies have reported responses proportional to the degree of cutting for these species (Haeussler et al. 1990, Bell 1991). Assuming that the sprouting continues over the next few years, and all the sprouts grow well, competition between established sprouts may increase following brushsaw cutting. However, massive suckering following clearcutting is typically followed by rapid declines due to self-thinning and other factors such as insect attack and animal browsing (Schier et al. 1985).

4.3 Assessment of Competition

Single applications of glyphosate may be sufficient in brush dominated jack pine stands to release the conifer seedlings from overtopping hardwoods. The single glyphosate application reduced the cover and competition index of the competing vegetation. Reduced cover of competing plants following glyphosate treatment increased the availability of photosynthetically active radiation (PAR) for the jack pine seedlings. Multiple applications of glyphosate did not reduce cover or increase PAR more than the single application. Although the brushsaw treatment reduced cover and increased PAR, it did not reduce the competition index. No decrease in the competition index combined with increasing density and height of the main competing woody species indicates that cutting would need to be repeated to keep the jack pine from being overtopped. Although the growth response of jack pine in this study has been slow, higher growth rates are associated with higher light availability (Logan 1966). Slow initial height growth of jack pine in the treated plots resembles the results of Miller et al. (1995) who found that loblolly pine (*Pinus taeda* L.) height growth increased at a slower rate between years one and four than years five to eight following release treatments.

When neighbouring vegetation occurs in sufficient density, cover, and height, it can seriously reduce the survival and growth of tree seedlings through competition for light, water, or nutrients. As a basis for competition models, a consistent method is required to describe the degree of competition to which crop seedlings are exposed. Several competition indices (CI) have been proposed to describe and assess competition (Brand 1986, DeLong 1991, Wagner and Radosevich 1991). The index proposed by Brand (1986) was used in this study to assess the level of competition jack pine seedlings imposed by neighbouring competing species. In the control plots, about 80% of jack pine seedlings received more than 50% PAR transmission and no significant correlation was found between competition index and PAR transmission (Fig. 3). This indicates that the level of competition in the study site was not severe. In the control plots, competition index ranged from 18 to 115 near the jack pine seedlings. Comeau et al. (1993) suggested that vegetation control is required only when competition index exceeds 150. However, substantial variability in both PAR transmission and jack pine seedling growth occurs at competition levels below 150. Results of this study suggest that when competition is not severe, competition index does not effectively predict inter-specific competition. Cover of competing species seems to be more effective for predicting brush competition since a significant linear relationship between cover of brush species and PAR transmission was found in the control plots (Fig. 2). DeLong (1991) and Ter-Mikaelian et al. (1999) also recommend cover of competing brush species as a useful tool to predict light transmission through the canopy.

Since the vegetative sprouts in the brushsaw treatment had not reached the height of crop tree seedlings, competition index and PAR transmission may not accurately predict the level of competition. In glyphosate treated plots, there was a significant correlation between PAR transmission and competition index, and PAR transmission and cover of competing species. High percentages of aerial shoots of the competing species were killed by the herbicide treatments, allowing more light to penetrate to the tree seedlings. Jack pine seedlings on the multiple glyphosate-treated plots were completely free from competing plants and shade (low PAR) was no longer restricting their growth. Positive effects are apparent in increased basal diameter three years after the treatments.

4.4 Crop Tree Response

Although ability to control unwanted vegetation has been the principal criterion for selecting vegetation management treatments, these treatments must also be silviculturally effective (Wagner 1993). Three years after the release treatments, a significant increase in jack pine basal diameter growth was observed between the control and the treated plots. The strong linear relationships between cover of competing plants, competition index, and jack pine diameter growth on the control and release treatment plots implies that competition in the control plots was restricting the growth of jack pine. Stem diameter of young trees has consistently been shown to be the growth variable most sensitive to levels of competition in vegetation management studies (Zedaker et al. 1987, Britt et al. 1991), including several recent studies on Scots pine (*Pinus sylvestris* L.) (Nilsson and Gemmel 1993) and jack pine (Wagner et al. 1996, Pitt et al. 1999, Bell et al. 2000).

The growth gains observed in this study are relatively low compared to gains that may have been achieved with chemical site preparation or earlier release treatments. For example, a single site preparation application of hexazinone to a similar site in northwestern Ontario provided a 2.3 fold gain in stem volume five years post-treatment (Pitt et al. 1999). In an earlier study in northern Ontario, Sutton (1984) demonstrated that glyphosate treatment in July at the rate of 2–4 kg ha^{-1} was very effective in controlling competing vegetation such as aspen, alder, cherry and willow as in the present study. Jack pine responded with no significant increase in height growth in glyphosate and manual (breaking all hardwood and shrub stems above 50 cm) treatments compared to control three years after the treatments. However, fall application of the treatments resulted in significant increase in plant height compared to control in the third year post-treatment. On a coarse-textured site in Ontario, Wagner et al. (1996) showed that jack pine achieves its greatest growth potential if it is never subjected to interspecies competition. From Finland Siiplehto and Lyly (1995) reported a marginally significant increase in height growth of Scots pine (*Pinus sylvestris* L.) with two spot application of glyphosate around seedlings in early August at the rate of 2 kg ha^{-1} a.i. Two other European studies indicate that even relatively shade tolerant species such as Norway spruce (*Picea abies* L.) would show postponed growth reaction related to the length of the period of competition prior to release (Lund-Høie 1984, Lund-Høie and Grønvold 1987). Despite this knowledge, forest managers may continue to defer conifer release treatments to manage for other multiple values. In northwestern Ontario, coarse textured soils are the primary sites for blueberry production, which are of value to both people and wildlife. Our study and that of Moola et al. (1998) show that it is possible to delay conifer release treatments in order to produce blueberries for up to seven years and ensure that jack pine responds to the release treatments.

4.3 Floristic Response to Release Treatments

Forest management has the potential to alter biological diversity, and it is important that this be considered when planning silvicultural treatments (Kimmins 1997). In northwestern Ontario, young fire origin jack pine forests are typically dominated by jack pine, with an admixture of black spruce (*Picea mariana* [Mill.] B.S.P.). Blueberries and green alder are the dominant shrubs and twinflower (*Linnaea borealis* L.), wild lily-of-the-valley, and wild sarsaparilla (*Aralia nudicaulis* L.) the dominant herbs. Feather moss and lichens (*Cladina* spp.) are also abundant (Zoladeski and Maycock 1990). In this study, the brushsaw treatment had little or no effect on the importance values (IV) of these species. Glyphosate treatments typically reduced the IV of woody species and lichens and increased the IV of herbs and mosses. Significant increases in Hill's and evenness indices suggest that glyphosate reduced the number of effective species in the plant communities. Decreased abundance of woody species with increased herbaceous cover commonly occurs following the use of glyphosate. In our study, the abundance of white birch, green alder, poplar, pin cherry, beaked hazel, bracken fern, and blueberry plants decreased following release treatments, whereas both the cover and frequency of jack pine, red raspberry, large-leaved aster and grasses increased. Changes in diversity following the use of glyphosate have been observed in Acadian softwood (Freedman et al. 1993), Allegheny hardwood (Horsley 1994), boreal spruce (Lund-Høie and Grønvold 1987, Sullivan et al. 1996) and boreal mixedwood (Newmaster and Bell 2001) forests. Lund-Høie and Grønvold (1987) were the first to document an increase in species richness after glyphosate applications. In our study the minor increase in species richness in the glyphosate treated plots can be attributed to the presence of two herbs, common yarrow (*Achillea millefolium* L. ssp. *millefolium*) and Bicknell's crane's-bill (*Gerarium bicknelli* Britt.).

A significant change in effective species following the glyphosate applications is an important finding. In our study site, trembling aspen rather than jack pine dominated the control plots, even though the site was a shrub-rich jack pine mixedwood (Sims et al. 1989) prior to harvest. If no further silvicultural interventions are taken the control and brushsaw treatments will likely result in a stand conversion from jack pine to aspen. The conversion of a single stand from conifer to hardwood is of little consequence but repeated use of these treatments could cause species changes over time at the landscape level.

5 Management Implications

A single application of glyphosate can be used to release jack pine up to seven years after clearcutting by controlling woody species, such as trembling aspen, pin cherry, and other shrubs. This late application allows time for blueberry production on the site. Glyphosate application reduces the potential for shrub-rich jack pine mixedwoods to become aspen-dominated mixedwoods. However, a short-term change in species composition and diversity may occur. Single cutting with brushsaws, even when applied during the optimum time of the year, may not reduce the density or importance value of trembling aspen since the plant regenerates vegetatively by stem base sprouting. Multiple cuttings may be required to keep new plantations on this site type from becoming dominated by aspen.

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